OPERATION OF DISTRIBUTION SYSTEMS WITH DISTRIBUTED GENERATION

Ph.D Thesis

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OPERATION OF DISTRIBUTION SYSTEMS WITH DISTRIBUTED GENERATION

This thesis is submitted as a partial
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Under the Supervision of
Prof. Manoj Fozdar

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This is to certify that ***Mr.Narayanan. K*** (I.D. No. 2011 REE 7128) has worked under my supervision for the award of the degree ***Doctor of Philosophyin Electrical Engineering*** on the topic entitled, "***Operation of Distribution Systems with Distributed Generation***". He has successfully defended his thesis work in viva-voce examination in front of the Oral Defense Committee and satisfactorily incorporated the changes suggested by the examiners in this revised version of the thesis.

The Thesis was examined and has been recommended for the award of the degree of ***Doctor of Philosophyin Electrical Engineering.***

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Mr.Narayanan. K (I.D. No. 2011 REE 7128) has successfully defended his thesis work in viva-voce examination in front of the Oral Defense Committee and satisfactorily incorporated the changes suggested by the examiners in this revised version of the thesis.

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Member ODC & External Examiner

DEDICATIONS

This thesis is dedicated to my father (late) ***Sh. N. Krishnan*** *who taught me the virtues of discipline, honesty and sincerity.*

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For any glitches or inadequacies that may remain in this work, the responsibility is entirely my own.

(Narayanan.K)

CONTENTS

ABSTRACT

The operation of electric distribution system is becoming challenging with the present trend of deregulation and competitive business environment in power systems. An analysis of customer failure statistics of most utilities have shown that the distribution system makes the greatest contribution to the unavailability of supply to a customer. The integration of Distributed Generation (DG) units in existing power system with bi-directional power flow has made the reliable operation of the system more complex. Thus there is a pressing need to have a comprehensive approach in planning the expansion of the system with the incorporation of DG units for effective and reliable operation of the system. The methods adopted for DG installation need to be robust for changes in operating condition. As the reliability of power supply to the customer is of utmost importance, there is a need to develop a method to enable the uninterrupted operation of the islanded system with only DGs. In this work, two different types of DG units namely type-1 and type-3 DG units have been installed in the standard IEEE-33 Bus Test System and IEEE-69 Bus Test Systems. Two methods have been proposed in this work for the placement and sizing of the DG units in the test systems. The formulation of the objective function also played a vital role in the final results. The proposed method was compared with other existing Artificial Intelligence (AI) techniques for different objective functions and the results obtained were promising in terms of voltage stability enhancement and loss reduction.

With different types of DG units being placed in the system, monitoring the parameters of the system has become more complicated. With the existing passive Islanding Detection Techniques (IDT), the monitoring of the system and detection of vulnerable bus for islanding is difficult. There is a pressing need to re-investigate the existing IDT and evolve an islanding detection method which successfully incorporates all the variations in the system introduced by the installation of DG units. With ever-increasing load demand, the system is vulnerable for unintentional islanding. Generally, passive techniques are used for detection of the vulnerable bus for islanding. But, the passive islanding detection technique generally have Non-Detection Zones (NDZ). The active methods are complex to implement and degrades the system by introducing perturbations in the system and have slow response times. In such a scenario, suitable methods are required to be developed with faster response time and lesser non-detection zones. Two Hybrid Islanding Detection Techniques (HIDT) have been proposed in the presence of different types of DGs in the system. The voltage, frequency and Active Power of the system are monitored and are used in the existing passive IDTs to detect the islanding event. In the proposed scheme, these parameters are used as alarm signals for an impending islanding event. In

addition to these parameters, Voltage-Active Power sensitivity and Frequency-Reactive Power sensitivity parameters are utilized for robust islanding detection. The usage of these parameters avoid the false triggering of islanding event. In the presence of Type-I DG, only Voltage-Active Power sensitivity parameter is used. However, in the presence of Type-3 DG, both Voltage-Active Power sensitivity and Frequency-Reactive Power sensitivity parameters are used. The proposed HIDTs have been tested on the IEEE-33 bus and IEEE-69 bus systems by placing the DGs in the system for the proposed multi-objective algorithm. The results show that the proposed method of islanding detection is faster and significantly overcomes the problem of NDZ than the existing passive IDTs .

The power mismatch in the island, if not taken care of could lead to failure of the island. Normally under such conditions under-frequency load shedding is initiated to alleviate the power mismatch. However, in the existing load shedding schemes, the amount of load shed is more than the necessary load to be shed to regain frequency stability. Thus, there is a need to design proper load-shedding measures, which takes into account the available DG power and shed loads accordingly at the most affected buses to avoid cascaded failure of the island. In the proposed work, after identification of islanding event by the proposed HIDT methods, a priority based-load shedding scheme is initiated, where only the necessary amount of loads are shed. The vulnerable buses for load shedding are identified by a Decisive Participation Coefficient (DPC). The results show that, the proposed scheme is able to regain the system stability in the island with less amount of load shedding. In order to quantify the effectiveness of the proposed load shedding scheme, reliability analysis based on the failure data of the components of the system and repair time is performed. The reliability of the islanded system after load shedding is found to be better by the proposed load shedding scheme.

The work carried out in the thesis for DG installation, islanding detection and load shedding based emergency control scheme may provide a comprehensive solution for both planning and effective operation of the distribution systems incorporating DG units. In the end of the thesis the future direction of the research work in context of the present work is discussed.

LIST OF ABBREVIATIONS

DG	**D**istributed **G**eneration
LSE	**L**oad **S**erving **E**ntities
DISCO	**DIS**tribution **CO**mpany
REG	**R**enewable **E**nergy **G**enerators
WTP	**W**illingness **T**o **P**ay
NDZ	**N**on-**D**etection **Z**one
DSO	**D**istrbution **S**ystem **O**perator
SVR	**S**tep **V**oltage **R**egulator
ULTC	**U**nder **L**oad **T**ap **C**hanger
DNO	**D**istrbution **N**etwork **O**perator
OPF	**O**ptimal **P**ower **F**low
ISO	**I**ndependent **S**ystem **O**perator
LDC	**L**ocal **D**istribution **C**ompany
ENS	**E**nergy **N**ot **S**upplied
AI	**A**rtificial **I**ntelligence
GA	**G**enetic **A**lgorithm
PSO	**P**article **S**warm **O**ptimization
ABC	**A**ritificial **B**ee **C**olony
LSF	**L**oss **S**ensitivity **F**actors
SA	**S**imulated **A**nnealing
CSO	**C**at **S**warm **O**ptimization
HSA	**H**armony **S**earch **A**lgorithm
WTGU	**W**ind **T**urbine **G**eneration **U**nit
CLPSO	**C**omprehensive **L**earning **P**article **S**warm **O**ptimization

SVM	**S**upport **V**ector **M**achine
CB	**C**ircuit **B**reaker
ALFC	**A**utomatic **L**oad-**F**requency **C**ontroller
ISR	**I**slanding **S**ecurity **R**egion
ANN	**A**rtificial **N**eural **N**etwork
ALS	**A**utomatic **L**oad **S**hedding
RODG	**R**eliability **O**ptions for **D**istributed **G**eneration
GCOT	**G**eneralized **C**apacity **O**utage **T**ables
VPP	**V**irtual **P**ower **P**lant
DE	**D**ifferential **E**volution
HIDT	**H**ybrid **I**slanding **D**etection **T**echnique
IDT	**I**slanding **D**etection **T**echnique
ROCOF	**R**ate **O**f **C**hange **O**f **F**requency
ROCOP	**R**ate **O**f **C**hange **O**f Active **P**ower
ROCOQ	**R**ate **O**f **C**hange **O**f Reactive Power
TDS	**T**ime **D**omain **S**imulation
DPC	**D**ecisive **P**articipation **C**oefficient
SAIDI	**S**ystem **A**verage **I**nterruption **D**uration **I**ndex
SAIFI	**S**ystem **A**verage **I**nterruption **F**requency **I**ndex
CAIDI	**C**ustomer **A**verage **I**nterruption **D**uration **I**ndex
ENS	**E**nergy **N**ot **S**upplied
AENS	**A**verage **E**nergy **N**ot **S**upplied

LIST OF SYMBOLS

CHAPTER 3

V_S	Voltage Stability Margin
i	Individual bus number
m	Number of buses in the system
V_i	Voltage of individual bus without DG (p.u)
$V_{i,DG}$	Voltage of individual bus with DG (p.u)
P_{Loss}^{diff}	Active Power Loss Reduction
P_{Loss}	Active Power Loss of system without DG
$P_{Loss,DG}$	Active Power Loss of system with DGs
Q_{Loss}^{diff}	Reactive Power Loss Reduction
Q_{Loss}	Reactive Power Loss of system without DG
$Q_{Loss,DG}$	Reactive Power Loss of system with DGs
W_1	Weight assigned for Voltage Stability Margin Improvement
W_2	Weight assigned for Loss Reduction
k	Number of lines in the system
R_m	Resistance of the line connecting any two adjacent buses
X_m	Reactance of the line connecting any two adjacent buses
P_m	Real Power flow between two adjacent buses
Q_m	Reactive Power flow between two adjacent buses
Y_m	Admittance Matrix of two adjacent buses
P_i	Active Power of individual bus
Q_i	Reactive Power of individual bus
$P_{DG,m}$	Active Power supplied by DG in kW
$P_{min,m}^{DG}$	Minimum Active Power of DG in kW

$P^{DG}_{max,m}$	Maximum Active Power of DG in kW
P_{PL}	Active Power Penetration level of DG
P_{Grid}	Active Power supplied by the Grid in kW
$Q_{DG,m}$	Reactive Power supplied by DG in kVA
$Q^{DG}_{min,m}$	Minimum Reactive Power of DG in kVA
$Q^{DG}_{max,m}$	Maximum Reactive Power of DG in kVA
Q_{PL}	Reactive Power Penetration level of DG
Q_{Grid}	Reactive Power supplied by the Grid in kVA

CHAPTER 4

dV	Voltage Variation (Volts)
δV_t	Voltage Parameter
σ	Threshold for Voltage Parameter
df	Frequency Variation (Hz)
δf_t	Frequency Parameter (or) Rate of Change of Frequency
ϵ	Threshold for Frequency Parameter
dP	Active Power Variation
δP_t	Rate of Change of Active Power
Λ	Threshold for Rate of Change of Active Power
ΔV_P	Voltage-Active Power Sensitivity Parameter
μ	Threshold for Voltage-Active Power Sensitivity
δQ_t	Rate of change of Reactive Power
ψ	Threshold for Reactive Power Parameter
Δf_Q	Frequency-Reactive Power Sensitivity Parameter
β	Threshold for Frequency-Reactive Power Parameter

CHAPTER 5

DPC_i	Decisive Participation Coefficient of bus ‘i’
C_i	Rank of each bus
$P_{Load,i}$	Load at bus ‘i’
ζ_f	Coefficient of frequency component of a bus

ζ_f	Coefficient of voltage component of a bus
$f_{i,t}$	Frequency at bus ‘i’ when load shedding is initiated
$f_{init,0}$	Frequency of the islanding bus when the islanding is detected
$V_{i,t}$	Voltage at bus ‘i’ when load shedding is initiated
$V_{init,0}$	Voltage of the islanding bus when the islanding is detected
$P_{L,island}$	Power Demand in the island
U_i	Annual outage time of load point ‘i’
N_i	Number of customers at load point ‘i’
$L_{a(i)}$	Average Load connected at load point ‘i’
λ_i	Failure Rate of customers at at load point ‘i’

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CHAPTER 1

INTRODUCTION

In recent years, power and energy industries have undergone a lot of changes. There has been growing trends of privatization, restructuring and deregulation of electric utilities. With the integration of distributed energy sources in the existing system, the operation and control of the power system has become complex and challenging. This necessitates incorporation of intelligent schemes for the secure operation of the power system.

The existing distribution system has undergone tremendous changes in recent years with deregulation of power systems. The participation of private players, large to small, has made the operation of the distribution system more complex. With two way power flow in the distribution system now a reality, the challenges for the system operator have increased manifold. Analysis of the customer failure statistics of most utilities shows that the distribution system makes the greatest individual contribution to the interruption of supply to the customer [1]. With increased emphasis on clean energy and to reduce the effect of emissions on environment, the de-centralized Distributed Generation (DG) has got much prominence. The general definition for DG can be considered as "Distributed Generation is an electric power source connected directly to the distribution network or on the customer site of the meter" [2]. The presence of renewable and clean DG resources in the distribution system reduces the impact of emissions on the environment and at the same time improves the performance of the system [3].

The installation of DG units in the existing power system presents challenges for reliable operation of the system. The presence of DG may result in rise in voltage, power quality issues, mal-operation of protective devices etc. [4]. The possible innovative solutions in such complex system are characterized by both technical and non-technical components of the system [5]. The regulatory incentives, pricing, demand and technological innovation have to be considered in short and long terms. The Load Serving Entities (LSEs) play a crucial role as aggregators and catalysts of customer choice. The conventional problem of distribution system planning for peak load has large investment costs involved with lower utilization efficiency [6]. DG has attracted the attention of DIStribution COmpany (DISCO) planners as DG can even be a small-scale generating unit located close to the load being served. For the benefit of both DISCO planners and the customers, incentives to use DG in the demand side for peak shaving need to be encouraged.

The modern distribution system designs should incorporate auto configuration capability, integrate renewable resources, optimize assets to operate efficiently, self-heal from power disturbance events, operate resiliently against physical and cyber attack, accommodate all generation and storage options [7]. The modern distribution system should also offer high reliability, efficiency and penetration of Renewable Energy Generators (REGs), which causes bidirectional power flow [8]. Since most of the renewables depend on weather conditions, they present a challenge in integrating them into the system [9]. This has further emphasized on need for a more robust communication and energy storage as a solution.

With the increased penetration level of DGs in the system, the ability of the DG to operate in islanded mode has gained significance. However, early detection of the islanding event can go a long way in preventing cascaded failure of the entire system. The traditional islanding detection techniques have major drawbacks of large Non-Detection Zone (NDZ) near a power balance situation leading to unwanted tripping of DG [10]. Distributed generation installation and operation costs are optimized against the reliability value, expressed as customers Willingness To Pay (WTP) to avoid power interruptions. Integrating dispatchable DG with distribution systems reduces utilities annual costs due to their capability of enabling successful islanding operation and minimizing interruption costs [11]. Thus, a methodology for allocating dispatchable DG units in distribution systems to economically improve system reliability has to be developed.

In Scandinavian countries, the cost associated with reliability as an incentive in distribution system expansion has been incorporated into their regulations. From a DISCO's perspective, the reliability analysis has to be performed for customers adhering to existing reliability limits [12]. Significant differences occur in the cost incurred by a DISCO and the estimated cost the customers are willing to pay to avoid interruption, when the regulator applies penalties for not abiding by the limits for reliability indices. A number of alternatives are available to the utilities in order to achieve acceptable customer reliability. However, it is not possible to compare quantitatively the merits of such alternatives or to compare their effect per monetary unit expended without utilizing quantitative reliability evaluation. Reliability indices and their associated costs are just used as indicators to provide a broad solution scope.

In this thesis, two effective algorithms are proposed for optimal placement and sizing of DG units for reducing the active power losses and improving the voltage stability margin simultaneously. In the first algorithm, the system is divided into zones to reduce the search space of the optimization problem. However, in the second proposed algorithm the entire space is searched for the optimization problem fixing the number of DG units. The different combinations of DG location and capacity are obtained to test the proposed islanding detection techniques and load shedding schemes presented in the subsequent chapters. The increasing load demand can cause unintentional islanding in the system. The system operator needs to be prepared for initiate appropriate action to avert the blackout in the island. For initiating counter remedial action effectively, the islanding event has to be detected early and accurately. For detecting the islanding event, two hybrid islanding detection techniques (HIDTs) are proposed in the thesis. In addition to the parameters utilized in the existing passive islanding detection techniques two new parameters are proposed for early and accurate detection of islanding event. The presence of the DG in the island makes the operation of the islanded network possible, however the power mismatch may lead to collapse of the island. Hence, appropriate corrective measures need to be initiated considering the reliability limits of the system. In this thesis, a priority based load shedding for alleviating the power mismatch is proposed to avert the cascaded failure of the island. The reliability of the islanded system before and after load shedding is computed for finding the effectiveness of the proposed load shedding scheme.

This thesis is divided into six chapters, this chapter presents a brief introduction of the research work carried out in this thesis with description of the research motivation.

Chapter 2 gives the detailed literature survey of the existing methods of DG placement, islanding detection techniques, load shedding methods and reliability analysis along with the limitations of the existing methods. Finally the research objectives framed are presented based on the literature survey.

Chapter 3 gives the different ways of DG placement for various objectives. It also presents the results of placement of different types of DGs. The chapter also shows the results of analysis under overloaded condition for different types of DGs.

Chapter 4 presents two hybrid islanding detection techniques in the presence of DGs. A hybrid islanding detection technique overcoming the limitations of the existing techniques for different types of DGs is proposed. The applicability of the hybrid islanding detection technique under overloaded condition is also presented.

Chapter 5 describes the emergency control scheme of the islanded system. A priority based load shedding scheme is proposed in the presence of DG for effective operation of the island. The reliability of the island before and after load shedding is also discussed.

In Chapter 6 the conclusions of the research work is presented with a brief description of the future scope of this research work.

CHAPTER 2

LITERATURE SURVEY

The optimal installation of DG units has attracted the attention of researchers and investors all over the World. Most of the techniques developed for DG installation consider a single objective function. However, the interests of the investors are best served by considering multiple objectives but the complexity of the problem is further increased. A robust and fast methodology consisting of multiple objectives needs to be developed. The existing islanding detection techniques have inherent drawbacks of Non-Detection Zones (NDZ) or slow response time or degradation of the system. Thus fast and more accurate techniques are required for detecting an islanding event. The control action prevalent in most of the proposed methods needs to be re-investigated for mitigating the power mismatch. The control actions are required to be introduced only in the affected portion of the island. The quantitative reliability analysis before and after applying emergency measures in the island can provide the effectiveness of the load shedding performed.

In this chapter, literature survey on various methodologies for optimal placement and sizing of DG units for various objectives such as voltage stability margin improvement, active power loss reduction etc. is carried out. It also discusses the existing techniques for islanding detection during operation after placing the DG in the system. Finally literature survey of the existing methods of emergency control in the detected island for power balance is presented with quantitative reliability assessment methods. A brief literature survey of these existing methods is presented in the following sections and based on the critical review of the methods available in the literature research objectives are framed for the present work.

2.1 Distributed Generation (DG)

The integration of DG units in the distribution system has become significant in modern power systems. The aim of the optimal DG placement and sizing is to provide the best locations and sizes of DGs to optimize electrical distribution network operation and planning. A detailed state-of-the-art models and optimization methods applied in solving this problem is presented by Pavlos *et al.* in [13]. Most DG operate (i) to reduce losses, (ii) to minimize peak loads, (iii) to improve reliability of the system. Analytical approaches were popular for the optimal allocation of DG units based on the the calculation of exact loss formula and using sensitive buses for the location of DG units. Such methods are direct, non-iterative and involves no convergence issues even for systems with high X/R branch ratio [14]-[19]. In [20], Duong *et al.* proposed analytical expressions to determine the optimal size and power factor of DG unit simultaneously for dispatchable and non-dispatchable type of DGs for minimizing the power losses. The expressions were adapted to minimize the energy losses with the time-varying demand and generation characteristics. The same authors also proposed the analytical expressions for determining the penetration levels of PV units with time varying load models in [21]. Ali *et al.* also proposed planning of dispatchable and non-dispatchable DG units for reducing the annual energy losses using Particle Swarm Optimization in [22].

Many researchers have used the objective of reducing losses in distribution system by installing DGs. J.S.Savier *et al.* [23] proposed a method to allocate the real power losses to each consumer by a *pro rata* and quadratic loss allocation scheme. In [24], Zeinab *et al.* proposed a loss allocation in radial systems for each node. However, to calculate the energy losses throughout a day the method becomes cumbersome and time consuming due to iterative nature of the steps. In [25], Enrico *et al.* adapted a method of loss allocation originally developed for transmission systems in order to make them suitable for distribution system with DG units. Kushal *et al.* proposed a loss allocation in distribution systems with different load models with non-linear characteristics power and current based approach in [26] and power and voltage based approach in [27]. In [28], a mixed integer non-linear programming is proposed for DG placement and sizing for reducing the power losses and maximizing the voltage stability margin. In order to achieve the best possible result, the objective functions are fuzzified into a single objective function. M.M. Aman *et al.* proposed a new power system stability index in [29] for studying the impact of DG on losses, voltage profile and voltage stability.

Many researchers considered the voltage profile, voltage stability maximization as the objective for placing the DG units. With the increase in penetration level of DG, the generated power alters the power flow even in the transmission system. Hence the connection of DG to the network may influence the stability of the power system. Hasan *et al.* considered the continuation power flow and voltage collapse for placement of DG in [30]. Chris *et al.* considered the voltage step limits to restrict the ability of the network to limit the connection of the DG in [31]. R.S. Al Abri *et al.* in [32] proposed a method to install the DG units on the system, based on the sensitivity of the buses to voltage profile thus leading to an improvement in voltage stability margin.

Renewable power DGs are capable of operating in two modes. Jamian *et al.* proposed a new Active power Voltage Stability Index (P-VSI) for measuring the stability and predicting the voltage collapse as a result of incremental loading in [33]. This index helps the planner to take into consideration the impact of the DG modes on voltage stability index. Murty *et al.* proposed a voltage stability index for DGs operating under different power factors and different load conditions in [34] and compared a power loss sensitivity method with four other methods in [35]. This index can be used for planning both real and reactive power sources placement in the distribution system. Po-Chen Chen *et al.* in [36] analyzed the possible impacts of different penetration levels of DG on voltage profiles in the low-voltage secondary distribution networks. Most of the network protective devices were tripped due to surplus DG power in the localized areas of the secondary network. Rafael *et al.* have performed analysis on network costs to the Distribution System Operators (DSOs) due to different penetration levels of DGs under different scenarios of demand and generation in [37].

In [38], Tomonobu *et al.* proposed an optimal control of distribution voltage with Step Voltage Regulator (SVR) with a tap changing. However, the coordination of all controllers like LRT, SC, ShR and SVC are not reported. In [39], Mohamad *et al.* considered voltage regulators as control variables when using less amount of reactive power. The DGs and reactive power sources were optimally placed by Tabu search. Miyoung *et al.* proposed a method for designing Under Load Tap Changer (ULTC) parameters for variations in load and DG outputs in [40]. With the integration of distributed generation, the security and adequacy needs to be assessed. Deigo *et al.* utilized the bulk power system adequacy and security concepts in distribution system applications using a discrete-continuous simulation model in [41]. This information can be used in planning the protection/control settings and assess their impact on the performance of the distribution system. Alireza *et al.* proposed a fuzzy evaluation tool for analyzing the effect of DG units on active power losses and the ability of the distribution network in the presence of uncertainties in [42]. This method can be used by Distribution Network Operators (DNOs) in making decisions for network reinforcements or reconfiguration of the system in periods of uncertainties associated with DG units and load demand. In [43], Hossein has determined the optimal DG size and location to reduce the annual energy losses by using a multi-period AC Optimal Power Flow (OPF) by considering the hourly load fluctuations and incorporating various system constraints. The method based on Benders decomposition technique splits the original problem into linear and nonlinear problems to solve iteratively. Vinicius *et al.* incorporated the load response uncertainties and load growth for DG integration for system expansion in [44]. Milad *et al.* proposed a dynamic model to improve the voltage and frequency profile by predicting the necessary control action needed ahead in [45]. The proposed method can be used in online application. Abdelazeem *et al.* in [46] considered the power quality issues with the increase in non-linear loads in modern power system while planning the DG units in the system.

Since the DG installation involves an initial cost and cannot supply the entire load, it is necessary to take into consideration the amount of power demand that cannot be supplied. Sung *et al.* considered the maximization of cost-savings of Energy Not Supplied (ENS) and cost-savings of energy loss in the distribution system due to renewable DG installation in [47] from the viewpoint of Independent System Operator (ISO) in a practical Korea

Electric Power Corporation system. Mostafa *et al.* in [48] and Amir *et al.* in [49] and [50] considered the DG placement problem for profit maximization and deferral of upgrade investments from Local Distribution Company (LDC) and DG owner's point of view.

2.2 AI Techniques in DG planning

The high initial investment cost of DG installations motivated the researchers to consider multiple objectives for the optimal placement and sizing of DG units. However, this increases the complexity of the problem. Since the problem is a complex combinatorial problem consisting of discrete variables (locations of DG units) and continuous variables (size of the DG units), it led to the usage of different Artificial Intelligence (AI) techniques by researchers all over the World to solve this problem. The application of AI techniques to the problem has given the flexibility to combine different objectives to utilize the advantages offered by the DG installation to the maximum.

These AI techniques have been modified by the researchers to achieve the best possible result for the DG placement and sizing problem considering multiple objectives. GA has been used in [51], [52] and modified using Cloud theory and used in [53] for achieving multiple objectives. A goal programming approach using Genetic Algorithm (GA) was utilized in [54] to reduce the dependency on the experience of the planner for problem formulation for solution identification. Particle Swarm Optimization (PSO) was used for a multi-objective index based approach for optimally locating non-unity power factor load models in [55]. Artificial Bee Colony (ABC) Algorithm was used for DG placement and sizing to reduce losses in [56]. A method for reducing the active and reactive power losses by exhaustive search method and weighted exhaustive search method were proposed in [57] and [58] respectively. A Fuzzified Clonal Selection algorithm for Artificial Immune System (AIS) and a modified teaching-learning based algorithm were used in [59] and [60] respectively.

Cuckoo search algorithm was used for solving a multi-objective function in [61]. A harmony search algorithm with differential operator was used for achieving multiple objectives with DG installation in [62]. A modified firefly algorithm was used for loss reduction by DG in [63]. A combination of Loss Sensitivity Factors (LSF) and Simulated Annealing (SA) was used for loss reduction with a voltage stability index constraint in [64]. A fast converging big bang-big crunch method was used for placing multiple DG units with multiple objectives in [65]. In [66], a Cat Swarm Optimization (CSO) technique has been considered for the optimization process with a composite reliability index as a objective function. Only reliability indices has been considered as constraints for DG placement in [67] and [68].

Reconfiguration is a process of closing and opening strategic switches in the distribution system to reduce the losses. Reconfiguration of a system is a complex process as voltage, current and thermal constraints need to be considered. Researchers have tried reconfiguration by analytical methods [69]. Researchers have performed reconfiguration using AI Techniques for reliability improvement [70] and considering uncertainties in the objective function [71]. In order to make the network more reliable and with multiple constraints, simultaneous placement of DG units with reconfiguration has been performed in [72]. In [73] an Ant Colony Algorithm has been considered for loss minimization and load balancing with simultaneous reconfiguration and DG placement. Rao *et al.* have given a detailed study of only DG placement, reconfiguration, sequential placement of DG and reconfiguration and simultaneous placement of DG and reconfiguration using Harmony Search Algorithm (HSA) in [74]. The authors have also commented upon the impact of number of DG units on the system. In [75] and [76] simultaneous placement of DG units and capacitors are considered for reducing the real power losses, reactive power losses and energy losses. Since the capacitor placement problem is also a non-convex and non-linear problem like DG placement, researchers are motivated to explore the application of AI techniques in placement of capacitors and simultaneous placement of DG units and capacitors. In [77], PSO is used to plan multiple DGs in the system. In [78], different types of DGs supplying real and reactive power are considered for minimizing the losses. In [79], DG and DSTATCOM are optimally placed to reduce the losses using PSO. In [80], Wind Turbine Generation Unit (WTGU) and Photovoltaic (PV) array with multi-objective PSO is proposed.

2.3 Islanding

"Islanding is a condition where the distribution system becomes electrically isolated from the rest of the power system due to abnormal conditions while being energized by the DG connected to it" [81]. Many standards have been developed to act as guidelines for the utilities to operate the island system. According to IEEE Standard 1547 "The islanding has to be detected within 2 cycles and the DG should be isolated from the system".

The installation of DG units in the distribution system makes the intentional islanded operation of the system possible. With major faults upstream or failure of grid leading to a complete blackout of the system, intentional islanding can reduce amount of load shedding. In [82], Shahmohammadi *et al.* analyzed different conditions for creation of islands and DG units were allocated accordingly to help intentional islanding. Ant search algorithm for identifying proper islanding scenarios in the network with generation control reserve, load shedding capacity and dynamic and operational characteristic as constraints in [83]. In [84] Comprehensive Learning PSO (CLPSO) has been used to optimally partition the distribution system incase of upstream loss and power balance has been achieved through load shedding. Irvin *et al.* in [85] proposed a control scheme for the DG inverter system to implement grid connected and intentional islanding operations of DG units.

In unintentional islanding the loads of faulty lines are transferred to adjacent line. The interconnection of DG units poses challenges in traditional load transfer methods. In [86], a stepwise optimal algorithm for load transfer is proposed. With the installation of DG units, a major challenge is with the protection devices coordination with bi-directional power flows of fault current. A comprehensive survey on various islanding protection schemes is presented in [87]. The proper detection of islanding can enhance the system reliability and quality of power supply. A comprehensive review of computational islanding detection techniques is presented in [88].

The islanding detection techniques can be broadly classified as (i) Active and (ii) Passive Detection Techniques. The active method has smaller non-detection zones than passive methods. The active method introduces perturbations in the system and may degrade the system power quality. The usage of active power shift and voltage drift come under active scheme. The implementation of active method is more complex than compared to passive method. The passive method utilizes local measurements of voltage and current signals to make decisions. Normally, the schemes based on under/over frequency, under/over voltage, rate-of-change of frequency, rate-of-change of power fall under passive schemes. But the passive schemes require large time for detection of islanding. In [89], Ankita *et al.* proposed a VPF control scheme with a complex frequency-dependent ZIP-exponential load model to assess the load's active power frequency dependence impact on islanding. In [90], an active islanding detection method for inverter-based DG system is proposed. The DC/AC inverter is considered as a virtual capacitor as the frequency from the inverter is slightly lower than the fundamental frequency of the utility.

In [91], the variation of voltage angle is used as a feedback for detection of islanding event. In [92], the magnitude and phase of the voltage is measured directly to detect islanding. It further reduced the oscillations of the reactive power and improved the system stability. An active islanding detection technique is proposed to overcome the problem of Non-Detection Zone in [93]. The method is implemented by injecting a negative sequence current through the interface of the Voltage-Sourced Converter (VSC) of the DG unit to introduce a perturbation. An average absolute frequency deviation based method is proposed in [94]. The major advantage of this method is that the stable operation point of DG is not lost in case of islanding detection. The method also clearly discriminates between islanding event and switching transients.

A passive islanding scheme for inverter based DGs based on empirical mode decomposition technique is presented in [95]. Measurement of one cycle data window of one phase of PCC voltage is used. A passive two-part control scheme for avoiding the non-detection zone is presented in [96] using the natural instability associated with the grid-connected control scheme and by making small adjustments to the reactive power output of the generator. In [97], a hybrid technique using average rate of voltage change and capacitor switching event is used to detect islanding event. This method works well even when generation and demand gap is small. In [98] and [99], a classification of islanding detection event using neural networks in the presence of DG units is presented. A positive feedback of voltage harmonic distortion is used for islanding detection in [100].

A simple technique combining the advantages offered by active and passive methods with negligible Non-Detection Zones is proposed in [101]. The method utilizes the P-V characteristic of the DG and the load, it also determines the best operating characteristic of the DG when connected to the grid and loses it in islanded condition. With the evolution of super computers and the application of intelligent classifiers along with signal processing techniques has enabled achievement of higher accuracy and faster detection of islanding. A comprehensive analysis of signal processing based techniques has been presented in [102]. Application of Fourier transform and wavelet transform fall under the category of signal processing techniques. Discrete wavelet transform using voltage signals of the DG bus has been used for islanding detection for various types of faults in [103]. A two stage method has been proposed in [104]. In this method, in the first stage the signal features from voltage and current signals at the point of common coupling are extracted. In the second stage the extracted signals are given as input to advanced machine learning technique based on support vector machine to predict the islanding. In [105], a new approach using wavelet design and machine learning has been used for islanding detection. The time-frequency transform of wavelet retains both time and frequency characteristic of the transient. However, different wavelets may affect the performance of the classification model. In [106], a half-cycle modified discrete Fourier transform algorithm has been used to compute the rate of change of impedance. The rate of change of impedance of each phase has been used for islanding detection.

A parametric technique has been used to extract signal features from voltage and current signals at point of common coupling to the grid. Support Vector Machine (SVM) has been used to predict the islanding state in the second stage, by taking calculated features as inputs. The time-delay in the prediction of the islanding event is independent of the real/reactive power mismatch. A wavelet transform on voltage signal for fixed speed wind turbine method has been proposed in [107]. In this scheme, when the synchronism is lost, the changes in voltage phasor is sensed and islanding event is classified. In [108], an adaptive technique based on voltage drifting and change in the active power reference has been used for islanding detection. In [109], a rate of change of reactive power and load connecting strategy is used for islanding detection when multiple mini hydro DGs are connected. This method is adaptable for small and large power mismatch in the island.

A proportional power spectral density of the voltage period at point of coupling has been used as a normalized measure for islanding detection in [110]. The utility Circuit Breaker (CB) current has been measured at the grid side and based on the features extracted from the measurements by discrete wavelet transform the neural network has been trained to detect islanding in [111].

A data-mining technology based method which combines various system parameters for a system with multiple DG resources and under different operating conditions has been proposed in [112]. This method has produced results with high degree of accuracy. An intelligent technique using input signals to the governor to cluster various occurrences into islanding and non-islanding categories has been proposed in [113] for synchronous generator based DGs. This method adjusts the frequency to a constant value and helps in adjusting the Automatic Load-Frequency Controller (ALFC). A suitable active power and frequency control strategies in islanded mode has been analyzed and a new LFC mode has been proposed for islanded operation in [114].

With the improvement in communication technologies, the remote islanding detection techniques are being preferred. A remote islanding detection technique monitoring the grid, local loads and the output of the PV inverter in real time with communication of circuit breakers has been proposed in [115]. An Islanding Security Region (ISR) has been developed to give the information to the system operator regarding intentional islanding operation in [116]. Artificial Neural Network (ANN) has been used to increase the computational efficiency for fast ISR information. In [117], intelligent relays employing multivariate analysis and data mining techniques has been used for islanding protection of synchronous DG with high speed reclosing. The relay settings are calculated by using dependability and security performance indices. In [118], an anti-islanding protection of DG using a utility owned and operated system has been proposed. The method was utilized for a single generator based on a synchronous machine.

2.4 Load Shedding

Traditionally load shedding has been considered for mitigating the power imbalance in the islands. In [119], an analytical criterion for undervoltage load shedding to avoid voltage collapse has been proposed. A simple adaptive Automatic Load Shedding (ALS) has been proposed in [120]-[122] using frequency and rate of change of frequency and the magnitude of disturbance has been measured for determining the amount of load shedding. Using Newton-based approximation and interpolating the frequency second derivative, the frequency minimum can be forecasted for actual load shedding. A method addressing the issue of voltage and frequency stability issue has been proposed in [123], [124]. The synchrophasor measurements are used for the proposed load shedding and the issue of voltage stability has been addressed using modal analysis.

With increasing penetration of DG in the power system, when the DG is islanded, the frequency changes are positive or negative depending upon the generation-demand difference. Traditional load shedding scheme cannot be implemented as the load shedding strategy cannot be solely on technical reason, but also dependent on economic reasons as well. In [125], a load shedding scheme based on frequency information, rate of change of frequency, customers' willingness to pay and load histories has been proposed. The load shedding scheme has been used to stabilize the frequency. An adaptive approach with communication link between the dispatch centre and the already present underfrequency relay has been proposed in [126]. The load shedding amount has been substantially reduced by the proposed method with economic interests being considered. In order to have an optimum amount of load shedding, a new under-frequency load shedding technique has been proposed in [127], using a combination of random and fixed priority loads. The load shedding strategy uses frequency, rate of change of frequency and combination of fixed and random priority of loads. In this scheme, the frequency recovers to a nominal value without any overshoot. A combination of adaptive and intelligent techniques for under-frequency load shedding has been proposed in [128]. The optimal load shedding has been based on well determined load prioritization.

In case of hybrid power systems, with different types of DG resources, the output power of the DG units may vary during the load shedding process. An underfrequency load shedding independent of the system parameters and considers the output power variation of the DG unit during the load shedding process has been proposed in [129]. In [130], the frequency emergency has been alleviated by load shedding and the frequency security has been achieved by optimizing the DG power output to maintain the operating parameters. In [131], a new combinational load shedding method using locally measured frequency and voltage signals has been used to increase the power system security. The problem of inadequate reactive power margins in conventional methods has been overcome by this method.

Lyapunov's energy methods have been applied in developing an energy based load shedding scheme to overcome voltage instability problem in [132]. In this method, security region and stability margin has been obtained to aid load shedding decisions. The energy surfaces can also identify vulnerable areas in the power system for voltage collapse. In [133], L-indicator index has been used for identifying the optimum location and quantity of loads to be shed. An optimum load-shedding algorithm using static voltage stability margin and its sensitivity at the maximum loading point or collapse point has been presented in [134]. The loading margin allocates reactive power supply locally using a PSO algorithm. A value based reliability approach based on customers' willingness to improve the system reliability has been proposed in [135]. In this method, optimal DG units are allocated based on the ability to improve the system reliability through successful islanding operation.

2.5 Reliability Analysis

A new reliability assessment method for distribution systems with DGs having maximum equivalent load as objective function has been presented in [136]. The optimization model of distribution network islanding program has been developed and the probability of islanding has been calculated for the failure rate and outage time in the feeders. With device failure effect table, the influence of DG failure, structural changing of the system, configuration of the island and the position of DGs in the system, reliability evaluation by Monte-Carlo time sequential simulation has been presented in [137]. In [138], a market mechanism known as Reliability Options for Distributed Generation (RODG), has been proposed. This mechanism provides distribution system operators with an alternative to the investment in new distribution facilities sharing the benefits between operators and DGs.

A planning model using GA to reduce the life-cycle cost of DG systems under the energy reliability criterion has been proposed in [139]. In this, DG system consisting of wind turbine has been considered. This model can be used to plan a more complex system with multiple types of DG units in it. A generalized approach to evaluate the distribution system reliability in a multi microgrid smart network, under islanded operation for local and overall reliability improvement has been presented in [140]. A reliability evaluation from Multi-state models based on Generalized Capacity Outage Tables (GCOTs) were developed in [141]. For microgrids with intermittent sources, a simplified equivalent model known as Virtual Power Plant (VPP) has been used. An approach to determine the maximum deliverable capacity of the transmission network between an equivalent multi-state generator and each load point with both wind and conventional generating units has been proposed in [142].

In [143], a methodology for reliability design of a radial distribution system in the presence of distributed generation has been proposed. A multi-objective optimization problem to obtain optimum failure rates and repair times of each section with energy and customer based reliability indices has been solved using PSO and Differential Evolution (DE). In [144], a probabilistic analytical method has been developed to assess system reliability in terms of interruption duration index and interruption frequency index for distribution feeders containing both dispatchable and non-dispatchable renewable DG units. The proposed method has been implemented considering the technical constraints, possible failures of DG units, time-dependent patterns of load demand and DG power output. In [145], a probabilistic technique to evaluate the distribution system reliability utilizing segmentation concept and a novel constrained Grey predictor technique for wind speed profile estimation has been proposed. The reliability of the distribution system has been assessed during the islanding mode of operation. As the penetration level of wind increases, the reliability of the system begins to saturate.

A multi-objective function considering the investment cost, loss cost, load growth, voltage profile and reliability cost energy savings were proposed in [146] and [147]. A modified discrete particle swarm optimization has been used for solving this planning problem. A multiobjective function considering cost and reliability was solved using GA for the optimization of the feeder addition problem in islanded distribution system with DGs in [148]. In [149], a differentiated reliability options to customers have been provided based on allocation of DGs, reconfiguration of systems depending upon customer's preferences of payment. A quantitative study on the benefits and impacts of demand response on the service reliability has been presented in [150]. In [151], graph-theory based feeder routing of the power distribution system has been proposed. The impact of DG integration on the feeder routing has been observed. A comprehensive network planning based on the reliability assessment has been proposed. With the increasing penetration level of DGs in the distribution system, the reliability assessment of the distribution system has also increased the interaction between generation units, lines, components, communication system with proper models in place. In [152] and [153], the reliability of the system has been evaluated with intermittent DG sources installed and during islanded mode of operation. A comparison of different sampling techniques for reliability evaluation has been presented in [154].

2.6 Critical Review

From the literature survey it was found that, the proper planning of the DG units in the Distribution System plays a key role in effective operation of the modern power system. Since most of the DG units use renewable energy sources, the reliability of supply to the customers from DG sources create an additional problem. Hence the planning of the DG units in the system should be done considering all these factors, for achieving the overall socio-economic benefits. Majority of the research work for the placement of DG units did not take the load growth and uncertainties into consideration. This makes the placement of DG units a non-linear problem, hence formulation of the proper objective function without violating the constraints play a key role in it. Since the reliability of supply has become more crucial, the islanded operation of system with DG units has become important. Hence, it is necessary to consider the islanding issues which occur with increasing penetration of the DG units.

With different types of DGs being installed in the system the deficiencies in existing islanding detection techniques have become prominent. The existing techniques have certain disadvantages like non-detection zones or slow detection, which could lead to a cascaded failure of the entire island. With the increase in number of DG units along with an increase in penetration level of the DG units due to growing demand, the accurate identification of vulnerable bus for islanding becomes more complex. The vulnerable bus should be identified early and with no or negligible non-detection zones. It will be beneficial if the advantages offered by the existing techniques could be properly utilized without disturbing the system parameters. From the literature survey it was found that, majority of the islanding detection methods were based on passive methods due to its ease of implementation. However, there is a need to re-investigate the methods and evolve methods to detect islanding events early and accurately.

The presence of DG in the island make the operation of the islands possible, however the power balance needs to be maintained for stable operation of the island. Since the power mismatch in the island vary depending on the capacity of the DG units, fast emergency control needs to be activated. Most of the existing schemes in the literature shed the loads on discrete basis to maintain power balance, this leads to more loads being shed than necessary. Hence, there is need to devise a strategy to shed the optimal amount of loads to regain the frequency stability. Moreover, the critical loads in the system should not participate in the load shedding. Since the reliability of power supply to the customer is of prime importance, the reliability analysis has assumed major significance. In the literature the reliability of the system was computed under contingencies. However, it is also necessary to compute the reliability of the system under islanded operation. Since the intentional islanding is performed to increase the reliability of the island, it is necessary to ensure that the failures affecting the customers are minimum.

In light of the above literature survey and the critical analysis of the literature the following objectives were attempted in this thesis.

2.7 Research Objectives Attempted

1. To develop effective methods to determine location and capacity of different types of DGs in the distribution systems and analyze the effect of DG placement on the system under different operating conditions.
2. To test the developed methods on the standard test systems and compare them with the existing techniques of DG placement for evaluating the effectiveness of the proposed methods.
3. To devise new hybrid islanding detection methods incorporating the positive features of the existing methods with different types of DG units in the system.
4. The developed islanding detection techniques should determine the islanding events early along with information about the most vulnerable bus for islanding techniques.
5. To test the developed islanding detection schemes on the standard test system with optimally placed different type of DGs and to compare them with the existing techniques for finding its superiority.
6. To develop an effective load shedding based emergency control scheme for secure operation of the detected island.
7. To perform a quantitative reliability analysis of the island based on the customers being affected in the island.
8. To analyze the effectiveness of the developed load shedding scheme using quantitative reliability analysis in the island.

In this chapter, literature survey of different methods of DG placement, islanding issues and effective operation schemes is presented. The critical analysis of the literature survey related to these aspects has been carried out and the research objectives have been formulated.

In the next chapter the optimal placement of different DG units is analyzed along with the performance of the proposed scheme under different operating conditions.

CHAPTER 3

OPTIMAL CAPACITY AND PLACEMENT OF DGs

As a result of deregulation, electric power system is undergoing major structural changes from the present centralized generating systems. The most important development in the modern power system is the utilization of the DG units in the distribution system. This has led to bi-directional power flow in the system. The installation of the DG depends on the operator and the objective which is to be achieved from the installation. In this work, the installation of different types of DG units is performed to test the proposed islanding detection techniques and load shedding schemes proposed in the subsequent chapters.

The optimal placement of DG is a complex non-linear planning problem. The installation of DGs by most of the system planners is accomplished to achieve atleast one of the following: (i) loss minimization, (ii) voltage stability margin improvement, (iii) peak load shaving, (iv) reliability improvement of the system. With the application of AI techniques in modern power system planning, researchers have tried to incorporate AI techniques to solve the non-linear DG placement and sizing problem. Some of the commonly used AI techniques have been well understood and documented in [51]-[80]. However, with different types of DGs being installed in the system and increased emphasis on clean energy the DG placement placement problem has become complicated.

3.1 Types of DG

The emergence of diversified renewable energy resources has led to different types of DGs being used in the distribution system. Generally the DGs can be classified into four major types as [78]:

- Type-1 DG: Supplying Active Power only, like photovoltaic, fuel cells etc.
- Type-2 DG: Supplying Reactive Power only to improve voltage profile, like kvar compensator, capacitors etc.
- Type-3 DG: Supplying both Active and Reactive Power, like synchronous machines.
- Type-4 DG: Supplying Active but consuming Reactive Power, like induction generators used in wind farms.

Normally, type-2 DGs are mainly used for voltage profile improvement, therefore in this work only Type-1 and Type-3 DGs have been considered.

3.2 Problem Formulation for Optimal Placement of DG

The installation of DG units in the existing distribution network can offer several benefits. For practical situations, a few number of DGs are required to optimally control power flow in the whole distribution network which leads to the problem of optimal DG allocation. The optimal DG allocation problem involves the determination of optimal number, siting and sizing of DG units. This is a mixed integer, non-linear hard combinatorial problem. The voltage stability improvement and the loss reduction is crucial for planning and secured operation of the system. Therefore, in the proposed work objective function for DG placement is formulated to improve the stability margin and reduce the losses. The objective function for voltage stability improvement can be given as:

$$max\ f_1(V_S) = W_1 * max\Big[\frac{\sum_{i=1}^{m} V_{i,DG} - \sum_{i=1}^{m} V_i}{\sum_{i=1}^{m} V_i} * 100\%\Big] \tag{3.1}$$

where $V_{i,DG}$ is the Voltage of i^{th} bus in the presence of DGs and V_i is the Voltage of i^{th} bus without DG.

The objective function to reduce the total system losses is given by:

$$max\ f_2(P^{diff}_{Loss}) = W_2 * max\Big[\frac{P_{Loss} - P_{Loss,DG}}{P_{Loss}} * 100\%\Big] \tag{3.2}$$

where P^{diff}_{Loss} is the Active Power Loss Reduction, $P_{Loss,DG}$ is the Active Power Loss in the presence of DGs and P_{Loss} is the Active Power Loss without DG. W_1 and W_2 are the weights assigned to the objective function considered such that:

$$W_1 + W_2 = 1 \ \forall \ W_1, W_2 \geq 0 \tag{3.3}$$

The overall objective function for achieving both the objectives simultaneously can be obtained by combining the two objectives as:

$$F = max[f_1, f_2] \tag{3.4}$$

However for placing the Type-3 DG in the system, reactive power losses also needs to be minimized in addition to the real power losses. Thus in the objective function of the problem the following function is also maximized when Type-3 DG is considered.

$$max\ (Q^{diff}_{Loss}) = max\Big[\frac{Q_{Loss} - Q_{Loss,DG}}{Q_{Loss}} * 100\%\Big] \tag{3.5}$$

where Q^{diff}_{Loss} is the Reactive Power Loss Reduction, $Q_{Loss,DG}$ is the Reactive Power Loss in the presence of DGs and Q_{Loss} is the Reactive Power Loss without DG. When Type-3 DG installation is considered, the reactive power loss reduction is also included in the objective function and Equation 3.2 is modified as:

$$max\ f_2 = W_2 * max\Big[(P^{diff}_{Loss}) + (Q^{diff}_{Loss})\Big] \tag{3.6}$$

The power flow equations can be explained with a single line diagram of a main feeder as shown in Fig.3.1.

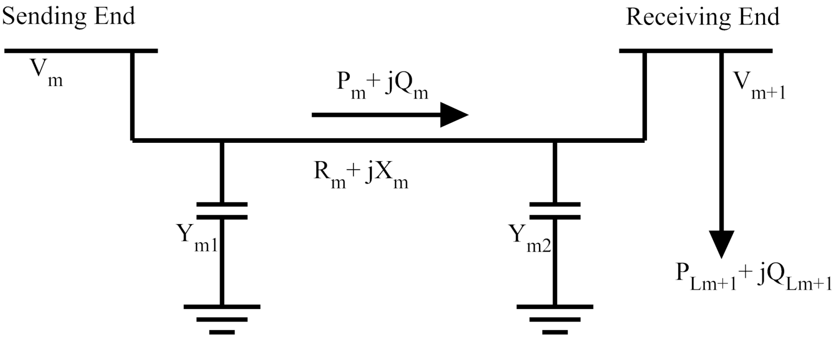

FIGURE 3.1: Representation of a single line diagram of a main feeder

The real and reactive power flow in each line of the feeder is given by equations 3.7 and 3.8 respectively:

$$P_{m+1} = P_m - \frac{R_m}{|V_i|^2} * P_m^2 + (Q_m + Y_m|V_m|^2)^2 - P_{Lm+1} \tag{3.7}$$

$$Q_{m+1} = Q_m - \frac{X_m}{|V_i|^2} * Q_m^2 + (Q_m + Y_m|V_m|^2)^2 - Y_m|V_i|^2 - Y_{m2}|V_{m+1}|^2 - Q_{Lm+1} \tag{3.8}$$

The individual bus voltages are calculated as:

$$V_{m+1} = V_m + \frac{R_m^2 + X_m^2}{|V_i|^2} * P_m^2 + (Q_m + Y_m|V_m|^2)^2 - 2(R_m P_m + X_m(Q_m + Y_m V_m^2)) \tag{3.9}$$

The line losses in the system is calculated by:

$$P_{Loss} = \left[\sum_{i=1}^{k} R_m * \frac{[P_m^2 + Q_m^2]}{|V_m^2|}\right] \tag{3.10}$$

where R_m is the Resistance of the line connecting any two adjacent buses. P_m, Q_m and V_m are the Active power, Reactive power and Voltage of the m^{th} bus respectively. The objectives are achieved by considering the following equality and inequality constraints: (i) Active and reactive power limits of the DGs, (ii) Voltage limits of all the buses, (iii) Active and Reactive power penetration level of the DG units.

The active power output of the DGs should be within the threshold limits as:

$$P_{min,m}^{DG} \leq P_{DG,m} \leq P_{max,m}^{DG} \tag{3.11}$$

where $P_{DG,m}$ is the active power output of the DG in kW. $P^{DG}_{min,m}$ and $P^{DG}_{max,m}$ are the minimum and maximum active power limits of the DG in kW respectively. The reactive power drawn from the DGs should be within the threshold limits expressed as:

$$Q^{DG}_{min,m} \leq Q_{DG,m} \leq Q^{DG}_{max,m} \tag{3.12}$$

where $Q_{DG,m}$ is the reactive power output of the DG in kVAr. $Q^{DG}_{min,m}$ and $Q^{DG}_{max,m}$ are the minimum and maximum reactive power limits of the DG in kVAr respectively. The voltage at each bus should not violate the minimum and maximum limits, mathematically can be expressed as:

$$V_{min,i} \leq V_i \leq V_{max,i} \tag{3.13}$$

where V_i is the voltage of i^{th} bus after placement of DG. $V_{min,i}$ and $V_{max,i}$ are the minimum and maximum voltage limits of the DG in p.u. The minimum and maximum limits are taken as 0.95 p.u and 1.05 p.u respectively in the present work.

The penetration of active power is calculated as:

$$Active\ Power\ Penetration\ Level\ (P_{PL}) = \frac{P_{DG}}{P_{DG} + P_{Grid}} * 100\% \tag{3.14}$$

where $P_{DG,m}$ is the active power output of the installed DG in kW. P_{Grid} is the active power supplied by the grid in kW. The maximum Active Power Penetration Level is taken as 30% [30]. The penetration of reactive power is calculated as:

$$Reactive\ Power\ Penetration\ Level\ (Q_{PL}) = \frac{Q_{DG}}{Q_{DG} + Q_{Grid}} * 100\% \tag{3.15}$$

where $Q_{DG,m}$ is the reactive power output of the installed DG in kVAr. Q_{Grid} is the reactive power supplied by the grid in kVAr.The maximum Reactive Power Penetration Level is also taken as 30% [30].

There are many optimization techniques used for the optimal placement and sizing problem of the DG. The simplicity, robustness and ability to deal with discrete decision variables makes Genetic Algorithm (GA) suitable for DG placement and sizing problem. Moreover GA has the ability to deal with discrete decision variables even in large scale problems. Therefore, in the present work, GA has been considered for optimal placement and sizing of DG units.

3.3 Genetic Algorithm (GA)

Evolutionary computation technique evaluates the objective function and uses less mathematical optimization. Moreover, evolutionary methods have the advantage of giving better results in the subsequent generations than their predecessors. Genetic Algorithm (GA) derives its behaviour from the process of Evolution [155]. The advantages offered by GA include simplicity and flexibility in approach, robustness in response to changing circumstances etc. A genetic algorithm is a problem solving method using search technique to find approximate solutions to optimization and search problems. GA has already shown to solve complex, combinatorial optimization problems. The various processes involved in solving the problem using GA are:

1. Selection.
2. Crossover.
3. Mutation.
4. Elitism.

3.3.1 Selection

Selection is a process of selecting two parents for crossover. There are two major selection methods.

1. Tournament Selection.
2. Roulette Wheel Selection.

The *Tournament Selection* is a rigorous selection process. It identifies the best individual among *N* possible individuals by the process of a tournament. The individual with the best fitness value is the winner of the tournament. In the *Roulette Wheel Selection* method, the roulette wheel is made up of *N-1* number of slots, where *N* is the number of individuals. The roulette wheel is a traditional GA selection technique which searches linearly through a roulette wheel with the slots in the wheel weighted in proportion to the individual's fitness values. In the present work, the main disadvantage of GA, requiring a vast population size, has been overcome by a rigorous process of selection. In this selection process, only the fittest individuals identified in the first round are selected for further GA processes. Since only the fittest individuals are considered for further stages, the quality of solutions obtained is better and the best possible solutions are obtained quickly.

3.3.2 Crossover

Crossover is the process of combining two parents to produce an offspring. The different types of crossover are:

1. Single Point Crossover.
2. Two-Point Crossover.
3. Multi-Point Crossover.

The *Single Point Crossover* divides the parent at a certain point, known as the cross over point and the genetic data are interchanged to form a child. The *Two Point Crossover* divides the parents at two cross over points and the data are interchanged to form a child. The *Multi Point Crossover* divides the parent into many cross over points and the data are interchanged to form a child. In Multi Point Crossover the characteristics of both the parents are evenly distributed in both the children.

3.3.3 Mutation

Mutation is the process by which the lost genetic material can be recovered. Mutation is performed to prevent the algorithm to be trapped in a local optima and maintain diversity in the population. The mutation rate is kept to a minimum to avoid the variation of too many characteristics in the child from the parents.

3.3.4 Elitism

Elitism is the process by which the best individual of the present generation replaces the weakest individual of the previous generation.

GA is considered for solving the objective function with all off-springs being produced by crossover only and 5% mutation rate. A higher mutation rate creates large variations in the off-springs from the parents. A mutated child creates a large deviation from the best solution in subsequent generations.

GA is a simple technique for solving the optimization problem of DG placement. However, the disadvantage of GA is a requirement of vast population size for achieving the best possible result. In this work, this has been largely overcome by considering a two-stage GA. In the initial stage the weaker solutions are eliminated by a knockout round and the fitter solutions are taken for the crossover and mutation process of GA. By this process the offsprings produced are of much better quality. Since the fitter individuals are considered for crossover and mutation the offsprings produced are better than the parents and the convergence of solution is faster.

3.4 Proposed Optimal Placement of DGs by Dividing the system in zones

In this method, the entire test system is divided into a number of zones for the optimal placement of DG units. The number of zones can be taken as per the discretion of the system operator with each zone having atleast one DG in it. The maximum size of the DG unit in each zone is fixed without violating the maximum allowable penetration level in each zone.

Steps for Placement of DGs in zones

1. Generate an initial population of 500 sites and sizes in each zone.
2. Check the fitness of initial population for the objective function considered.

3. Select (Number of buses-1) best population in each zone for the next stage.
4. Create a roulette wheel with (Number of buses-1) slots for the selection of parents.
5. Perform crossover and mutation with the selected parents.
6. With the produced off-spring repeat Step 4 until the maximum iterations are reached or optimal solution is achieved.

A flowchart of the proposed method of placement of DG is shown in Fig. 3.2.

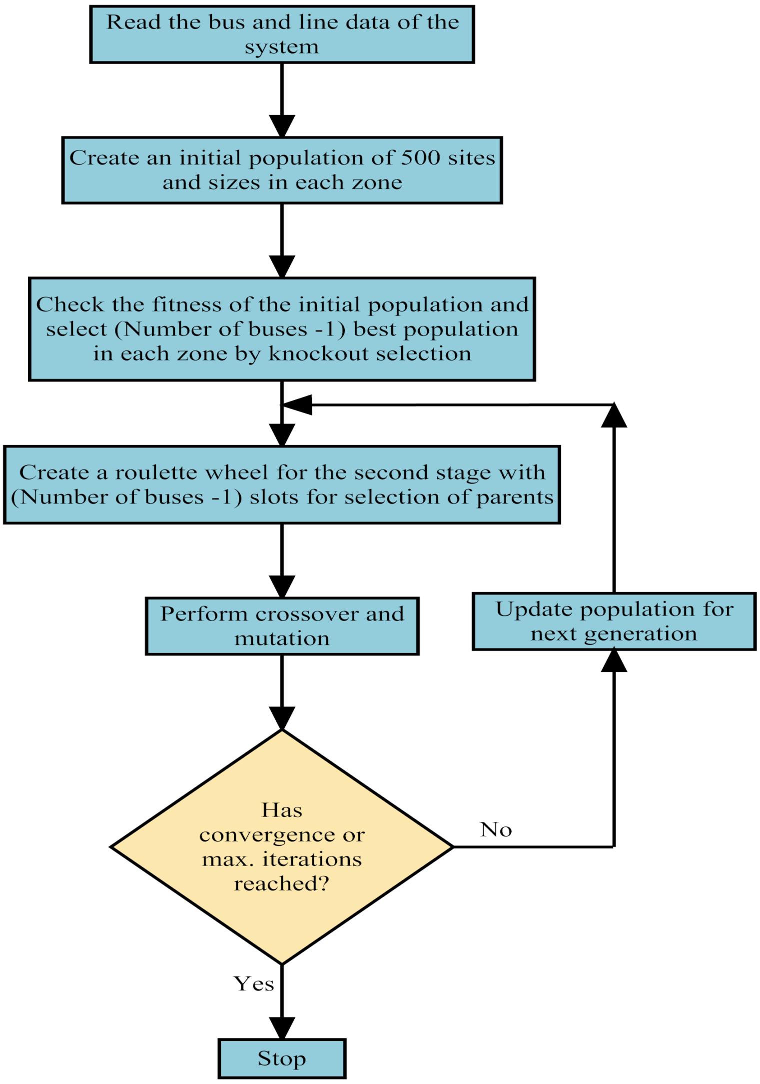

FIGURE 3.2: Optimal Placement and Sizing of DGs in zones

In this work, the division of zones is performed in accordance with the maximum number of radial branches available in the system. The number of buses vary in each branch. This division of zones is performed to find the best possible division of the system into zones. The division of zones is system specific and can vary depending on the size of the system and number of buses available. The two test systems considered are IEEE 33 Bus and IEEE 69 Bus radial distribution systems.

The IEEE 33 Bus System has been divided into 3 and 4 zones and the division is shown in Table. 3.1.

TABLE 3.1: Division of IEEE 33 Bus System into zones

Cases	**Zones**	**Number of Buses**	**From Bus**	**To Bus**
3 ZONES	Zone 1	17	2	18
	Zone 2	7	19	25
	Zone 3	8	26	33
4 ZONES	Zone 1	17	2	18
	Zone 2	4	19	22
	Zone 3	4	23	25
	Zone 4	8	26	33

The IEEE 69 Bus System was divided into 4, 5 and 6 zones. Table 3.2 shows the division of the system and the number of buses in each zone.

TABLE 3.2: Division of IEEE 69 Bus System into zones

Cases	**Zones**	**Number of Buses**	**From Bus**	**To Bus**
4 ZONES	Zone 1	36	2 47 66	27 52 69
	Zone 2	8	28	35
	Zone 3	11	36	46
	Zone 4	13	53	65
5 ZONES	Zone 1	30	2 66	27 69
	Zone 2	8	28	35
	Zone 3	11	36	46
	Zone 4	6	47	52
	Zone 5	13	53	65
6 ZONES	Zone 1	17	2	18
	Zone 2	8	28	35
	Zone 3	11	36	46
	Zone 4	6	47	52
	Zone 5	13	53	65
	Zone 6	4	66	69

SIMULATION AND RESULTS

In the present work the DG units are placed for Voltage Profile Improvement and/or Loss Reduction. The proposed methods are tested on IEEE 33 bus and IEEE 69 bus test systems. All the simulations are carried out using MATLAB R2010a [156] and PSAT [157] Intel Core i5, 2.5 GHz, 4 GB RAM machine.

3.4.1 Test Results of IEEE 33 Bus System

- **Analysis with Type-1 DGs**

  The IEEE 33 Bus system is divided into 3 zones and 4 zones respectively and Type-1 DGs are optimally located and sized for different objectives. The overall penetration of DGs in the system varies from 28.12% to 29.30% for all combinations of W_1 and W_2 when divided into 3 zones. The overall penetration of DGs in the system varies from 27.75% to 28.98% when divided into 4 zones. The comparison of voltage profiles when divided into 3 zones and 4 zones respectively are shown in Figs. 3.3 and 3.4. The locations and sizes of DGs obtained for different objectives is also shown in the Table. 3.3. From the table it can be seen that the results when considering a multi-objective function tends to give almost similar result as that of a single objective function.

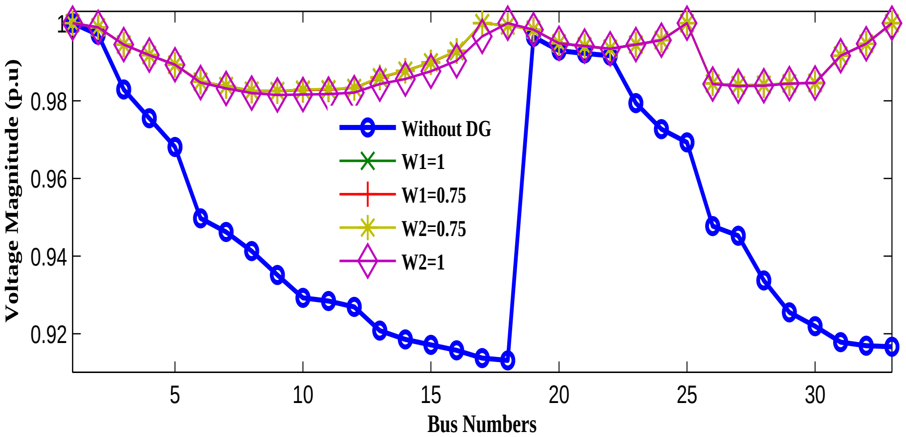

FIGURE 3.3: Comparison of Voltage Profiles for Type-1 DGs with 3 zones at Base Load (IEEE 33 Bus System)

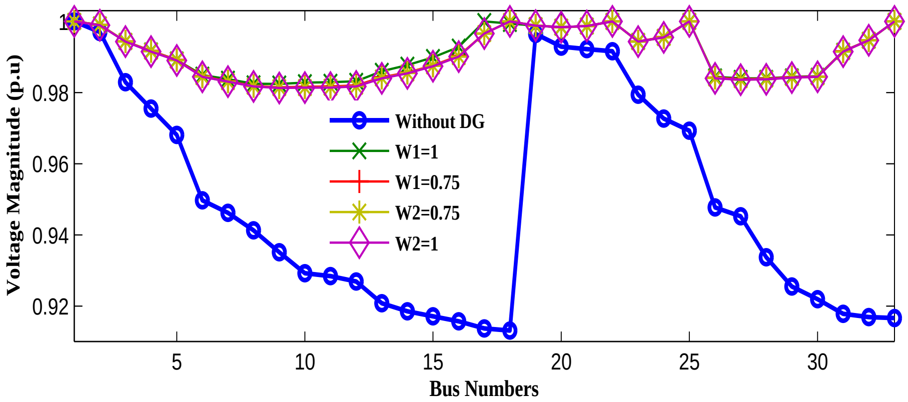

FIGURE 3.4: Comparison of Voltage Profiles for Type-1 DGs with 4 zones at Base Load (IEEE 33 Bus System)

TABLE 3.3: Analysis of Results with Type-1 DGs at Base Load (IEEE 33 Bus System)

zones	**Cases**	**DG location**	**DG size (kW)**	**Minimum Voltage (p.u)**	**Improvement in Voltage Stability Margin (%)**	**Active Power Loss (MW)**	**Reduction in Active Power Loss (%)**
Without DG		-	-	0.9131	-	0.20267	-
3 zones	$W_1 = 1$	17,25, 33	616,536, 381	0.9825	4.45	0.09532	52.97
	$W_1 = 0.75$	17,25, 33	621,553, 376	0.9825	4.45	0.08783	56.66
	$W_2 = 0.75$	17,25, 33	617,550, 374	0.9820	4.42	0.08483	58.14
	$W_2 = 1$	18,22, 33	650,574, 400	0.9815	4.39	0.08298	59.06
4 zones	$W_1 = 1$	18,22, 25,33	603,144, 378,380	0.9824	4.5	0.09425	53.5
	$W_1 = 0.75$	18,22, 25,33	619,146, 383,387	0.9815	4.44	0.08693	57.11
	$W_2 = 0.75$	17,22, 25,33	610,144, 379,376	0.9814	4.43	0.08622	57.46
	$W_2 = 1$	18,22, 25,33	649,150, 400,400	0.9813	4.43	0.08253	59.28

- **Analysis with Type-3 DGs**

The IEEE 33 Bus system is divided into 3 zones and 4 zones respectively and Type-3 DGs are optimally placed and sized for different objectives. The overall penetration of DGs in the system varies from 29% to 29.10% when divided into 3 zones. The overall penetration of DGs in the system varies from 28.68% to 29.05% for all possible combinations of W_1 and W_2 considered when divided into 4 zones. From Table. 3.4 it can be seen that the placement of DG for a multiple objective function gives almost the same result as that of a single objective function. A comparison of voltage profiles when divided into 3 zones and 4 zones is shown in Figs. 3.5 and 3.6. The real and reactive power losses are also reduced with the placement of Type-3 DGs.

Table 3.4: Analysis of Results with Type-3 DGs at Base Load (IEEE 33 Bus System)

zones	**Cases**	**DG location**	**DG size (kVA)**	**Minimum Voltage (p.u)**	**Improvement in Voltage Stability Margin (%)**	**Active Power Loss (MW)**	**Reduction in Active Power Loss (%)**	**Reactive Power Loss (MVAr)**	**Reduction in Reactive Power Loss (%)**
Without DG		-	-	0.9131	-	0.20267	-	0.13514	-
3 zones	$W_1 = 1$	17,25, 33	715,620, 552	0.9826	4.46	0.0756	62.7	0.04877	63.91
	$W_1 = 0.75$	17,25, 33	720,623, 552	0.9826	4.46	0.0563	72.22	0.03731	72.39
	$W_2 = 0.75$	18,25, 33	718,617, 555	0.9815	4.39	0.05500	72.86	0.03722	72.46
	$W_2 = 1$	18,25, 33	711,619, 555	0.9815	4.39	0.05472	73	0.03700	72.62
4 zones	$W_1 = 1$	17,22, 25,33	719,162, 447,562	0.9826	4.51	0.06750	66.69	0.04798	64.5
	$W_1 = 0.75$	17,22, 25,33	716,162, 439,556	0.9826	4.51	0.05610	72.32	0.03722	72.46
	$W_2 = 0.75$	17,22, 25,33	718,163, 446,553	0.9825	4.5	0.05482	72.95	0.03700	72.62
	$W_2 = 1$	17,22, 25,33	707,154, 440,555	0.9825	4.5	0.05395	73.38	0.03679	72.78

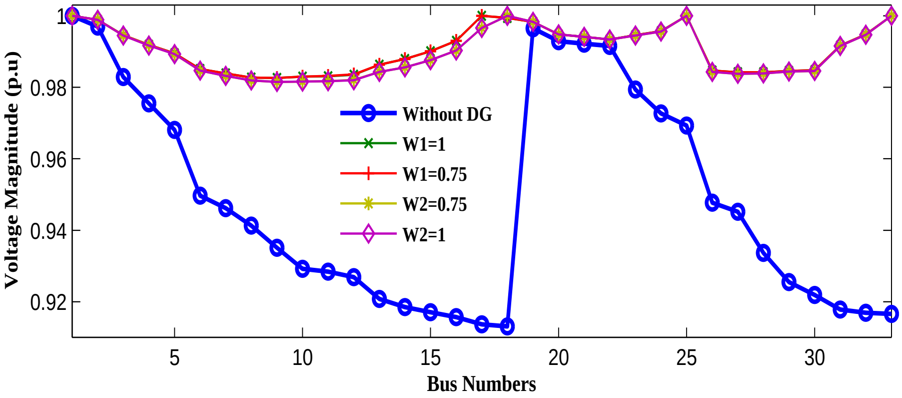

FIGURE 3.5: Comparison of Voltage Profiles for Type-3 DGs with 3 zones at Base Load (IEEE 33 Bus System)

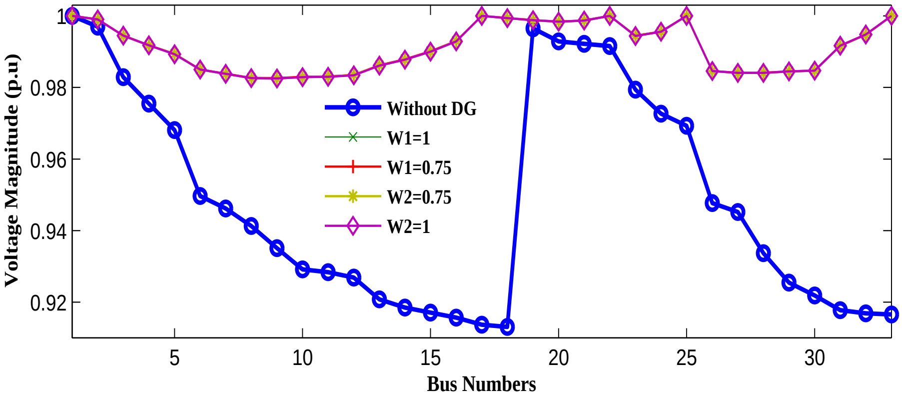

FIGURE 3.6: Comparison of Voltage Profiles for Type-3 DGs with 4 zones at Base Load (IEEE 33 Bus System)

The reduction in losses and improvement in voltage stability margin is only marginally better with the division of system into 4 zones. The optimal number of zones for the IEEE 33 Bus system with the proposed consideration of branches is 3 zones. Since, the installation of DG involves huge capital investment, it would be beneficial to divide the system into 3 zones and place atleast one DG in each zone to reduce the initial cost due to placement of DG.

3.4.2 Test Results of IEEE 69 Bus System

- **Analysis with Type-1 DGs**

The IEEE 69 Bus system is divided into 4 zones, 5 zones and 6 zones respectively and Type-1 DGs are optimally placed and sized in each zone. The overall penetration of DGs in the system varies from 27.24% to 28.19% with 4 zones. The overall penetration level of DGs varies from 26.80% to 27.52% for all the scenarios considered when the system is divided into 5 zones. When the system is divided into 6 zones the penetration level varies from 26.92% to 28.49%. An analysis of all the scenarios with the benefit offered in terms of improvement of Voltage Stability Margin and reduction in Active Power Losses is presented in Table. 3.5. A comparison of voltage profiles when the system is divided into 4 zones, 5 zones and 6 zones are shown in Figs. 3.7, 3.8 and 3.9.

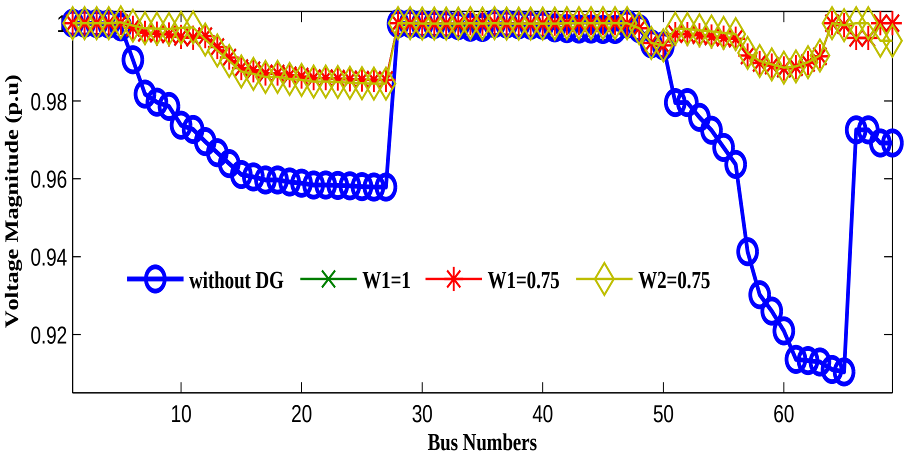

Figure 3.7: Comparison of Voltage Profiles for Type-1 DGs with 4 zones at Base Load (IEEE 69 Bus System)

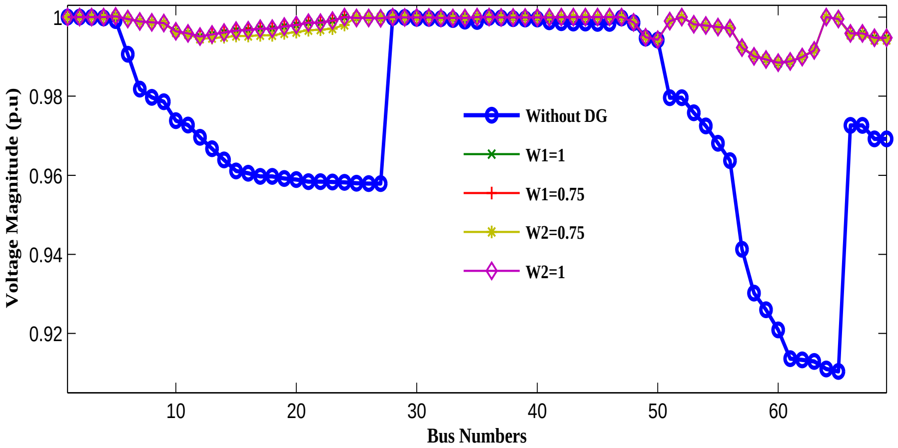

Figure 3.8: Comparison of Voltage Profiles for Type-1 DGs with 5 zones at Base Load (IEEE 69 Bus System)

TABLE 3.5: Analysis of Results with Type-1 DGs at Base Load (IEEE 69 Bus System)

zones	**Cases**	**DG location**	**DG size (kW)**	**Minimum Voltage (p.u)**	**Improvement in Voltage Stability Margin (%)**	**Active Power Loss (MW)**	**Reduction in Active Power Loss (%)**
Without DG		-	-	0.9104	-	0.225	-
4 zones	$W_1 = 1$	67,34, 46,64	667,38, 73,682	0.9854	2.18	0.0876	61.07
	$W_1 = 0.75$	69,35, 45,64	673,39, 74,745	0.9854	2.18	0.0860	61.78
	$W_2 = 0.75$	67,35, 46,64	662,40, 76,713	0.9845	2.17	0.08464	62.38
	$W_2 = 1$	69,34, 45,64	668,38, 75,747	0.9845	2.17	0.08	64.44
5 zones	$W_1 = 1$	24,35, 45,52, 64	314,38, 73,354, 649	0.9886	2.42	0.0877	61.02
	$W_1 = 0.75$	24,35, 45,52, 64	319,38, 73,352, 666	0.9885	2.42	0.0853	62.09
	$W_2 = 0.75$	25,35, 45,52, 64	305,38, 75,363, 700	0.9885	2.4	0.0839	62.71
	$W_2 = 1$	24,35, 46,52, 64	311,39, 73,356, 654	0.9884	2.38	0.08161	63.73
6 zones	$W_1 = 1$	23,34, 45,52, 64,69	265,39, 75,358, 649,38	0.9944	2.55	0.0861	61.73
	$W_1 = 0.75$	24,35, 45,52, 63,69	278,39, 73,346, 663,38	0.9943	2.53	0.086	61.78
	$W_2 = 0.75$	24,35, 45,52, 64,69	259,39, 74,349, 721,39	0.9892	2.49	0.0833	62.98
	$W_2 = 1$	25,34, 45,52, 63,69	296,38, 74,360, 747,39	0.9891	2.48	0.08062	64.17

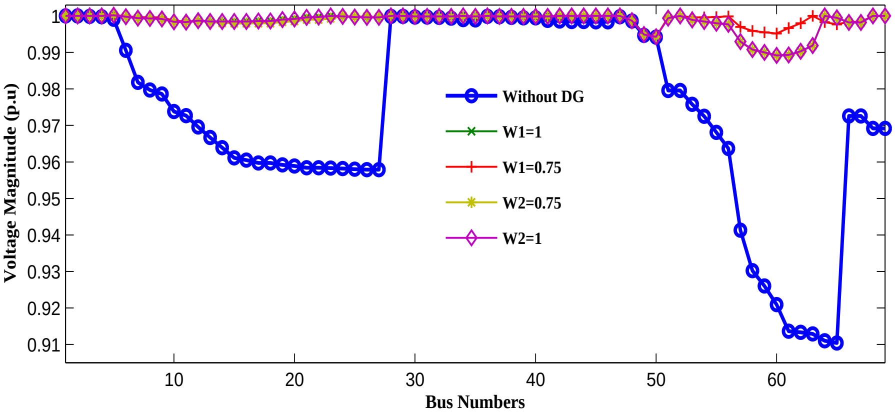

FIGURE 3.9: Comparison of Voltage Profiles for Type-1 DGs with 6 zones at Base Load (IEEE 69 Bus System)

- **Analysis with Type-3 DGs**

The proposed method of DG installation is tested on IEEE 69 bus system by dividing into 4 zones, 5 zones and 6 zones respectively and placing Type-3 DGs in the system for different objectives. The optimal locations and sizes obtained for different objectives and the effect on the system in terms of voltage stability margin improvement and loss reduction is shown in Table. 3.6. The overall penetration level of DGs varies between 27.22% and 27.97% with 4 DGs. The penetration level of DGs varies between 27.69% and 28.31% when divided into 5 zones. When divided into 6 zones the penetration level varies between 27.31% and 28.41% for different combinations of W_1 and W_2. A comparison of the voltage profiles when divided into 4 zones, 5 zones and 6 zones are shown in Figs. 3.10, 3.11 and 3.12 respectively.

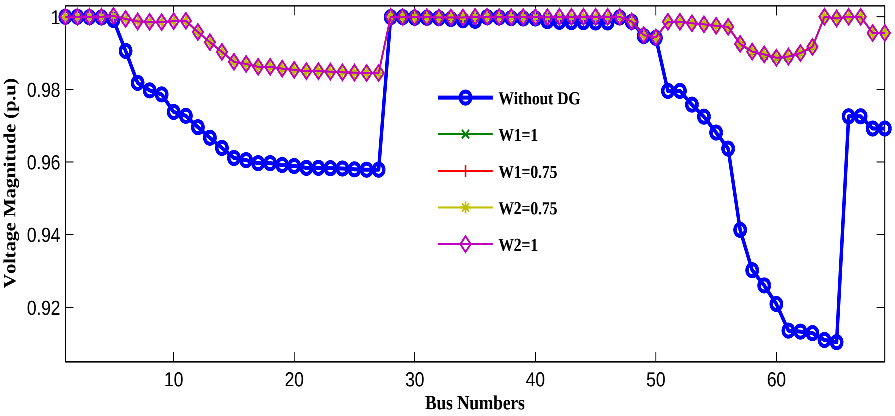

FIGURE 3.10: Comparison of Voltage Profiles for Type-3 DGs with 4 zones at Base Load (IEEE 69 Bus System)

TABLE 3.6: Analysis of Results with Type-3 DGs at Base Load (IEEE 69 Bus System)

zones	Cases	DG location	DG size (kVA)	Minimum Voltage (p.u)	Improvement in Voltage Stability Margin (%)	Active Power Loss (MW)	Reduction in Active Power Loss (%)	Reactive Power Loss (MVAr)	Reduction in Reactive Power Loss (%)
Without DG		-	-	0.9104	-	0.225	-	0.10219	-
4 zones	$W_1 = 1$	67,35, 45,64	802,48, 90,824	0.9845	2.18	0.07316	67.48	0.03675	64.04
	$W_1 = 0.75$	67,34, 45,64	793,47, 92,880	0.9845	2.18	0.06219	72.36	0.02981	70.83
	$W_2 = 0.75$	67,34, 45,64	816,46, 90,880	0.9844	2.17	0.06133	72.74	0.02960	71.03
	$W_2 = 1$	67,35, 45,64	800,47, 90,848	0.9843	2.17	0.05979	73.43	0.02851	72.10
5 zones	$W_1 = 1$	25,35, 45,52, 64	729,45, 91,441, 819	0.9889	2.42	0.07903	64.88	0.03522	65.53
	$W_1 = 0.75$	25,35, 45,52, 64	731,45, 88,438, 848	0.9886	2.42	0.0625	72.22	0.02931	71.32
	$W_2 = 0.75$	24,35, 45,52, 64	735,46, 88,448, 772	0.9885	2.39	0.05949	73.56	0.02873	71.89
	$W_2 = 1$	25,35, 45,52, 64	729,44, 89,435, 819	0.9885	2.38	0.05933	73.63	0.02830	72.31
6 zones	$W_1 = 1$	24,35, 45,52, 64,69	310,46, 88,430, 840,73	0.9891	2.49	0.06482	71.19	0.03054	70.11
	$W_1 = 0.75$	25,34, 45,52, 64,69	327,45, 87,435, 822,73	0.9889	2.48	0.06135	72.73	0.02920	71.43
	$W_2 = 0.75$	24,35, 45,52, 64,69	324,46, 92,456, 881,73	0.9888	2.48	0.05948	73.56	0.02810	72.50
	$W_2 = 1$	24,35, 45,52, 64,69	309,46, 87,450, 807,73	0.9888	2.46	0.05692	74.70	0.02808	72.52

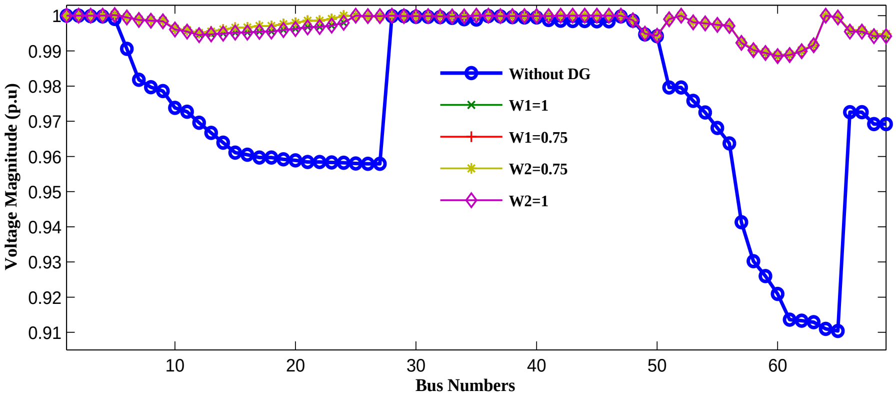

Figure 3.11: Comparison of Voltage Profiles for Type-3 DGs with 5 zones at Base Load (IEEE 69 Bus System)

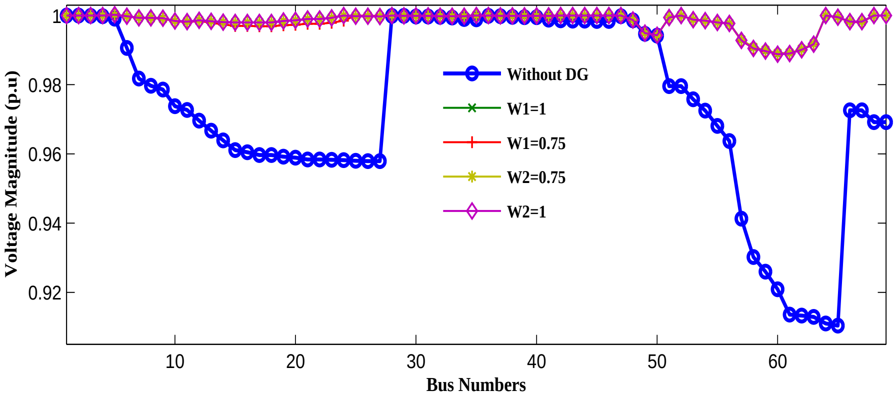

Figure 3.12: Comparison of Voltage Profiles for Type-3 DGs with 6 zones at Base Load (IEEE 69 Bus System)

In the IEEE 69 Bus system the losses are reduced with the addition of the 6^{th} DG in the system. However, the installation of additional DGs leads to an increase in the initial investment cost. The performance of the system needs to investigated by dividing the system into smaller zones before the investment in DG installation. The overall penetration of the DG units in the system is varied by the creation of multiple zones in the system.

3.5 Analysis of the proposed method under varying operating conditions (with zones)

The analysis of the proposed method under varying operating conditions was performed to test the effectiveness of placement strategy. The system loading was increased from base load to 140% of base load in steps of 10%. The voltage stability margin improvement and loss reduction at each incremental loading is observed. In the presence of Type-3 DG units, the reactive power losses reduction is also observed. The voltage stability margin and loss reduction were improved with the installation of DG units for all loading levels and the results obtained at 140% of base load is discussed in the following section.

3.5.1 Test Results of IEEE 33 Bus System (140% of Base Load)

- **Type-1 DG**

  The results of overload analysis in the presence of Type-1 DG when the IEEE 33 bus system is divided into 3 and 4 zones is shown in Table 3.7. Figs. 3.13 & 3.14 show the voltage profile when the system is divided into 3 and 4 zones respectively. It can be observed that the minimum voltage is much lower without DG and has been satisfactorily improved in the presence of DG.

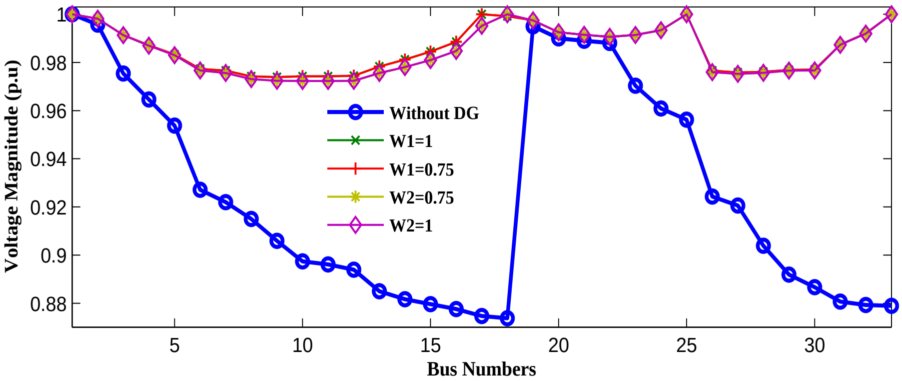

FIGURE 3.13: Comparison of Voltage Profiles for Type-1 DGs with 3 zones at 140% of Base Load (IEEE 33 Bus System)

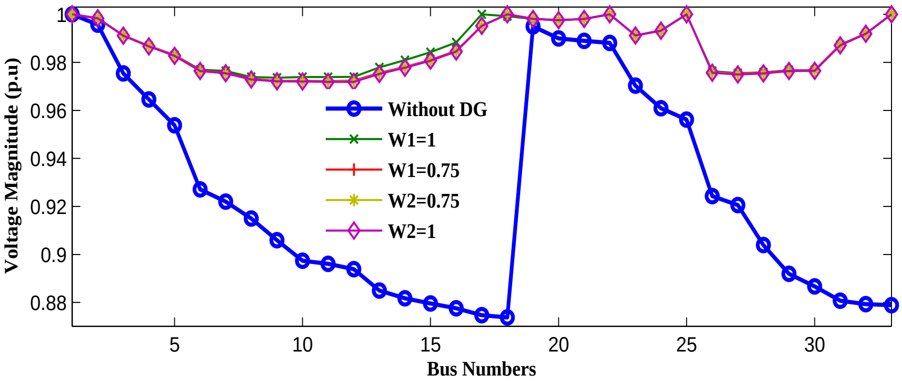

FIGURE 3.14: Comparison of Voltage Profiles for Type-1 DGs with 4 zones at 140% of Base Load (IEEE 33 Bus System)

Table 3.7: Analysis of Results with Type-1 DGs at 140% of Base Load (IEEE 33 Bus System)

zones	**Cases**	**DG location**	**DG size (kW)**	**Minimum Voltage (p.u)**	**Improvement in Voltage Stability Margin (%)**	**Active Power Loss (MW)**	**Reduction in Active Power Loss (%)**
Without DG		-	-	0.8738	-	0.42464	-
3 zones	$W_1 = 1$	17,25, 33	616,536, 381	0.9738	6.538	0.21664	48.98
	$W_1 = 0.75$	17,25, 33	617,550, 374	0.9737	6.537	0.21642	49.03
	$W_2 = 0.75$	17,25, 33	621,553, 376	0.9736	6.536	0.21579	49.18
	$W_2 = 1$	18,22, 33	650,574, 400	0.9723	6.45	0.20928	50.71
4 zones	$W_1 = 1$	18,22, 25,33	603,144, 378,380	0.9736	6.603	0.22463	47.1
	$W_1 = 0.75$	18,22, 25,33	619,146, 383,387	0.9722	6.522	0.22366	47.32
	$W_2 = 0.75$	17,22, 25,33	610,144, 379,376	0.9720	6.509	0.22165	47.8
	$W_2 = 1$	18,22, 25,33	649,150, 400,400	0.9719	6.503	0.21581	49.17

- **Type-3 DG**

  The results of overload analysis in the presence of Type-3 DG when the IEEE 33 bus system is divided into 3 and 4 zones is shown in Table 3.8. Figs. 3.15 and 3.16 show the voltage profile when the system is divided into 3 and 4 zones respectively. It can be observed that the minimum voltage is much lower without DG and has been satisfactorily improved in the presence of DG.

Table 3.8: Analysis of Results with Type-3 DGs at 140% of Base Load (IEEE 33 Bus System)

zones	**Cases**	**DG location**	**DG size (kVA)**	**Minimum Voltage (p.u)**	**Improvement in Voltage Stability Margin (%)**	**Active Power Loss (MW)**	**Reduction in Active Power Loss (%)**	**Reactive Power Loss (MVAr)**	**Reduction in Reactive Power Loss (%)**
Without DG		-	-	0.8738	-	0.42464	-	0.28343	-
3 zones	$W_1 = 1$	17,25, 33	715,620, 552	0.9740	6.552	0.15453	63.6	0.12991	54.16
	$W_1 = 0.75$	17,25, 33	720,623, 552	0.9739	6.551	0.15412	63.7	0.12152	57.12
	$W_2 = 0.75$	18,25, 33	718,617, 555	0.9723	6.452	0.15285	64.0	0.12129	57.20
	$W_2 = 1$	18,25, 33	711,619, 555	0.9722	6.451	0.15224	64.14	0.12027	57.56
4 zones	$W_1 = 1$	17,22, 25,33	719,162, 447,562	0.9740	6.62	0.15968	62.39	0.13388	52.76
	$W_1 = 0.75$	17,22, 25,33	716,162, 439,556	0.9739	6.618	0.15885	62.59	0.13342	52.92
	$W_2 = 0.75$	17,22, 25,33	718,163, 446,553	0.9738	6.616	0.15880	62.6	0.13338	52.94
	$W_2 = 1$	17,22, 25,33	707,154, 440,555	0.9736	6.615	0.15711	63	0.13231	53.31

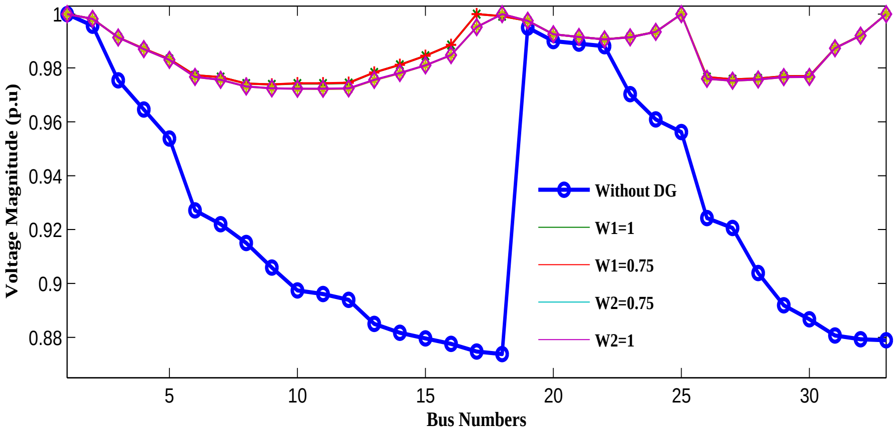

Figure 3.15: Comparison of Voltage Profiles for Type-3 DGs with 3 zones at 140% of Base Load (IEEE 33 Bus System)

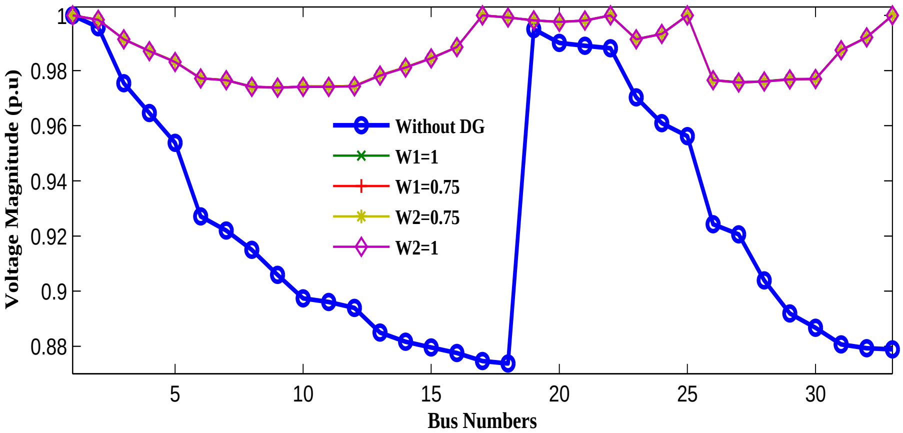

FIGURE 3.16: Comparison of Voltage Profiles for Type-3 DGs with 4 zones at 140% of Base Load (IEEE 33 Bus System)

It can be seen that, even under overloaded condition the performance of Type-3 DG units are better. With the 4^{th} DG in the IEEE 33 bus system the performance of the system deteriorates under overloaded condition.

3.5.2 Test Results of IEEE 69 Bus System (140% of Base Load)

- **Type-1 DG**

  The results of overload analysis in the presence of Type-1 DG when the IEEE 69 bus system is divided into 4 ,5 and 6 zones is shown in Table 3.9. Figs. 3.17, 3.18 & 3.19 show the voltage profile when the system is divided into 4, 5 and 6 zones respectively. It can be seen that the minimum voltage is improved satisfactorily with the installation of DG units.

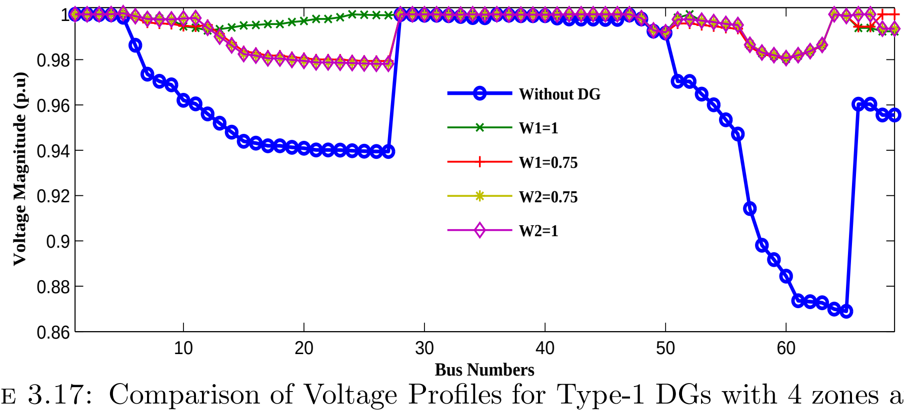

FIGURE 3.17: Comparison of Voltage Profiles for Type-1 DGs with 4 zones at 140% of Base Load (IEEE 69 Bus System)

Table 3.9: Analysis of Results with Type-1 DGs at 140% of Base Load (IEEE 69 Bus System)

zones	**Cases**	**DG location**	**DG size (kW)**	**Minimum Voltage (p.u)**	**Improvement in Voltage Stability Margin (%)**	**Active Power Loss (MW)**	**Reduction in Active Power Loss (%)**
Without DG		-	-	0.8690	-	0.47768	-
4 zones	$W_1 = 1$	67,34, 46,64	667,38, 73,682	0.9794	3.184	0.23808	45.55
	$W_1 = 0.75$	69,35, 45,64	673,39, 74,745	0.9790	3.181	0.23260	46.8
	$W_2 = 0.75$	67,35, 46,64	662,40, 76,713	0.9782	3.173	0.22362	48.85
	$W_2 = 1$	69,34, 45,64	668,38, 75,747	0.9780	3.171	0.22347	48.89
5 zones	$W_1 = 1$	24,35, 45,52, 64	314,38, 73,354, 649	0.9808	3.519	0.23926	45.28
	$W_1 = 0.75$	24,35, 45,52, 64	319,38, 73,352, 666	0.9805	3.518	0.23845	45.46
	$W_2 = 0.75$	25,35, 45,52, 64	305,38, 75,363, 700	0.9804	3.517	0.23579	46.07
	$W_2 = 1$	24,35, 46,52, 64	311,39, 73,356, 654	0.9803	3.472	0.23034	47.32
6 zones	$W_1 = 1$	23,34, 45,52, 64,69	265,39, 75,358, 649,38	0.9916	3.728	0.23853	45.45
	$W_1 = 0.75$	24,35, 45,52, 63,69	278,39, 73,346, 663,38	0.9911	3.705	0.22763	47.94
	$W_2 = 0.75$	24,35, 45,52, 64,69	259,39, 74,349, 721,39	0.9819	3.631	0.22222	49.18
	$W_2 = 1$	25,34, 45,52, 63,69	296,38, 74,360, 747,39	0.9816	3.616	0.22149	49.34

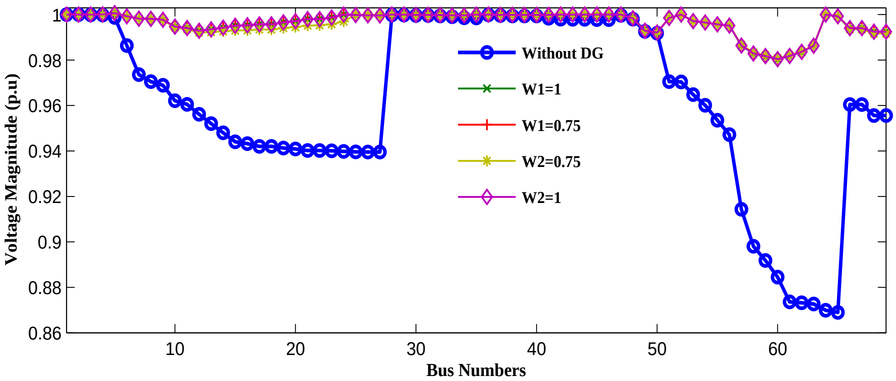

FIGURE 3.18: Comparison of Voltage Profiles for Type-1 DGs with 5 zones at 140% of Base Load (IEEE 69 Bus System)

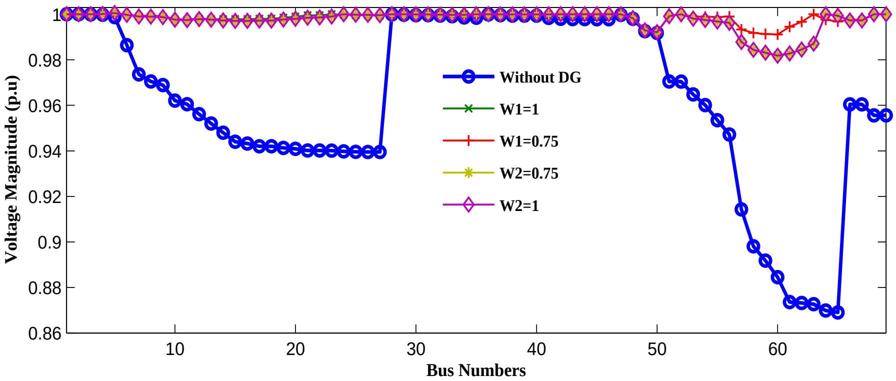

FIGURE 3.19: Comparison of Voltage Profiles for Type-1 DGs with 6 zones at 140% of Base Load (IEEE 69 Bus System)

- **Type-3 DG**

  The results of overload analysis in the presence of Type-3 DG when the IEEE 69 bus system is divided into 4 ,5 and 6 zones is shown in Table 3.10. The voltage profiles when the IEEE 69 bus system is divided into 4, 5 and 6 zones is shown in Figs. 3.20, 3.21 & 3.22. The minimum voltage is improved with the installation of DG units in the system.

Table 3.10: Analysis of Results with Type-3 DGs at 140% of Base Load (IEEE 69 Bus System)

zones	**Cases**	**DG location**	**DG size (kVA)**	**Minimum Voltage (p.u)**	**Improvement in Voltage Stability Margin (%)**	**Active Power Loss (MW)**	**Reduction in Active Power Loss (%)**	**Reactive Power Loss (MVAr)**	**Reduction in Reactive Power Loss (%)**
Without DG		-	-	0.8690	-	0.47768	-	0.216	-
4 zones	$W_1 = 1$	67,35, 45,64	802,48, 90,824	0.9784	3.189	0.19254	55.96	0.08836	54.81
	$W_1 = 0.75$	67,34, 45,64	793,47, 92,880	0.9782	3.188	0.18798	57.01	0.08648	55.77
	$W_2 = 0.75$	67,34, 45,64	816,46, 90,880	0.9781	3.183	0.18244	58.27	0.08421	56.93
	$W_2 = 1$	67,35, 45,64	800,47, 90,848	0.9780	3.180	0.18169	58.44	0.08381	57.13
5 zones	$W_1 = 1$	25,35, 45,52, 64	729,45, 91,441, 819	0.9814	3.528	0.18504	57.68	0.08551	56.26
	$W_1 = 0.75$	25,35, 45,52, 64	731,45, 88,438, 848	0.9806	3.519	0.17906	59.05	0.08259	57.76
	$W_2 = 0.75$	24,35, 45,52, 64	735,46, 88,448, 772	0.9805	3.469	0.17983	59.08	0.08252	57.79
	$W_2 = 1$	25,35, 45,52, 64	729,44, 89,435, 819	0.9804	3.362	0.17552	59.86	0.08109	58.52
6 zones	$W_1 = 1$	24,35, 45,52, 64,69	310,46, 88,430, 840,73	0.9818	3.617	0.18905	56.76	0.08744	55.28
	$W_1 = 0.75$	25,34, 45,52, 64,69	327,45, 87,435, 822,73	0.9814	3.614	0.18680	57.28	0.08646	55.78
	$W_2 = 0.75$	24,35, 45,52, 64,69	324,46, 92,456, 881,73	0.9811	3.610	0.18363	58	0.08524	56.4
	$W_2 = 1$	24,35, 45,52, 64,69	309,46, 87,450, 807,73	0.9810	3.581	0.17457	60.07	0.08135	58.39

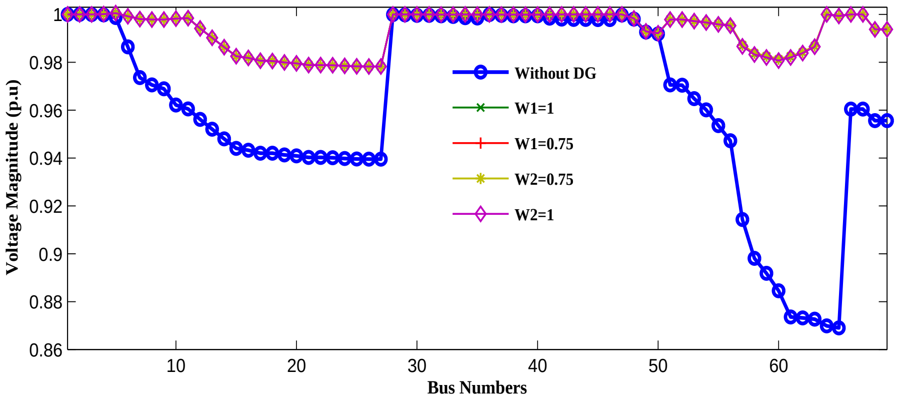

FIGURE 3.20: Comparison of Voltage Profiles for Type-3 DGs with 4 zones at 140% of Base Load (IEEE 69 Bus System)

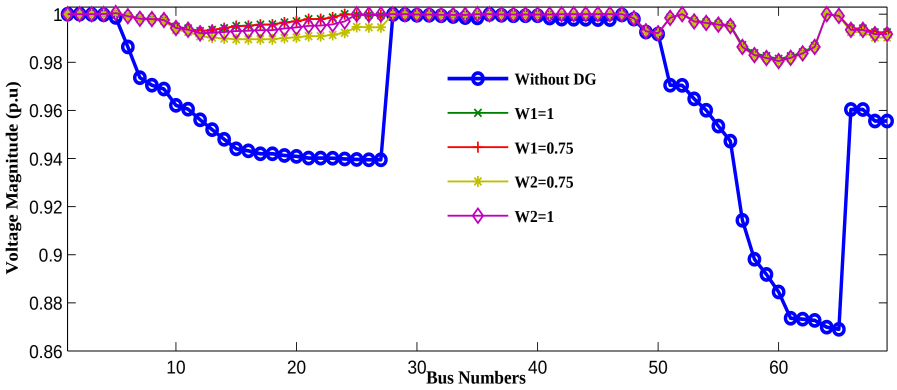

FIGURE 3.21: Comparison of Voltage Profiles for Type-3 DGs with 5 zones at 140% of Base Load (IEEE 69 Bus System)

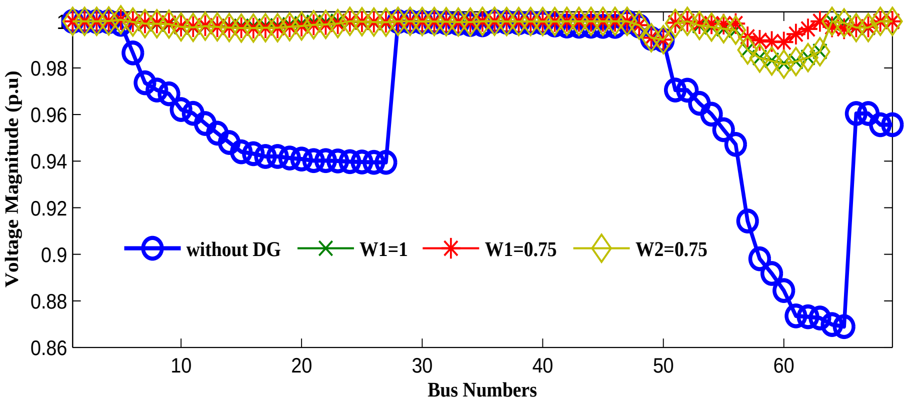

FIGURE 3.22: Comparison of Voltage Profiles for Type-3 DGs with 6 zones at 140% of Base Load (IEEE 69 Bus System)

The following conclusions can be drawn from the Proposed Method of DG installation:

- In 33 Bus system, better results are achieved when W_1 is considered as 0.75 for type-1 and type-3 DG installation.

- In 69 Bus system, the performance is improved when W_1 is considered as 0.75 when the system is divided into 4 and 6 zones for type-1 and type-3 DG installation. When the system is divided into 5 zones better results are achieved when W_2 is considered as 0.75 for DG installation.
- The overall penetration level of DGs in the system can be varied by dividing the system into zones. With DG units installed at different parts of the system, the performance is improved with lesser power from individual DG units.
- The increase in number of zones leads to better performance of the system. However, the performance cannot be improved beyond the optimal number of divisions. Since, DG installation increases the initial investment cost, identification of the ideal number of zones is critical.
- The creation of number of zones is system specific. Since, the load demand and number of buses in each radial branch varies from system to system, it is crucial to identify the ideal number of buses in each zone.

3.6 Proposed Optimal Placement of DGs without zones

In this method, the entire test system is searched for the optimal placement of DG units satisfying the objective. The total size of the DG units should not exceed the maximum allowable penetration level. In this method, in the initial stage, multiple possible combinations of individuals are formed. The fitness of each combination is checked and the best combination is taken for further processes. The weaker combinations are neglected at the initial stage itself. Since the best combination of individuals is considered for crossover and mutation processes, the off-springs produced have the best characteristics of the parents making them better individuals for further generations. The flowchart for the proposed method of DG placement and sizing is shown in Fig. 3.23.

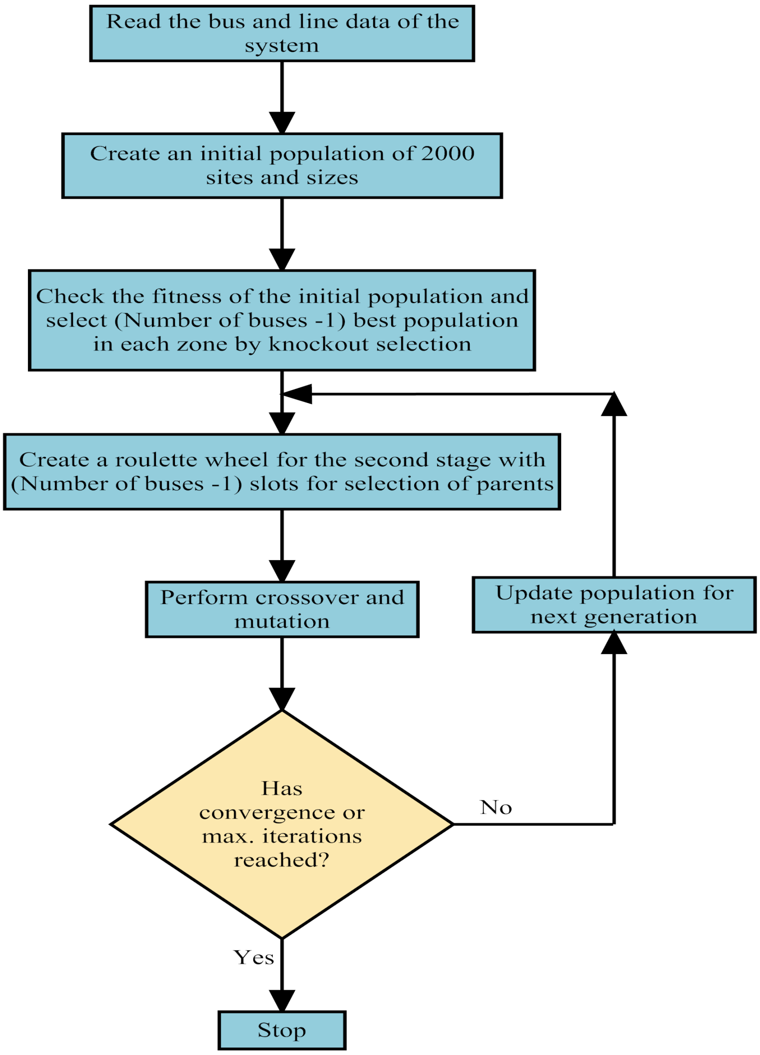

FIGURE 3.23: Optimal Placement and Sizing of DGs in zones

Steps for Placement of DGs without zones

1. Generate an initial population of 2000 sites and sizes in each zone.
2. Check the fitness of initial population for the objective function considered.
3. Select (Number of buses-1) best population for the next stage.
4. Create a roulette wheel with (Number of buses-1) slots for the selection of parents.
5. Perform crossover and mutation with the selected parents.
6. With the produced off-spring repeat Step 4 until the maximum generation is reached or optimal solution is achieved.

3.6.1 Test Results of IEEE 33 Bus System

- **Type-1 DG**

The results obtained for optimal location and sizes by the proposed method are shown in Table 3.11 for different values of W_1 and W_2. The method has been tested for various combinations of weights for achieving different objectives. The results are compared with two existing methods where single objective is considered.

TABLE 3.11: Analysis of Results with Type-1 DGs at Base Load (IEEE 33 Bus System)

Cases	DG location	DG size (kW)	Minimum Voltage (p.u)	Improvement in Voltage Stability Margin (%)	Active Power Loss (MW)	Reduction in Active Power Loss (%)
Without DG	-	-	0.9131	-	0.20267	-
$W_1 = 1$	14,5, 31	897,664, 26	0.9902	4.99	0.08315	58.97
$W_1 > W_2$	23,30, 13	477,345, 769	0.9902	4.97	0.08283	59.13
$W_1 < W_2$	13,30, 23	786,745, 42	0.9872	4.96	0.07856	61.24
$W_2 = 1$	30,12, 24	589,947, 53	0.9835	4.95	0.07041	65.26
SA [64]	17,18, 33	719,113, 1043	0.9693	4.32	0.09832	51.48
HSA [74]	17,18, 33	572,107, 1046	0.9670	4.29	0.09676	52.26

When W_1 is considered as 1, the optimal locations of DGs are 14, 5 and 31 with sizes 897kW, 664kW and 26kW respectively resulting in a voltage stability margin of 4.99% and loss reduction of 58.97%. When W_1 is considered more than 0.5, the optimal locations achieved are 23, 30 and 13 with optimal sizes as 477kW, 345kW and 769kW respectively, giving a voltage stability margin improvement of 4.97% and loss reduction of 59.13%. When W_2 is taken more than 0.5, then the optimal locations are 13, 30 and 23 with sizes being 786kW, 745kW and 42kW respectively, resulting in a voltage stability improvement of 4.96% and loss reduction of 61.24%. When W_2 is considered as 1, the optimal sites are 30, 12 and 24 with sizes being 589kW, 947kW and 53kW respectively, resulting in a voltage stability improvement of 4.95% loss reduction of 65.26%. The overall penetration level of DGs varies between 28.64% and 28.88%. Figs. 3.24 and 3.25 show the comparison of voltage profiles and active power losses respectively with the installation of type-1 DG for different values of W_1 and W_2 and existing methods of DG installation. It can observed from fig. 3.25, the loss reduction by the proposed method of DG installation is better than by existing method. The optimal results are obtained when W_2 is considered more than 0.5.

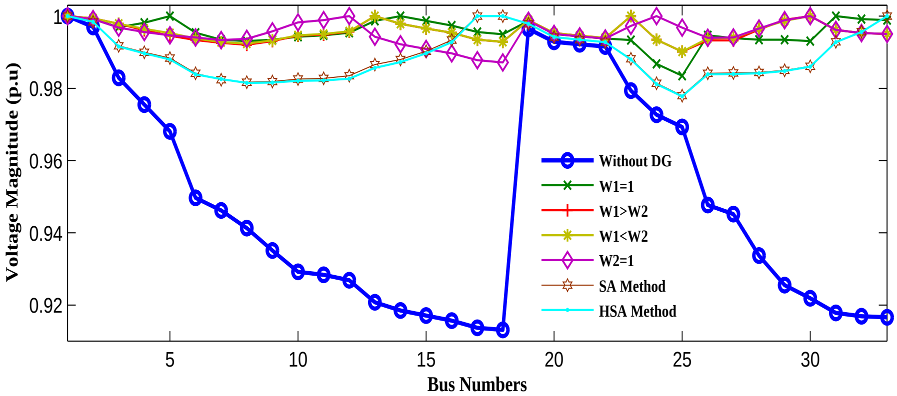

FIGURE 3.24: Comparison of Voltage Profiles with Type-1 DGs at Base Load (IEEE 33 Bus System)

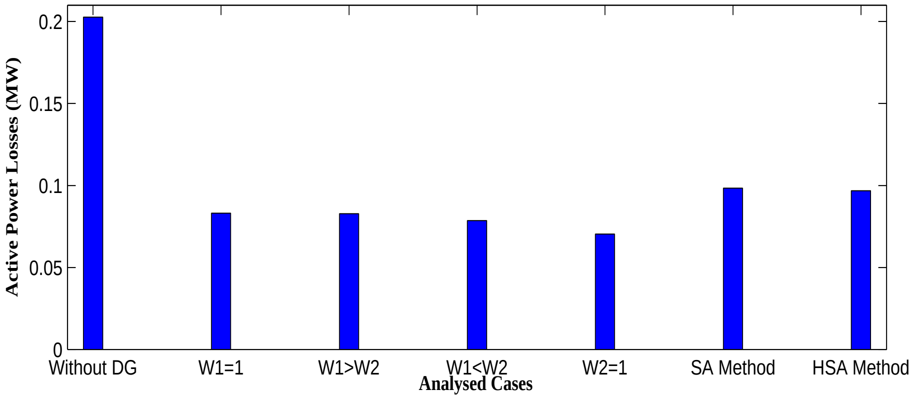

FIGURE 3.25: Comparison of Active Power Losses with Type-1 DGs at Base Load (IEEE 33 Bus System)

- **Type-3 DG**

The results obtained for optimal location and sizes by the proposed method is shown in Table 3.12 for different values of weights. The method has been tested by varying the weights for achieving different objectives for voltage stability margin improvement and reduction of active and reactive power losses.

TABLE 3.12: Analysis of Results with Type-3 DGs at Base Load (IEEE 33 Bus System)

Cases	**DG location**	**DG size (kVA)**	**Minimum Voltage (p.u)**	**Improvement in Voltage Stability Margin (%)**	**Active Power Loss (MW)**	**Reduction in Active Power Loss (%)**	**Reactive Power Loss (MVAr)**	**Reduction in Reactive Power Loss (%)**
Without DG	-	-	0.9131	-	0.20267	-	0.13514	-
$W_1 = 1$	14,5, 30	1154,375, 320	0.9924	5.02	0.05349	73.61	0.03784	72
$W_1 > W_2$	30,13, 24	1443,404, 13	0.9914	5.00	0.05340	73.65	0.03573	73.56
$W_1 < W_2$	13,30, 24	833,963, 22	0.9909	4.98	0.05182	74.43	0.03583	73.49
$W_2 = 1$	14,24, 30	893,336, 547	0.9836	4.96	0.04253	79.02	0.02858	78.85
PSO [78]	6	3025	0.9509	3.83	0.07612	62.44	0.05797	57.1

When W_1 is considered as 1, the optimal locations of DGs are 14, 5 and 30 with sizes 1154kVA, 375kVA and 320kVA respectively resulting in a voltage stability margin of 5.02%, active power loss reduction of 73.61% and reactive power loss reduction of 72%. When W_1 is considered more than 0.5, the optimal locations achieved are 13, 30 and 24 with optimal sizes as 1443kVA, 404kVA and 13kVA respectively, giving a voltage stability margin improvement of 5%, active power loss reduction of 73.65% and reactive power loss reduction of 73.56%. When W_2 is taken more than 0.5, then the optimal locations are 13, 30 and 24 with sizes being 833kVA, 963kVA and 22kVA respectively, resulting in a voltage stability improvement of 4.96% and active power loss reduction of 74.43% and reactive power loss reduction of 73.49%. When W_2 is considered as 1, the optimal sites are 14, 24 and 30 with sizes being 893kVA, 336kVA and 547kVA respectively, resulting in a voltage stability margin improvement of 4.96% active power loss reduction of 79.02% and reactive power loss reduction of 78.85%. The overall penetration level of DGs varies between 27.78% and 28.72%.

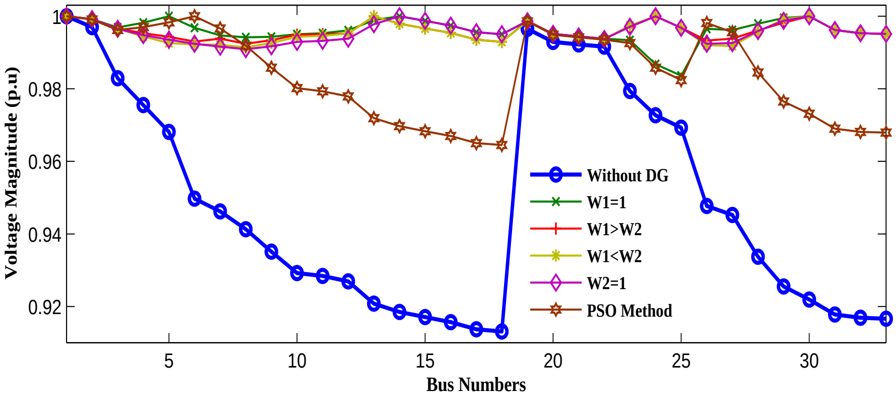

FIGURE 3.26: Comparison of Voltage Profiles with Type-3 DGs at Base Load (IEEE 33 Bus System)

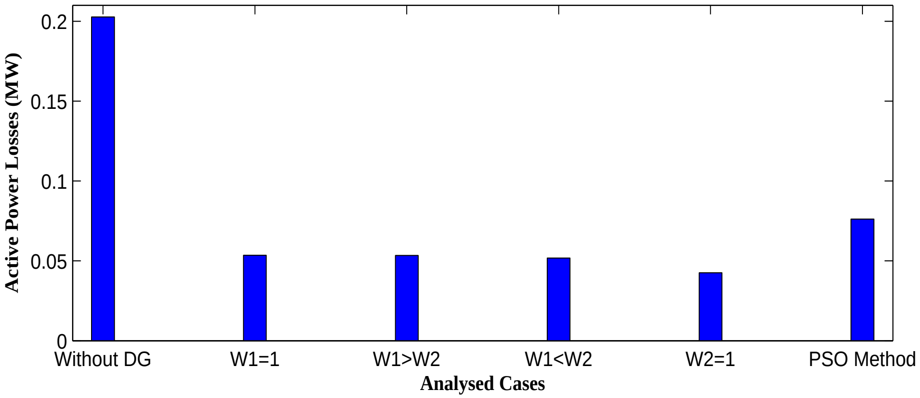

FIGURE 3.27: Comparison of Active Power Losses with Type-3 DGs at Base Load (IEEE 33 Bus System)

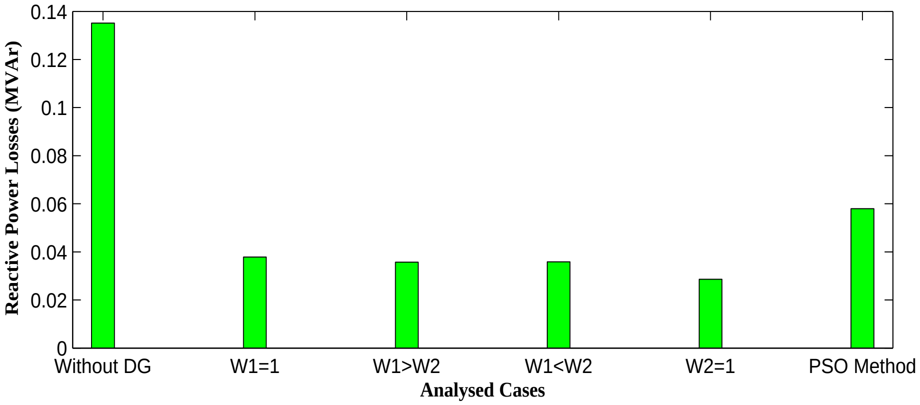

FIGURE 3.28: Comparison of Reactive Power Losses with Type-3 DGs at Base Load (IEEE 33 Bus System)

It can also be observed from the table that the placement of DGs for a multiple objective function gives almost the same results as a single objective function. Hence, it can be more beneficial to consider multiple objectives for optimal placement and sizing of DGs. Figs. 3.26, 3.27 and 3.28 show the comparison of voltage profiles and active and reactive power loss reduction after placement of DGs for different weights. It can be seen that the minimum voltage and overall voltage stability margin improves when multi objective function is considered. The optimal results are obtained when W_1 is considered more than 0.5.

3.6.2 Test Results of IEEE 69 Bus System

- **Type-1 DG**

The results obtained for optimal location and sizes by the proposed method is shown in Table 3.13 for different values of weights.

Table 3.13: Analysis of Results with Type-1 DGs at Base Load (IEEE 69 Bus System)

Cases	**DG location**	**DG size (kW)**	**Minimum Voltage (p.u)**	**Improvement in Voltage Stability Margin (%)**	**Active Power Loss (MW)**	**Reduction in Active Power Loss (%)**
Without DG	-	-	0.9104	-	0.225	-
$W_1 = 1$	21,61, 26	461,678, 259	0.9944	2.52	0.0786	65.07
$W_1 > W_2$	62,43, 16	788,644, 45	0.9943	2.48	0.0779	65.38
$W_1 < W_2$	62,43, 16	788,644, 45	0.9943	2.48	0.0779	65.38
$W_2 = 1$	6,61, 18	27,1016, 143	0.9940	2.45	0.06781	69.86
SA [64]	26, 65	656, 1606	0.9808	2.08	0.10520	53.24
HSA [74]	63,64, 65	1302,369, 101	0.9677	2.04	0.08677	61.44

The method has been tested by varying the weights for achieving different objectives. When W_1 is considered as 1, the optimal locations of DGs are 21, 61 and 26 with sizes 461kW, 678kW and 259kW respectively resulting in a voltage stability margin of 2.52% and loss reduction of 65.07%. When either W_1 or W_2 is considered more than 0.5, the optimal locations achieved are 62, 43 and 16 with optimal sizes as 788kW, 644kW and 45kW respectively, giving a voltage stability margin improvement of 2.48% and loss reduction of 65.38%. When W_2 is considered as 1, the optimal sites are 6, 61 and 18 with sizes being 27kW, 1016kW and 143kW respectively, resulting in a voltage stability margin of 2.45% and loss reduction of 69.86%. The overall penetration level of DGs varies between 23.32% and 27.47%.

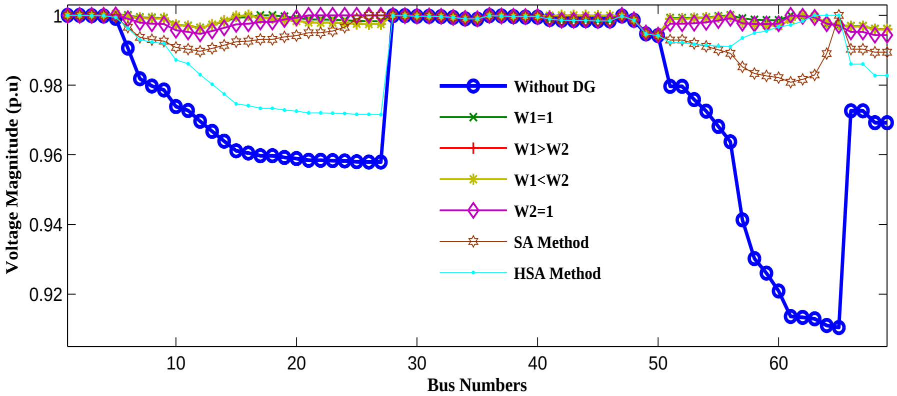

FIGURE 3.29: Comparison of Voltage Profiles with Type-1 DGs at Base Load (IEEE 69 Bus System)

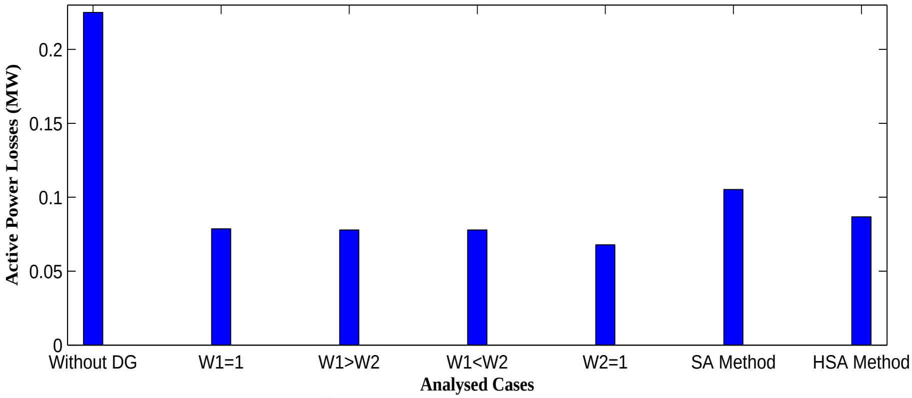

FIGURE 3.30: Comparison of Active Power Losses with Type-1 DGs at Base Load (IEEE 69 Bus System)

Figs. 3.29 and 3.30 show the comparison of voltage profiles and loss reduction after placement of DGs for different weights. It can be seen that the minimum voltage and overall voltage stability margin improves when multi objective function is considered.

- **Type-3 DG**

The optimal location and sizes of Type-3 DGs in IEEE 69 bus system by the proposed method is shown in Table 3.14 for different values of weights in the objective function. The method has been tested by varying the weights for achieving different objectives ranging from single objective to multiple objectives.

TABLE 3.14: Analysis of Results with Type-3 DGs at Base Load (IEEE 69 Bus System)

Cases	DG location	DG size (kVA)	Minimum Voltage (p.u)	Improvement in Voltage Stability Margin (%)	Active Power Loss (MW)	Reduction in Active Power Loss (%)	Reactive Power Loss (MVAr)	Reduction in Reactive Power Loss (%)
Without DG	-	-	0.9104	-	0.225	-	0.10219	-
$W_1 = 1$	61,22, 6	589,242, 259	0.9945	2.59	0.05922	73.68	0.02717	73.41
$W_1 > W_2$	67,61, 22	594,737, 237	0.9944	2.58	0.05920	73.69	0.02686	73.72
$W_1 < W_2$	61,18, 11	937,551, 259	0.9943	2.51	0.05510	75.51	0.02510	75.44
$W_2 = 1$	61,18, 12	1441,336, 160	0.9940	2.5	0.02823	87.45	0.01630	84.05
PSO [78]	61	2243	0.9935	2.42	0.08801	60.88	0.04353	57.04

When W_1 is considered as 1, the optimal locations of DGs are 61, 22 and 6 with sizes 589kVA, 242kVA and 259kVA respectively resulting in a voltage stability margin of 2.59%, active power loss reduction of 73.68% and reactive power loss reduction of 73.41%. When W_1 is considered more than 0.5, the optimal locations achieved are 67, 61 and 22 with optimal sizes as 594kVA, 737kVA and 237kVA respectively, giving a voltage stability margin improvement of 2.58%, active power loss reduction of 73.69% and reactive power loss reduction of 73.72%. When W_2 is considered more than 0.5, the optimal locations achieved are 61, 18 and 11 with optimal sizes as 937kVA, 551kVA and 259kVA respectively, giving a voltage stability margin improvement of 2.51%, active power loss reduction of 75.51% and reactive power loss reduction of 75.44%. When W_2 is considered as 1, the optimal sites are 61, 18 and 12 with sizes being 1441kVA, 336kVA and 160kVA respectively, resulting in active power loss reduction of 87.45% and reactive power loss reduction of 84.05%. The overall penetration level of DGs varies between 24.95% and 29.11%. It can also be observed from the table that the placement of DGs for a multiple objective function is most beneficial. Figs. 3.31, 3.32 and 3.33 show the comparison of voltage profiles and loss reduction after placement of DGs for different weights.

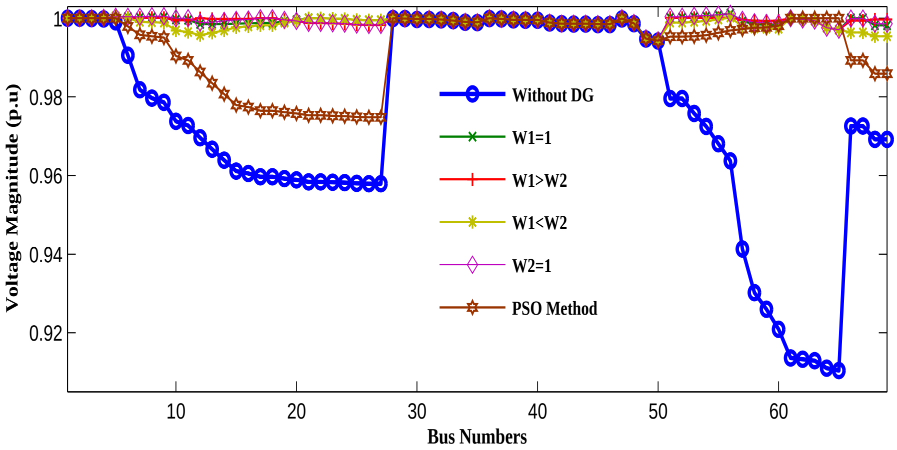

FIGURE 3.31: Comparison of Voltage Profiles with Type-3 DGs at Base Load (IEEE 69 Bus System)

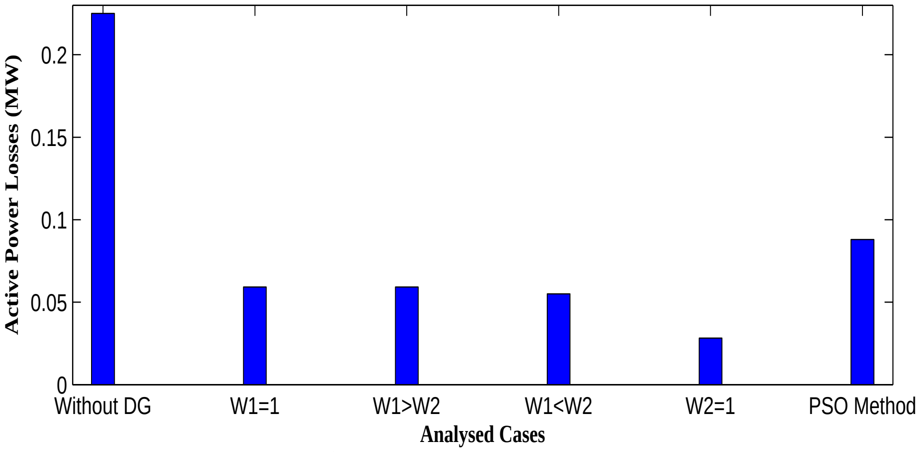

FIGURE 3.32: Comparison of Active Power Losses with Type-3 DGs at Base Load (IEEE 69 Bus System)

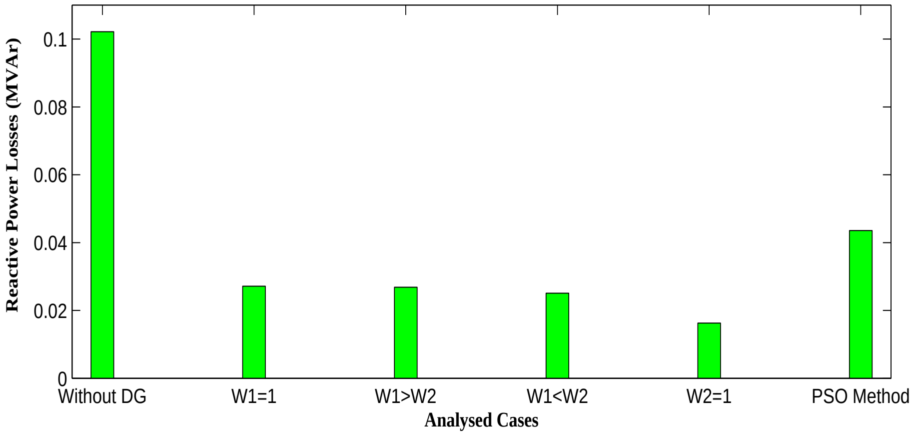

FIGURE 3.33: Comparison of Reactive Power Losses with Type-3 DGs at Base Load (IEEE 69 Bus System)

It can be seen that the minimum voltage and overall voltage stability margin improves when multi objective function is considered. Since the size of IEEE 69 bus system is large, the performance of the multi-objective function is not affected much with the variation in weights.

From the results of both the test systems, it has been found that considering multiple objectives for optimal placement and sizing of DG units was beneficial. With different types of DG units placed in the system, the voltage stability margin improvement, active power loss reduction and reactive power losses changes are influenced. It can be seen that, installation of type-3 DG is beneficial as both real and reactive powers are supplied at the same bus.

3.7 Analysis of the proposed method under varying operating conditions (without zones)

The analysis of the proposed method under varying operating conditions was performed to test the effectiveness of placement strategy. The system loading was increased in steps of 10% from base load to 140% of base load. The effectiveness of DG placement was computed in terms of voltage stability margin improvement and active power loss reduction at each step. In the presence of Type-3 DG units, the reactive power losses reduction is also considered. The results obtained at 140% of base load is discussed in the following section.

3.7.1 Test Results of IEEE 33 Bus System (140% of Base Load)

- **Type-1 DG**

  The results of overload analysis in the presence of Type-1 DG in the IEEE 33 Bus system is shown in Table 3.15. From Fig. 3.34 it can be observed that the minimum voltage is much lower without DG and has been satisfactorily improved in the presence of DG when placed by the proposed method by considering a multi-objective function. From Fig. 3.35 it can be seen that the active power losses is more in the absence of DG. From the Table 3.15 it can be seen that when W_1 is considered lesser than W_2 the results obtained are satisfactory.

Table 3.15: Analysis of Results with Type-1 DGs at 140% of Base Load (IEEE 33 Bus System)

Cases	**DG location**	**DG size (kW)**	**Minimum Voltage (p.u)**	**Improvement in Voltage Stability Margin (%)**	**Active Power Loss (MW)**	**Reduction in Active Power Loss (%)**
Without DG	-	-	0.8738	-	0.42464	-
$W_1 = 1$	14,5, 31	879,664, 26	0.9862	7.41	0.20031	52.83
$W_1 > W_2$	23,30, 13	477,345, 769	0.9821	7.39	0.19942	53.04
$W_1 < W_2$	13,30, 23	786,745, 42	0.9766	7.36	0.19219	54.74
$W_2 = 1$	30,12, 24	589,947, 53	0.9756	7.34	0.18454	56.54
SA [64]	13,30, 23	719,113, 1043	0.9688	6.34	0.21494	49.38
HSA [74]	13,30, 23	572,107, 1046	0.9683	6.31	0.21120	50.26

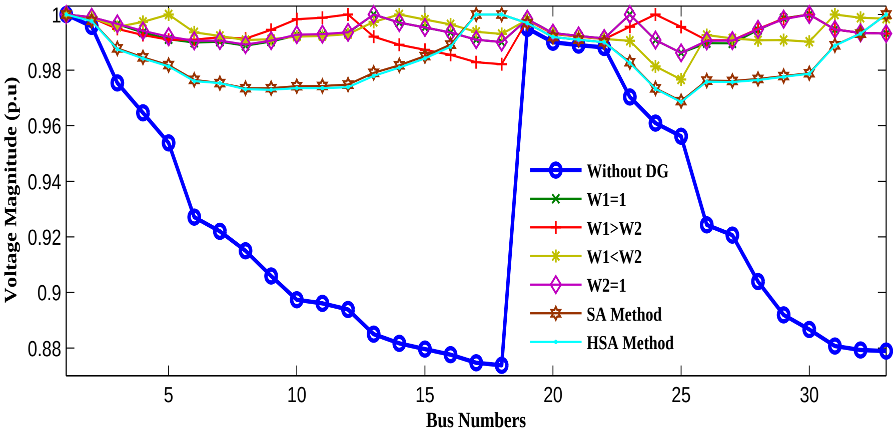

FIGURE 3.34: Comparison of Voltage Profiles with Type-1 DGs at 140% of Base Load (IEEE 33 Bus System)

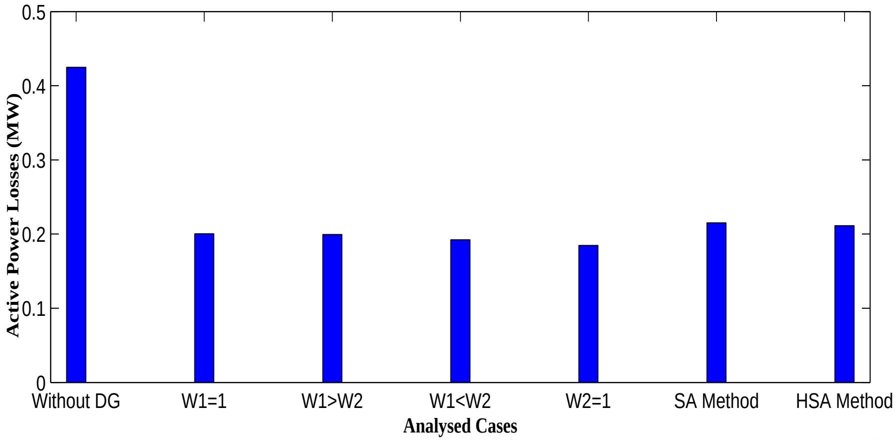

FIGURE 3.35: Comparison of Active Power Losses with Type-1 DGs at 140% of Base Load (IEEE 33 Bus System)

- **Type-3 DG**

The results of performance of Type-3 DG units in the IEEE 33 bus system is shown in Table. 3.16. From Fig. 3.36 it can be observed that the minimum voltage is much lower without DG and has been improved within tolerance limits in the presence of DG when placed by the proposed method by considering a multi-objective function. From the Table 3.16 it can be observed that when W_1 is considered lesser than W_2 the results obtained are satisfactory. From Figs. 3.37 and 3.38 it can be seen that the active power losses is more in the absence of DG.

Table 3.16: Analysis of Results with Type-3 DGs at 140% of Base Load (IEEE 33 Bus System)

Cases	DG location	DG size (kVA)	Minimum Voltage (p.u)	Improvement in Voltage Stability Margin (%)	Active Power Loss (MW)	Reduction in Active Power Loss (%)	Reactive Power Loss (MVAr)	Reduction in Reactive Power Loss (%)
Without DG	-	-	0.8738	-	0.42464	-	0.28343	-
$W_1 = 1$	14,5, 30	1154,375, 320	0.9888	7.47	0.15392	63.75	0.11439	59.64
$W_1 > W_2$	30,13, 24	1443,404, 13	0.9874	7.41	0.15187	64.24	0.11365	59.9
$W_1 < W_2$	13,30, 24	833,963, 22	0.9866	7.37	0.14890	64.94	0.10613	62.56
$W_2 = 1$	14,24, 30	893,336, 547	0.9863	7.35	0.12874	69.68	0.08386	70.41
PSO [78]	6	3025	0.9509	5.71	0.16069	62.16	0.11913	57.96

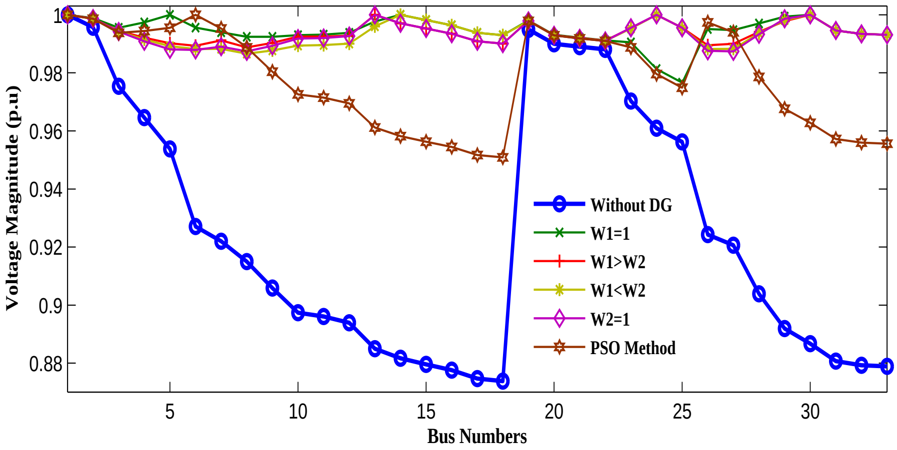

Figure 3.36: Comparison of Voltage Profiles with Type-3 DGs at 140% of Base Load (IEEE 33 Bus System)

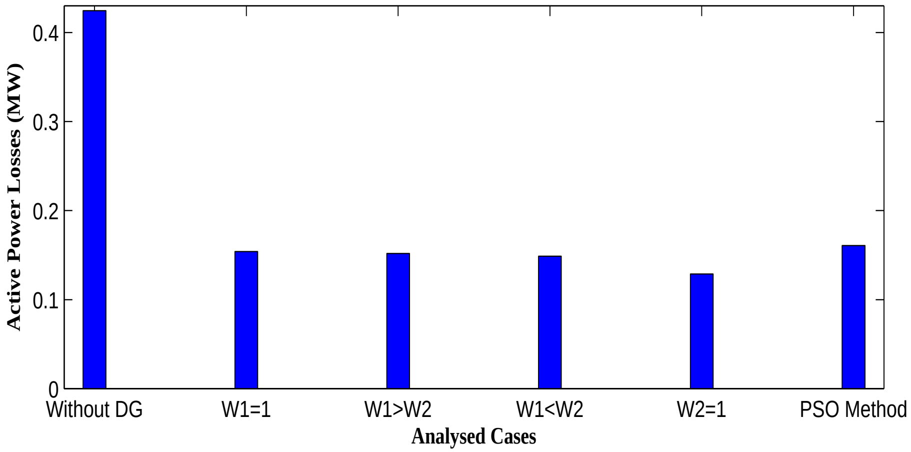

FIGURE 3.37: Comparison of Active Power Losses with Type-3 DGs at 140% of Base Load (IEEE 33 Bus System)

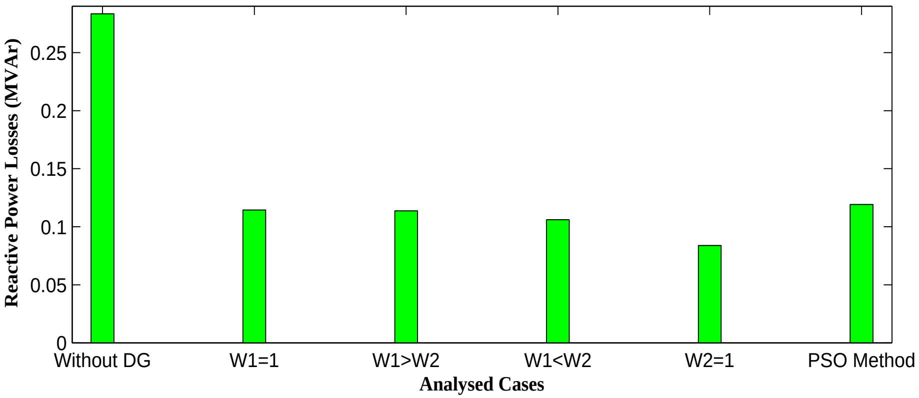

FIGURE 3.38: Comparison of Reactive Power Losses with Type-3 DGs at 140% of Base Load (IEEE 33 Bus System)

3.7.2 Test Results of IEEE 69 Bus System (140% of Base Load)

The effectiveness of optimal DG placement and sizing of Type-1 and Type-3 DG units by the proposed method is tested on IEEE 69 bus system.

- **Type-1 DG**

  The results of performance of Type-1 DG units in the IEEE 69 bus system is shown in Table. 3.17. The comparison of voltage profiles and active power losses is shown in Figs. 3.39 and 3.40. From Fig. 3.39, it can be observed that the minimum voltage has been improved in the presence of DG when placed by the proposed method by considering a multi-objective function. From Fig. 3.40, it can be seen that the active power losses is more in the absence of DG.

Table 3.17: Analysis of Results with Type-1 DGs at 140% of Base Load (IEEE 69 Bus System)

Cases	**DG location**	**DG size (kW)**	**Minimum Voltage (p.u)**	**Improvement in Voltage Stability Margin (%)**	**Active Power Loss (MW)**	**Reduction in Active Power Loss (%)**
Without DG	-	-	0.8690	-	0.47768	-
$W_1 = 1$	21,61, 26	461,678, 259	0.9921	3.7	0.19099	57.34
$W_1 > W_2$	63,42, 16	788,644, 45	0.9918	3.66	0.18752	58.11
$W_1 < W_2$	63,42, 16	788,644, 45	0.9918	3.66	0.18752	58.11
$W_2 = 1$	6,61, 18	27,1016, 143	0.9916	3.64	0.18189	59.37
SA [64]	26, 65	656, 1606	0.9718	3.11	0.21919	54.11
HSA [74]	63,64, 65	1302,369, 101	0.9698	3.05	0.19801	55.77

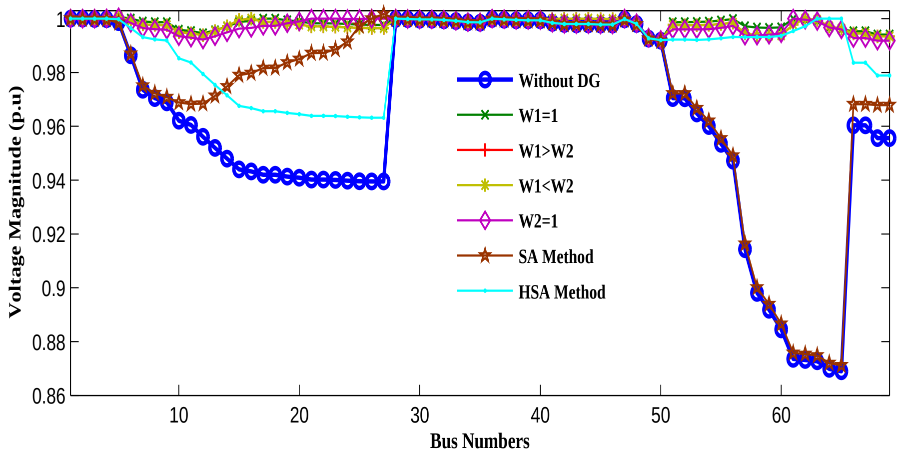

Figure 3.39: Comparison of Voltage Profiles with Type-1 DGs at 140% of Base Load (IEEE 69 Bus System)

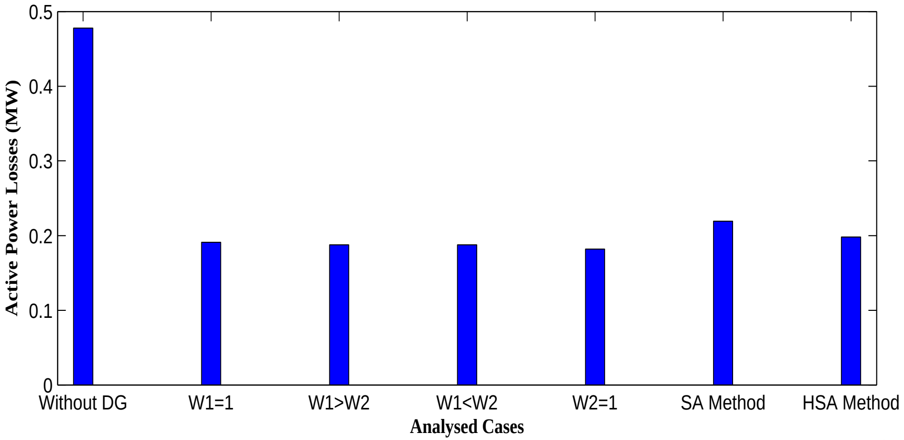

FIGURE 3.40: Comparison of Active Power Losses with Type-1 DGs at 140% of Base Load (IEEE 69 Bus System)

- **Type-3 DG**

  The results of performance of Type-3 DG units in the IEEE 69 bus system is shown in Table. 3.18.

TABLE 3.18: Analysis of Results with Type-3 DGs at 140% of Base Load (IEEE 69 Bus System)

Cases	**DG location**	**DG size (kVA)**	**Minimum Voltage (p.u)**	**Improvement in Voltage Stability Margin (%)**	**Active Power Loss (MW)**	**Reduction in Active Power Loss (%)**	**Reactive Power Loss (MVAr)**	**Reduction in Reactive Power Loss (%)**
Without DG	-	-	0.8690	-	0.47768	-	0.216	-
$W_1 = 1$	61,22, 6	589,242, 259	0.9922	3.79	0.23078	48.45	0.11169	48.29
$W_1 > W_2$	67,61, 22	594,737, 237	0.9922	3.78	0.21340	52.33	0.09924	54.06
$W_1 < W_2$	61,18, 11	937,551, 259	0.9921	3.77	0.18733	58.16	0.08847	59.04
$W_2 = 1$	61,18, 12	1441,336, 160	0.9918	3.75	0.11903	73.41	0.05980	72.31
PSO [78]	61	2243	0.9639	2.75	0.23585	47.32	0.11286	47.75

From Fig. 3.41 it can be observed that the minimum voltage is less without DG and has been satisfactorily improved in the presence of DG when placed by the proposed method by considering a multi-objective function. From Figs. 3.42 and 3.43 it can be seen that the active power losses is more in the absence of DG. From the Table 3.18 it can be observed that when W_1 is considered lesser than W_2 the results obtained are satisfactory. However, it was noted that the performance of the proposed algorithm gradually reduces with gradual increase in load. Nevertheless, the results obtained by the proposed algorithm is better compared to the performance of the existing methods proposed in [64], [74] and [78].

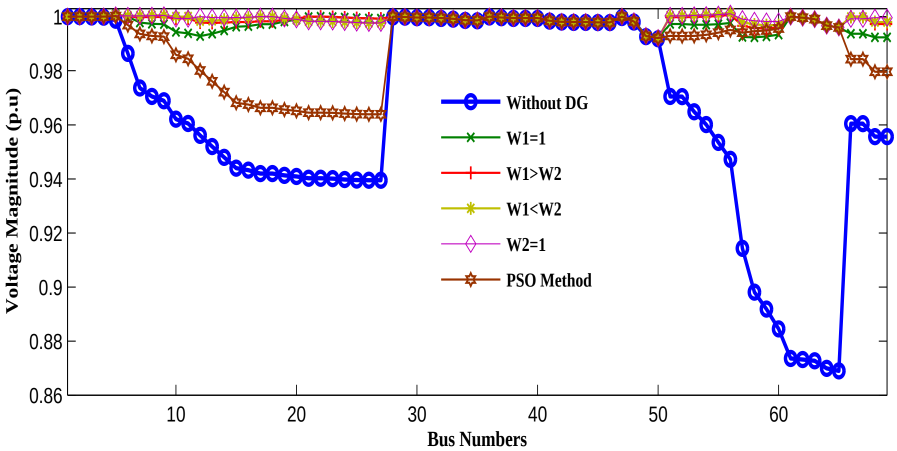

FIGURE 3.41: Comparison of Voltage Profiles with Type-3 DGs at 140% of Base Load (IEEE 69 Bus System)

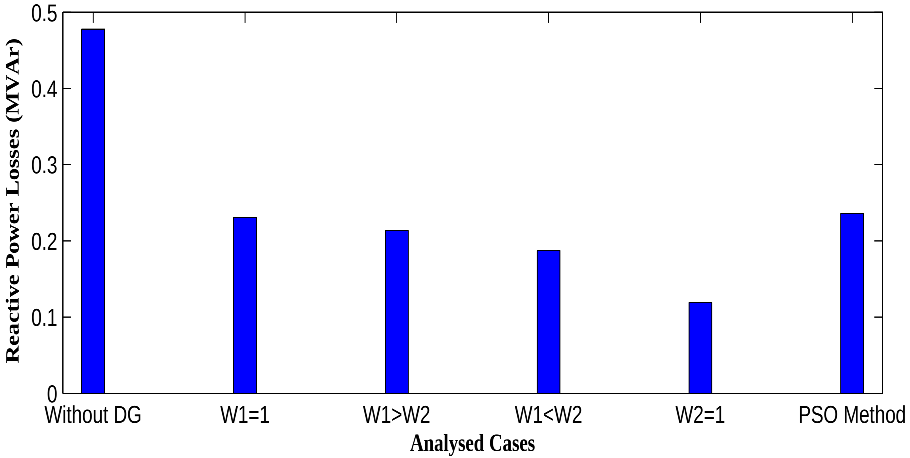

FIGURE 3.42: Comparison of Active Power Losses with Type-3 DGs at 140% of Base Load (IEEE 69 Bus System)

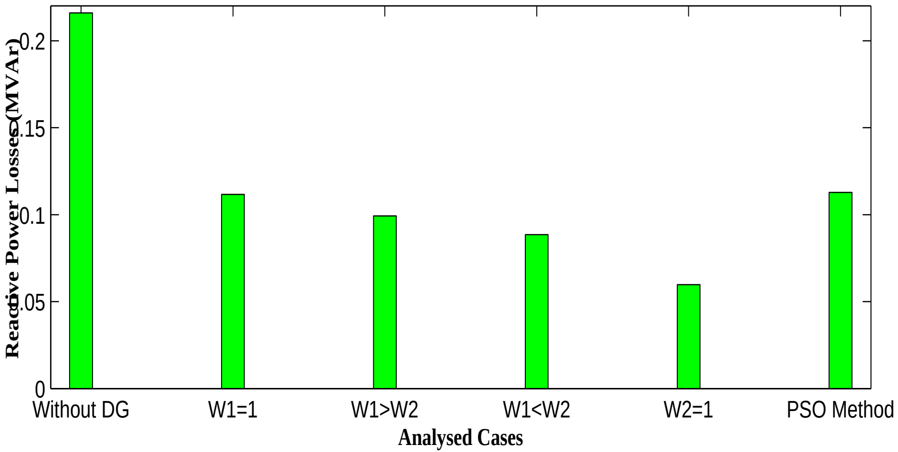

FIGURE 3.43: Comparison of Reactive Power Losses with Type-3 DGs at 140% of Base Load (IEEE 69 Bus System)

The following conclusions can be drawn from this section:

- The optimal installation of DG unit without dividing the system into zones is more effective than by dividing the system into zones as the proposed method is not dependent on specific values of the weights in the objective function.
- In the IEEE 33 Bus system for type-1 DG installation, results are better when W_1 is considered greater than W_2. However for type-3 DG installation, considering W_1 lesser than W_2 is beneficial.
- In the IEEE 69 Bus system for type-1 DG installation, any value of $W_1 > W_2$ and $W_1 < W_1$, gives the same result. For type-3 DG installation considering $W_1 > W_2$ gives better results.
- As the size of the system increases, the effect of variation of weights decreases.

3.8 Summary

The findings of this chapter are summarized as follows:

1. Two methods of DG installation have been proposed in this chapter. In the first method, the system is divided into zones and one DG is optimally installed in each

zone. In the second method, the number of DG units are fixed and optimal location and size is searched throughout the system. Both the methods have been tested by installing type-1 and type-3 DG units at base load condition on IEEE 33 Bus and IEEE 69 Bus systems.

2. A two-stage selection process is utilized for eliminating the weaker solutions and finding the optimal solution using GA. The two-stage GA ensures that the solutions achieved are better as the off-springs are produced from stronger individuals.

3. In the first method of DG installation by dividing the system into zones, better results are achieved when W_1 is considered as 0.75 for type-1 and type-3 DG installation in the IEEE 33 Bus system. This is achieved as a result of slightly higher sized DG units installed in the system. Since the DG units are not installed at the terminal nodes, the results achieved in terms of voltage stability maximization and loss minimization are better.

4. In 69 Bus system, the performance is better when W_1 is considered as 0.75 when the system is divided into 4 and 6 zones for type-1 and type-3 DG installation . When the system is divided into 5 zones better results are achieved when W_2 is considered as 0.75 for DG installation respectively. The results achieved are due to the presence of type-1 DG unit at bus number 69 when the system is divided into 4 and 6 zones. In case of type-3 DG units, the DG units are installed at bus 67 when the system is divided into 4 and 6 zones. The buses 67 and 69 are connected near the mid-point of the radial system, thereby influencing the results when the system is divided into 4 and 6 zones.

5. The creation of zones with DG in each zone, the overall penetration level of DGs in the system is variable. With DG units installed at different parts of the system, the performance is improved with lesser power from individual DG units.

6. The increase in number of zones leads to better performance of the system. However, beyond the optimal number of divisions, the performance cannot be improved. Since, DG installation increases the initial investment cost, identification of the ideal number of zones is critical.

7. The creation of number of zones is system specific. Since, the load demand and number of buses in each radial branch varies from system to system, it is crucial to identify the ideal number of buses in each zone. The increase in number of zones does not effect much on the overall reduction of losses and improvement of voltage stability margin.

8. The optimal installation of DG unit without dividing the system into zones is more effective than by dividing the system into zones as the proposed method is not dependent on specific values of the weights in the objective function.

9. In the IEEE 33 Bus system for type-1 DG installation, results are better when W_1 is considered greater than W_2 as the sizes of the DGs installed are evenly distributed throughout the system. However for type-3 DG installation, considering W_1 lesser than W_2 is better as two DGs of almost same sizes are installed in the system.

10. In the IEEE 69 Bus system for type-1 DG installation, values $W_1, W_2 \not\in \{0,1\}$, gives the same result. As only Active power is supplied by the DG units in the system the variation of weights do not affect the performance in terms of voltage stability maximization and loss reduction. For type-3 DG installation considering $W_1 > W_2$ gives better results as the supply of both active and reactive power is influenced by the location of DG units.

11. In both methods, the Type-3 DGs are effective in reducing the losses and improving the voltage stability margin as both active and reactive power is supplied at the same location.

12. As the size of the system increases, the variation in weights does not impact the performance of the system by the proposed algorithm. As the size of the system increases, the effect of DG is more evenly spread reducing the effect of variation of weights in the system.

13. The proposed methods were tested when the system operates at abnormal operating conditions (140% of base load). Even under overloaded condition, the performance of the proposed methods was better than existing methods of optimal DG installation.

From this chapter it has been observed that, installation of DG units significantly depends on the objective being considered. The ampacity of the conductors if considered does significantly impact the optimal sites and sizes of the DG units installed. However, even without considering the ampacity of the conductors for optimal installation of DG units, the current and thermal limits of the lines are not violated. The optimal solutions depend upon the objective function considered. Moreover, by incorporating more decision variables, the objective becomes more complex necessitating the usage of more sophisticated algorithms and techniques. The division of systems into zones allows the placement of smaller capacity DGs throughout the system rather than a single DG of larger capacity. But, the performance of GA improves by opening the search space for finding the optimal location and size of the DG units. The two stage GA optimization ensures that only the fittest individuals are selected for crossover and mutation process and hence the quality of solutions achieved is better. Any combination of Renewable and Alternate energy sources installed in the system makes the system controllable and the DG units dispatchable.

The next chapter discusses the issue of islanding of the distribution system in the presence of different types of DGs optimally installed by the second method discussed above.

CHAPTER 4

ISLANDING DETECTION METHODS

The faults upstream or failure of grid, leads to a complete blackout of the system. The major advantage of installation of DG units in the distribution system is the intentional islanded operation of the system. Intentional islanding can also reduce amount of load shedding needed. However, the unintentional islands may have active or reactive power imbalance leading to frequency, angle or voltage instability. These may further cause tripping of interconnected tie-lines leading to instability in the interconnected parts of the network. Hence, the unintentional islanding event has to be detected early to assist the system operator in taking appropriate control actions to avoid a blackout of the islanded region of the system. The unintentional islanding gives rise to a number of safety, commercial, power quality issues. Some issues of unintentional islanding are:

- Line worker and public safety are threatened as the utility does not have control over all the downed lines energized by the DG units.
- Protection systems on the island are likely to be uncoordinated due to change in the short circuit current availability.
- The existing utility breakers and circuit reclosers does not have the capability to re-synchronize the islanded systems.

4.1 Islanding Detection Techniques

The existing islanding detection techniques can be broadly classified as (i) Active and (ii) Passive Islanding Detection Techniques (IDT). The implementation of Active detection techniques is complex and it degrades the system by introducing perturbations in the system. The perturbations introduced at regular intervals are unnecessary during most of the operating conditions and take large time to detect the islanding than the passive methods. Most of the active IDTs are proposed for current controlled sources. Active techniques work satisfactorily for single DG unit only and their response at multiple DG units is not guaranteed. Many IDTs have been proposed in the literature [82]-[85]. With growing demand and increasing penetration level of DG units, the probability of unintentional islanding also varies.

The passive islanding detection techniques uses local measurements of voltage, frequency, current. The passive techniques have inherent disadvantage of large Non-Detection Zones (NDZ) and require precise setting of threshold values of different parameters. If threshold values are set too low, it results in unwanted tripping and higher threshold values may result in failure of detection of islanding event. Since the cost of implementation of passive IDTs is less along with early detection of islanding, these techniques are preferred. Many techniques ranging from usage of voltage variations and its derivatives, frequency variations and its derivatives, intelligent devices etc. have been proposed for islanding detection in the presence of DGs in the system in [91]-[117]. Since the DG can supply only a small amount of load, the islanding has to be detected early and accurately. If undetected, the instability in the islanded part can cascade into the stable part of the system resulting in complete failure of the system.

To overcome the disadvantages in the existing passive IDTs, the existing methods need to be re-investigated. In the presence of DG units, some more parameters need to be computed to detect the islanding early and accurately. The threshold values of the different parameters also need to be fixed appropriately to avoid unwanted triggering of the islanding event or non-detection of the islanding event. In this work, two Hybrid Methods are proposed. The proposed methods are based on three existing parameters of passive islanding detection techniques along with the additional proposed parameter. Hybrid Islanding Detection Technique (HIDT)-I is proposed for islanding detection in the presence of type-1 DG units. The proposed method method is utilizes the advantages offered by the existing passive IDTs. The proposed parameter is the calculation of change of voltage with active power variations. Hybrid Islanding Detection Technique (HIDT)-II is proposed for islanding detection in the presence of type-3 DG units in the system. The proposed parameter combines three existing passive IDTs. The additional proposed parameter is based on the variation of voltage with active power variations and change of frequency with reactive power variations in the system. The threshold values of the parameters are also identified after thorough simulations and their effectiveness is tested for various operating conditions.

4.2 Proposed Hybrid Islanding Detection Technique (HIDT)-I with type-1 DG

The proposed Hybrid Islanding Detection Technique (HIDT)-I is based on utilizing the advantages offered by various passive islanding detection techniques and including the proposed sensitive parameter during abnormal operating conditions. The additional parameter proposed is robust in identifying the islanding event early and accurately. The existing islanding detection techniques utilize local measurements like voltage, frequency, active power, rate of change of voltage, rate of change of frequency, rate of change of active power in each bus. The variation in voltage at each bus is measured for every time instant as:

$$Voltage\ Variation = dV\ (Volts) \tag{4.1}$$

The voltage parameter is computed by averaging the variation of voltage over five continuous cycles. The averaging of voltage over 5 continuous cycles is performed to avoid any errors in measurement and calculation. This parameter is measured in (V/sec).

$$Voltage\ Parameter\ (\delta V_t) = |\frac{dV}{dt}| < \sigma\ for\ 5\ cycles \tag{4.2}$$

σ is the predefined threshold value for the parameter and is taken as 160 V/sec [97]. The frequency at each bus is monitored and the variation in frequency is calculated for every time instant as:

$$Frequency\ Variation = df\ (Hz) \tag{4.3}$$

The Rate Of Change Of Frequency (ROCOF) is calculated as frequency parameter at every bus for each cycle in (Hz/sec).

$$Frequency\ Parameter\ (\delta f_t) = |\frac{df}{dt}| < \epsilon \tag{4.4}$$

The ROCOF is used for fast islanding detection. The ROCOF is calculated over a window of few cycles, usually between 2 and 50 cycles. The typical ROCOF settings installed in 60 Hz system are between 0.1 and 1.2 Hz/sec. The frequency variations are used for *ROCOF* relays for detecting the islanding event. However, the *ROCOF* relays may become ineffective if the power imbalance in the islanded system is less than 15%. The threshold value of ϵ is set as 2.18 (Hz/sec) for 60 Hz system [98].

The net active power is monitored at each bus for every cycle. Since the power available from DG units is fixed, the variation will be less in DG buses. However, the buses farther away from the DG bus will have more effect of variation of active power when the load demand changes.

$$Active\ Power\ Variation = dP\ (MW) \tag{4.5}$$

The Rate Of Change Of Active Power (ROCOP) is calculated at each bus for every time instant in (MW/sec).

$$Rate\ of\ change\ of\ Active\ Power\ (\delta P_t) = |\frac{dP}{dt}| < \Lambda \tag{4.6}$$

Λ is the pre-defined threshold limit and is fixed as 0.64 MW/sec [98].

The proposed HIDT-I is used for islanding detection in the presence of type-1 DG in the system. An additional Voltage-Active Power sensitivity parameter (ΔV_P) is proposed. The Voltage-Active Power sensitivity parameter is calculated by dividing eqn. (4.1) by eqn. (4.5). This gives the variation of voltage to real power parameter measured in

(V/MW).

$$Voltage\ Active\ Power\ Sensitivity\ Parameter\ (\Delta V_P) = |\frac{dV}{dP}| < \mu \tag{4.7}$$

The Voltage-Active Power sensitivity parameter is utilized for the effective identification of islanding event. The Voltage-Active Power sensitivity at each bus is computed for each time instant. The proposed parameter takes into account the impact of the type-1 DG units on each bus in terms of voltage and active power supplied by the DGs. The Voltage-Active Power sensitivity parameter ensures against the false triggering of islanding event by taking into account the effect of voltage variation and active power variation due to changes in operating conditions. 'μ' is the threshold value of the proposed Voltage-Active Power Sensitivity parameter and is determined as 10% after extensive testing. If the threshold is set less than 10%, it gives false triggering of the islanding event. If the threshold value is set more than 10%, some islanding events are not detected in the system, which could lead to cascaded failure in the system.

The islanding event is identified in a two-step process. In the first step, the islanding event is suspected by the local measurements of parameters at each bus. If either the voltage parameter (δV_t) or frequency parameter (δf_t) or Rate-of-change of Active Power (δP_t) violate the predefined threshold limit, the system operator is alerted for an impending islanding event and the system goes into alert state. Mathematically it can be expressed as:

$$Islanding\ Suspicion = |\frac{dV}{dt}| > \sigma\ (or)\ |\frac{df}{dt}| > \epsilon\ (or)\ |\frac{dP}{dt}| > \Lambda \tag{4.8}$$

In the second step, when the system is in alert state if the proposed Voltage-Active Power sensitivity (ΔV_P) parameter violates the threshold limit at any bus, it is classified as an islanding event and the bus at which the voltage parameter initially violates the limit is identified as the islanding bus. Mathematically it can be expressed as:

$$Islanding\ Detection = Islanding\ Suspicion\ and\ |\frac{dV}{dP}| > \mu \tag{4.9}$$

A flowchart of the proposed HIDT-I with type-1 DGs is shown in Fig. 4.1.

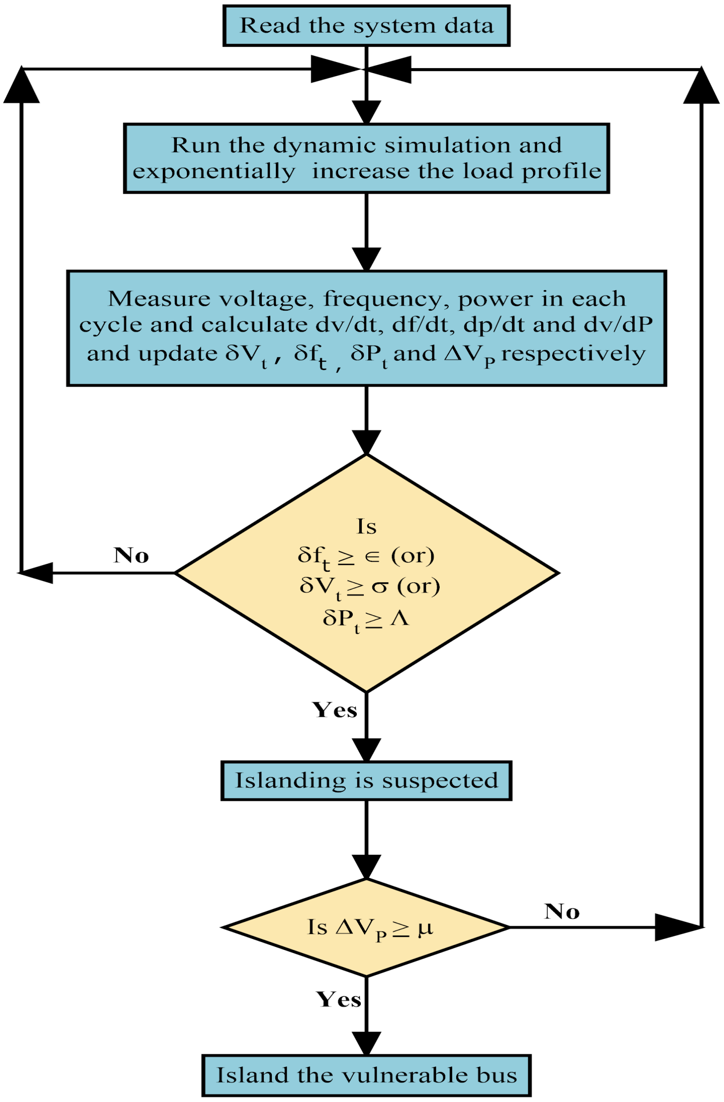

FIGURE 4.1: Proposed Hybrid Islanding Detection for type-1 DGs

Steps for implementation of proposed HIDT-I

1. Read the system data and perform load flow and Time Domain Simulation (TDS).
2. Increase the real and reactive power demands at all the buses exponentially.
3. Measure voltage, frequency and active power for each time instant and calculate $\frac{dV}{dt}$, $\frac{df}{dt}$, $\frac{dP}{dt}$ and $\frac{dV}{dP}$.
4. Update δV_t, δf_t, δP_t and ΔV_P after each cycle .
5. If either δV_t or δf_t or δP_t violate the threshold limits, alert the operator for an impending islanding and goto Step 6 else goto Step 2.

6. If ΔV_P also violate the limit during the alert state, island the vulnerable bus at that time instant else goto Step 2.

SIMULATION AND RESULTS

In the present work, Time Domain Simulation (TDS) is performed using PSAT [157] in MATLAB to simulate the load variation and islanding is detected in the presence of DG units. The different types of DG units are placed as described in the previous chapter. The proposed method is compared with three other existing passive IDTs using measurements of voltage, frequency and active power. Passive Method-I is based on the rate-of-change of frequency [98], Passive Method-II is based on the variation of voltage [97] and Passive Method-III is based on Rate-of-change of Active Power [98]. The proposed method is tested for three different loading conditions in the system: (i) At Base Load, (ii) At 120% of Base Load and (iii) At 140% of Base Load. The islanded bus and the time of detection of islanding by the proposed HIDT-I is compared with three existing passive IDTs. The unintentional islanding is simulated for proposed method of DG installation and with the existing techniques of DG installation proposed in [64] and [74].

4.2.1 Test Results of IEEE 33 Bus System

The proposed HIDT-I is tested on 33 bus system with type-1 DGs installed for multi-objective function. The DGs are optimally installed by without dividing the system into zones as described in the previous chapter.

- **CASE 1: At Base Load**

  The proposed HIDT-I is tested at base load condition. The loads are increased from base load to 160% of base load exponentially. The results obtained from proposed HIDT-I are compared with existing method of DG installations and existing passive IDTs. The comparative results are shown in Table 4.1. It can be seen from the table that, when DG units are installed by the proposed GA method, the system is islanded at bus 5 by the proposed HIDT-I, forming an island of 22 buses. When DG units are installed by existing techniques proposed in [64] and [74] the system is islanded at bus 3 creating an island of 27 buses. The detected islanded bus is nearer to the grid by the existing methods of DG placement techniques. More number of buses are connected to the DG increasing the stress on the DGs. The impact of unintentional islanding is also reduced by the proper placement of DG units in the system.

Table 4.1: Islanding Analysis in 33 Bus System with type-1 DG (Base Load)

DG Placement Technique	Islanding Detection											
	Passive Method-I			Passive Method-II			Passive Method-III			Proposed Method		
	Time of Detection	Islanded Bus No.	No. of Buses islanded	Time of Detection	Islanded Bus No.	No. of Buses islanded	Time of Detection	Islanded Bus No.	No. of Buses islanded	Time of Detection	Islanded Bus No.	No. of Buses islanded
Proposed GA Method	1.05	4	23	1.083	3	27	1.074	2	32	1.05	5	22
SA [64]	1.058	2	32	1.0833	2	32	1.074	2	32	1.058	3	27
HSA [74]	1.058	2	32	1.0833	2	32	1.074	2	32	1.058	3	27

It can also be seen from the table that, the passive method-I using frequency variation for islanding detection, the time of detection is after 3 cycles or when the imbalance is more than 15% from initial conditions. However, the bus identified by the existing passive IDTs is not the actual islanded bus. The passive method-II detects the islanding after 5 cycles. The detection is effected after one set of voltage measurements are averaged and available. The passive method-III using rate of change of active power is able to detect islanding earlier by one cycle than the passive method-II but the issue of NDZ is prominent in this method. The changes in voltage and active power may occur due to sudden load variations or capacitor switching events which may not result in islanding event. The proposed HIDT-I is able to detect the islanding event early than the existing passive IDTs and accurately. Since both voltage and active power variation at a bus are considered, the parameter identifies the islanding event accurately. The violation of the threshold value of ΔV_P occurs only when islanding event occurs. The HIDT-I is triggered by the parameter δf_t. The proposed method of DG installation ensures that, the islanded bus is away from the grid. Since, the proposed HIDT-I uses both voltage and active power variations at each bus, the probability of false triggering of islanding event is reduced.

A representation of the formation of islands in 33 bus system by the proposed HIDT-I, when a multi-objective function is considered for optimal siting and sizing of DGs by the proposed method and by existing techniques is shown in Fig. 4.2.

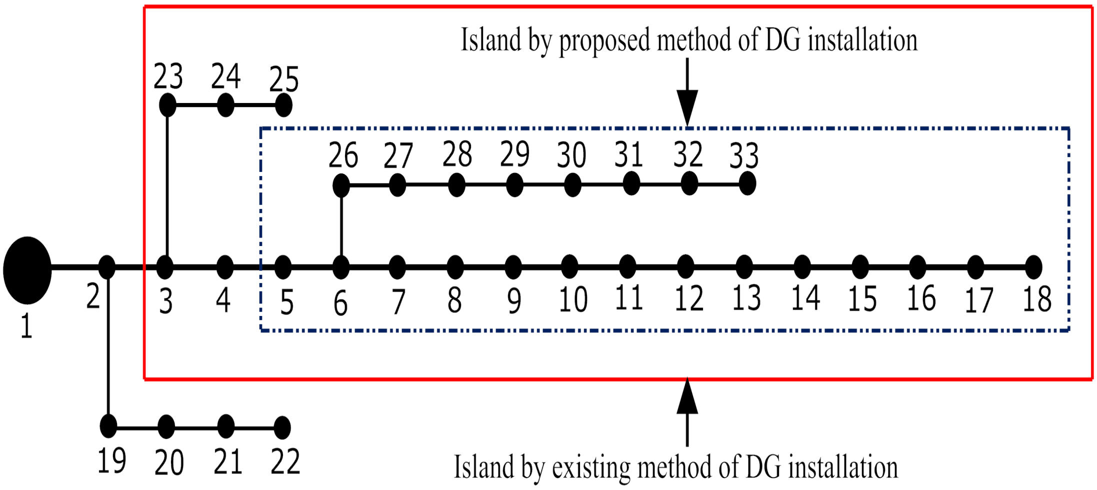

FIGURE 4.2: Formation of Island with type-1 DGs in 33 Bus System at Base Load

- **CASE 2: At 120% of Base Load**

The proposed HIDT-I is tested when the initial load demand is set to 120% of the actual base load. In this condition, loadflow and TDS is performed by increasing the load exponentially from new base load to 150% of the considered base load. The comparative results are shown in Table. 4.2.

TABLE 4.2: Islanding Analysis in 33 Bus System with type-1 DG (120% of Base Load)

DG Placement Technique	Islanding Detection											
	Passive Method-I			Passive Method-II			Passive Method-III			Proposed Method		
	Time of Detection	Islanded Bus No.	No. of Buses islanded	Time of Detection	Islanded Bus No.	No. of Buses islanded	Time of Detection	Islanded Bus No.	No. of Buses islanded	Time of Detection	Islanded Bus No.	No. of Buses islanded
Proposed GA Method	1.0495	4	23	1.083	3	27	1.075	2	32	1.0495	6	21
SA [64]	1.05	3	27	1.08457	2	32	1.075	2	32	1.05	3	27
HSA [74]	1.05	3	27	1.08457	2	32	1.075	2	32	1.05	3	27

It can be seen from the table that, when DG units are installed by the proposed GA method, the system is islanded at bus 6 with an island of 21 buses. When DG units are installed by existing techniques proposed in [64] and [74] the system is islanded at bus 3 forming an island of 27 buses. The proposed HIDT-I is activated by the δf_t. However, the time of detection is early in the proposed method of DG installation. The proposed HIDT-I ensures that the false triggering is avoided. In this case, the power mismatch is high for the trigger to be initiated by the passive method-I measuring the rate of change of frequency. However, the other passive IDTs have slow response time or increasing NDZ.

- **CASE 3: At 140% of Base Load**

The proposed HIDT-I is tested when the initial load demand is set to 140% of the actual base load. In this condition, loadflow and TDS is performed by increasing the load exponentially from new base load to 130% of the considered base load. The comparative results are shown in Table. 4.3.

TABLE 4.3: Islanding Analysis in 33 Bus System with type-1 DG (140% of Base Load)

DG Placement Technique	Islanding Detection											
	Passive Method-I			Passive Method-II			Passive Method-III			Proposed Method		
	Time of Detection	Islanded Bus No.	No. of Buses islanded	Time of Detection	Islanded Bus No.	No. of Buses islanded	Time of Detection	Islanded Bus No.	No. of Buses islanded	Time of Detection	Islanded Bus No.	No. of Buses islanded
Proposed GA Method	1.0412	4	23	1.085	3	27	1.077	2	32	1.0412	6	21
SA [64]	1.043	3	27	1.0916	2	32	1.079	2	32	1.043	3	27
HSA [74]	1.043	3	27	1.0916	2	32	1.079	2	32	1.043	3	27

It can be seen from the table that, when DG units are installed by the proposed GA method, the system is islanded at bus 6 forming an island of 21 buses. When DG units are installed by existing techniques proposed in [64] and [74] the system is islanded at bus 3 creating an island of 27 buses. The islanding event is detected early by the proposed HIDT-I than the existing passive IDTs. The proposed Voltage-Active Power sensitivity parameter does not falsely trigger the islanding event.

Fig. 4.3 shows the formation of islands in 33 bus system when a multi-objective function is considered for optimal siting and sizing of DGs by the proposed method and by existing techniques operating in overloaded condition.

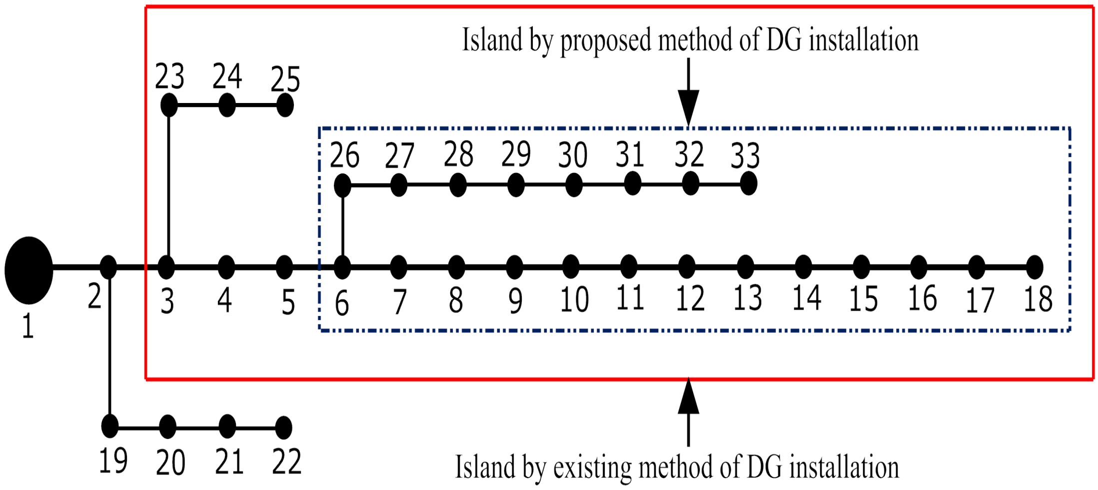

FIGURE 4.3: Formation of Island with type-1 DGs in 33 Bus System at overloaded condition

It can be observed that when the base loading is changed, to 120% or 140% the number of buses islanded in the presence of type-1 DG units installed by the proposed GA method is reduced. The vulnerable bus for islanding also moves away from the main grid and towards the DG buses. This occurs under overloaded condition as the effect of DG penetration cannot be effective on the buses away from the DG bus. The time of detection of islanding event also decreases with change in loading condition as the effect of voltage, frequency and net active power at each bus will be affected. The islanding by the proposed HIDT-I is triggered by δf_t as it is activated faster. However, the drawback of NDZ in this parameter due to insufficient power mismatch is overcome in the proposed HIDT-I by considering the change of voltage and active power at each bus.

4.2.2 Test Results of IEEE 69 Bus System

The proposed HIDT-I is tested IEEE on 69 bus system in the presence of type-1 DG units optimally installed for multiple objectives described in the previous chapter without dividing the system into zones.

- **CASE 1: At Base Load**

  The proposed HIDT-I is tested on IEEE 33 Bus system at base load condition. The loads are increased from base load to 160% of base load exponentially. The time of islanding and the vulnerable bus for islanding identified by the proposed HIDT-I are compared with existing method of DG installations and existing passive IDTs. A comparative analysis of results is shown in Table. 4.4.

Table 4.4: Islanding Analysis in 69 Bus System with type-1 DG (Base Load)

DG Placement Technique	Islanding Detection											
	Passive Method-I			Passive Method-II			Passive Method-III			Proposed Method		
	Time of Detection	Islanded Bus No.	No. of Buses islanded	Time of Detection	Islanded Bus No.	No. of Buses islanded	Time of Detection	Islanded Bus No.	No. of Buses islanded	Time of Detection	Islanded Bus No.	No. of Buses islanded
Proposed GA Method	1.05	7	40	1.083	21	7	1.07457	6	41	1.05	6	41
SA [64]	1.058	7	40	1.084	8	39	1.07457	8	39	1.058	6	41
HSA [74]	1.058	4	47	1.1162	7	40	1.07457	8	39	1.058	6	41

It can be seen that, when type-1 DG units are installed by the proposed GA method or by existing techniques, the bus 6 is identified as vulnerable bus for islanding. However, the time of islanding detection in the proposed method of DG installation is early. As in the existing methods, all the DG units are placed in the same radial branch, the islanding event is not easily distinguished from the non-islanding event. It has also seen that the proposed method of DG placement and sizing gives better voltage stability improvement and loss reduction than the existing techniques.

- **CASE 2: At 120% of Base Load**

The proposed HIDT-I is tested when the initial load demand is set to 120% of the actual base load. In this condition, loadflow and TDS is performed by increasing the load exponentially from new base load to 150% of the considered base load. The system gets islanded at bus 7 when DG units are installed by the proposed GA method of DG installation. In the existing methods of DG installation, the system gets islanded at bus 6. A comparative analysis of results is shown in Table. 4.5.

It can be seen from the table that the proposed HIDT-I detects the vulnerable bus for islanding earlier than other existing passive IDTs. The time of detection slightly increases than base loading condition. It can also be seen that the vulnerable bus for islanding also moves away from the main grid under overloaded condition by the proposed HIDT-I, when DG units are installed by the proposed GA method. Hence, the number of buses connected to the DGs must be less. The existing passive IDTs have slower response time than the proposed HIDT-I.

TABLE 4.5: Islanding Analysis in 69 Bus System with type-1 DG (120% of Base Load)

DG Placement Technique	Islanding Detection											
	Passive Method-I			Passive Method-II			Passive Method-III			Proposed Method		
	Time of Detection	Islanded Bus No.	No. of Buses islanded	Time of Detection	Islanded Bus No.	No. of Buses islanded	Time of Detection	Islanded Bus No.	No. of Buses islanded	Time of Detection	Islanded Bus No.	No. of Buses islanded
Proposed GA Method	1.045	7	40	1.083	15	13	1.078	7	40	1.045	7	40
SA [64]	1.048	7	40	1.1162	7	40	1.078	6	41	1.048	6	41
HSA [74]	1.048	7	40	1.1162	7	40	1.078	8	39	1.048	6	41

The formation of islands in 69 bus system with base load at 120% of initial base load condition, identified by the proposed HIDT-I for different methods of type-1 DG unit installation is shown in Fig. 4.4.

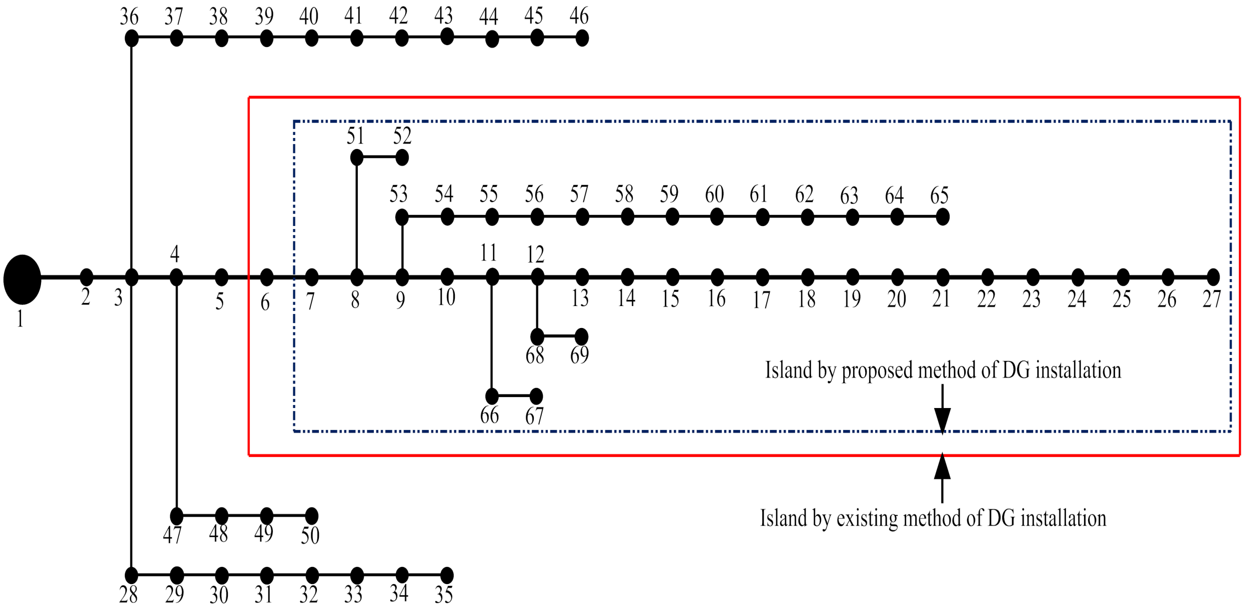

FIGURE 4.4: Formation of Island with type-1 DGs in 69 Bus System at 120% of Base Load condition

- **CASE 3: At 140% of Base Load**

The proposed HIDT-I is tested when the initial load demand is set to 140% of the actual base load. In this condition, loadflow and TDS is performed by increasing the load exponentially from new base load to 130% of the considered base load. The system gets islanded at bus 8 when DG units are installed by the proposed method of DG installation forming a 39 bus island. In the existing methods of DG installation, the system gets islanded at bus 6 forming a 41 bus island. A comparative analysis of results is shown in Table. 4.6.

TABLE 4.6: Islanding Analysis in 69 Bus System with type-1 DG (140% of Base Load)

DG Placement Technique	Islanding Detection											
	Passive Method-I			Passive Method-II			Passive Method-III			Proposed Method		
	Time of Detection	Islanded Bus No.	No. of Buses islanded	Time of Detection	Islanded Bus No.	No. of Buses islanded	Time of Detection	Islanded Bus No.	No. of Buses islanded	Time of Detection	Islanded Bus No.	No. of Buses islanded
Proposed GA Method	1.0412	7	40	1.0845	15	13	1.07457	7	40	1.0412	8	39
SA [64]	1.042	7	40	1.0857	7	40	1.07457	6	39	1.042	6	41
HSA [74]	1.042	7	40	1.1162	7	40	1.07457	8	39	1.042	6	41

A representation of the formation of islands in 69 bus system is shown in Fig. 4.5 with the DG units installed for multiobjective function and the minimum load in the system is considered to be 140% of the base load.

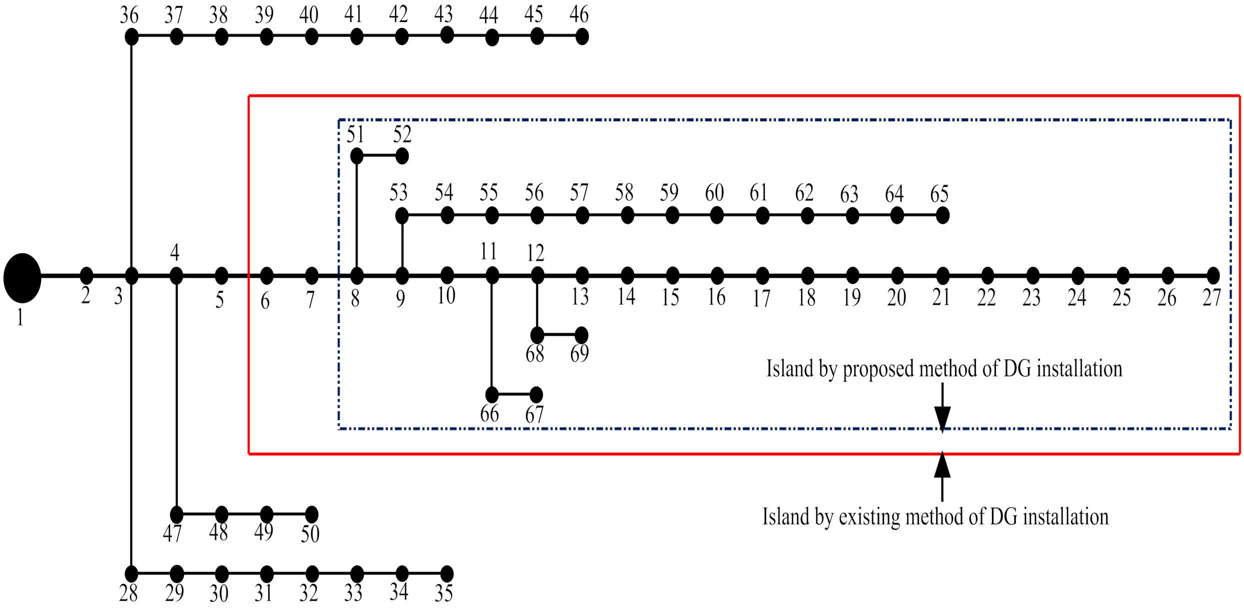

FIGURE 4.5: Formation of Island with type-1 DGs in 69 Bus System at 140% of Base Load condition

It can be seen from the table that, the proposed HIDT-I is effective in identifying the vulnerable bus for island early than any existing passive IDT. The proposed HIDT-I is triggered by the frequency based method. With increase in loading condition the frequency based method is triggered early for islanding event. However with the increase in load profile the islanded bus moves away from the main grid. This is identified by the proposed HIDT-I making it effective method for identifying the islanding event at the appropriate bus.

The following conclusions can be drawn from this section:

- The proposed HIDT-I is able to identify the islanding event earlier than existing passive IDTs based on voltage, frequency and active power measurements.
- The drawback of NDZ in passive IDT is largely overcome by the proposed HIDT-I as the variation of voltage and active power at each bus is calculated. The Voltage-Active Power sensitivity parameter calculates the effect of the DG installed in the system and hence the false triggering of the islanding event is avoided.
- The performance of the proposed HIDT-I is satisfactory in overloaded condition of the system in early identification of the vulnerable bus for islanding.
- As the base load of the system considered is increased, the vulnerable bus for islanding moves further away from the main grid.

4.3 Proposed Hybrid Islanding Detection Technique (HIDT-II) with type-3 DG

The proposed HIDT-II is utilized for detecting the vulnerable bus for islanding in the presence of type-3 DG units. The proposed method uses two additional parameters to detect the islanding event utilizing the benefits offered by the existing passive IDTs. The additional parameters used are Voltage-Active Power sensitivity parameter (ΔV_P) and Frequency-Reactive Power sensitivity parameter (Δf_Q). The Voltage-Active Power sensitivity parameter is calculated by dividing eqn. (4.1) by eqn. (4.5). In case of type-3 DG unit installation, since the DG supplies reactive power also the variation of reactive power at each bus is also monitored.

$$Reactive\ Power\ Variation = dQ\ (MVAr) \tag{4.10}$$

The Rate Of Change of Reactive Power (ROCOQ) is measured at each bus for every time instant in (MVAr/sec).

$$Rate\ of\ change\ of\ Reactive\ Power\ (\delta Q_t) = |\frac{dQ}{dt}| < \psi \tag{4.11}$$

The proposed Frequency-Reactive Power sensitivity parameter is calculated by dividing eqn. (4.3) by eqn. (4.10). The Frequency-Reactive Power sensitivity parameter is measured in (Hz/MVAr).

$$Frequency\ Reactive\ Power\ Sensitivity\ Parameter\ (\Delta f_Q) = |\frac{df}{dQ}| < \beta \tag{4.12}$$

β is the predefined threshold limit for the Frequency-Reactive Power sensitivity parameter. The threshold for β is considered as 2%. The Frequency-Reactive Power sensitivity parameter is highly sensitive. During simulations it was observed that if β is considered less than 2% it gives false tripping of islanding event and for β greater than 2%, some islanding events are not detected. 'μ' is the threshold value of the proposed Voltage-Active Power Sensitivity parameter and is determined as 10% after extensive testing. If the threshold is set less than 10%, it gives false triggering of the islanding event. If the threshold value is set more than 10%, some islanding events are not detected in the system, which could lead to cascaded failure in the system.

The islanding event is identified in a two-stage process. In the first step, the islanding event is suspected by the local measurements of parameters at each bus. If either the voltage parameter (δV_t) or frequency parameter (δf_t) or Rate-of-change of Active Power (δP_t) violate the predefined threshold limit, the system operator is alerted for a suspected islanding event and the system goes into alert state. Mathematically it can be expressed as:

$$Islanding\ Suspicion = |\frac{dV}{dt}| > \sigma\ (or)\ |\frac{df}{dt}| > \epsilon\ (or)\ |\frac{dP}{dt}| > \Lambda \tag{4.13}$$

In the second stage, when the system is in alert state if the Voltage-Active Power sensitivity (ΔV_P) parameter and the Frequency-Reactive Power sensitivity (Δf_Q) also violate the threshold limit at any bus, it is classified as an islanding event and the bus at which these proposed parameters initially violate the limit is identified for islanding. Mathematically it can be expressed as:

$$Islanding\ Detection = Islanding\ Suspicion\ and\ |\frac{dV}{dP}| > \mu\ and\ |\frac{df}{dQ}| > \beta \tag{4.14}$$

The Frequency-Reactive Power sensitivity parameter is used in the presence of type-3 DG as reactive power is also supplied by the DG units. The variation of frequency and the reactive power supplied by the DG units in the island is very sensitive to any changes in the operating conditions. Hence the false triggering of the islanding event is avoided. The variation of frequency is high in islanded systems and it helps in early detection of the islanding event.

Steps for implementation of the proposed HIDT-II

1. Read the system data and perform TDS.
2. Increase the load profile exponentially.
3. Measure voltage, frequency and active power for each cycle and calculate $\frac{dV}{dt}$, $\frac{df}{dt}$, $\frac{dP}{dt}$, $\frac{dV}{dP}$ and $\frac{df}{dQ}$ for each cycle at every bus.
4. Update δV_t, δf_t, δP_t, ΔV_P and Δf_Q after each cycle .
5. If either δV_t or δf_t or δP_t violate the threshold limits, the operator is alerted for a suspected islanding and goto Step 6 else goto Step 2.
6. If either ΔV_P and Δf_Q violate the threshold limit in the alert state, island the vulnerable bus else goto Step 2.

A flowchart of the proposed HIDT-II with type-3 DGs is shown in Fig. 4.6.

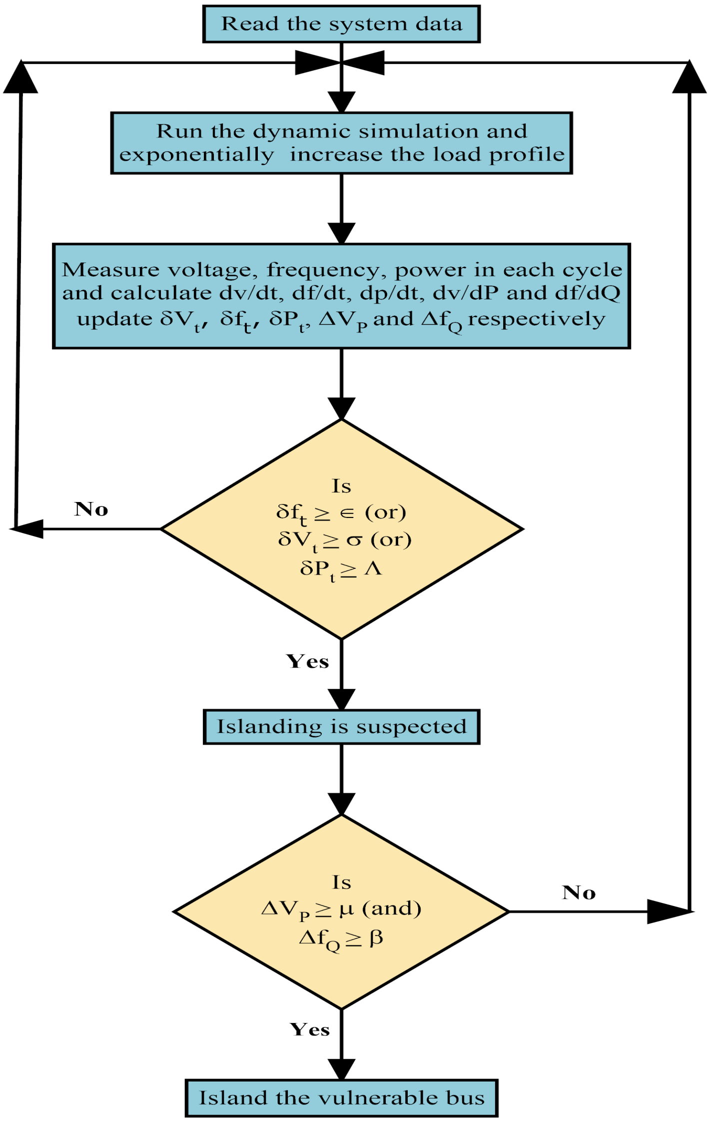

FIGURE 4.6: Proposed Hybrid Islanding Detection for type-3 DGs

4.3.1 Test Results of IEEE 33 Bus System

The proposed HIDT-II is tested on IEEE 33 bus system with type-3 DGs installed optimally by without dividing the system into zones as described in the previous chapter. The results obtained for islanding detection by the proposed method of DG installation are compared with the existing techniques of DG installation proposed in [78] at three different loading levels namely at (i) Base Load, (ii) 120% of Base Load and (iii) 140% of Base Load.

- **CASE 1: At Base Load**

The proposed HIDT-II is tested on IEEE 33 Bus system at base load condition and compared with existing method of DG installations and existing passive IDTs. The comparative results are shown in Table. 4.7.

TABLE 4.7: Islanding Analysis in 33 Bus System with type-3 DG (Base Load)

DG Placement Technique	Islanding Detection											
	Passive Method-I			Passive Method-II			Passive Method-III			Proposed Method		
	Time of Detection	Islanded Bus No.	No. of Buses islanded	Time of Detection	Islanded Bus No.	No. of Buses islanded	Time of Detection	Islanded Bus No.	No. of Buses islanded	Time of Detection	Islanded Bus No.	No. of Buses islanded
Proposed GA Method	1.05	4	23	1.083	3	27	1.07457	2	32	1.05	4	23
PSO [78]	1.058	4	23	1.084	13	6	1.07457	2	32	1.058	3	27

A formation of islands identified by the proposed HIDT-II, by both methods of DG installation is shown in Fig. 4.7.

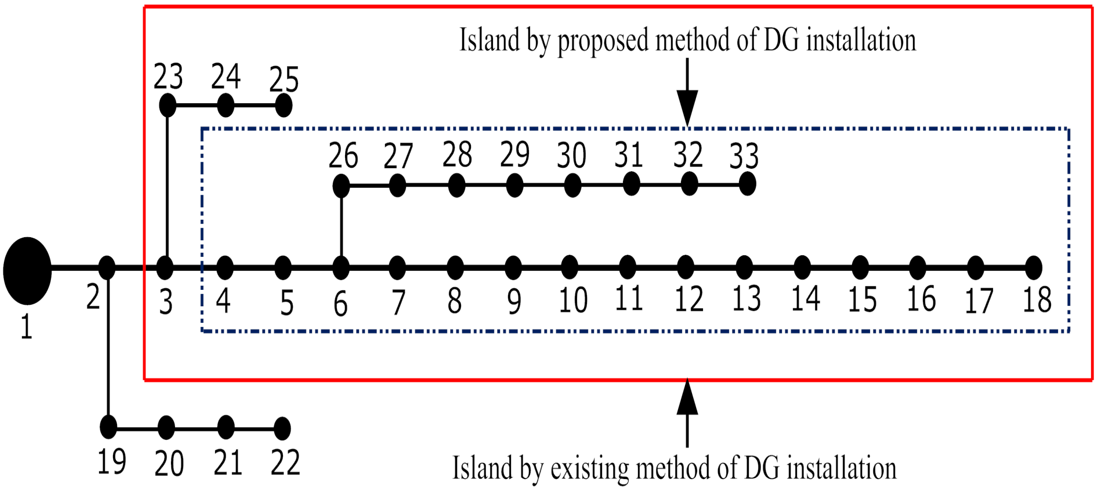

FIGURE 4.7: Formation of Island with type-3 DGs in 33 Bus System at Base Load

It can be seen from the table that, when DG units are installed by the proposed GA method, the system is islanded at bus 4 forming an island of 23 buses. When DG units are installed by existing technique proposed in [78] the system is islanded at bus 3 creating an island of 27 buses. The HIDT-II is triggered by the parameter δf_t in both the cases. The islanding event is identified slightly early by the proposed method of DG installation than the existing technique presented in [78]. The stress on the DG units are increased as more number of buses are connected to the DG buses. The detected islanded bus is nearer to the grid by the existing method of DG placement techniques. The impact of unintentional islanding is also reduced by the proper placement of DG units in the system.

- **CASE 2: At 120% of Base Load**

The proposed HIDT-II is tested with the base load set at 120% of the base load. The TDS is performed by increasing the load from the new base load to 150% of base load considered. The comparative results are shown in Table 4.8.

TABLE 4.8: Islanding Analysis in 33 Bus System with type-3 DG (120% of Base Load)

DG Placement Technique	Islanding Detection											
	Passive Method-I			Passive Method-II			Passive Method-III			Proposed Method		
	Time of Detection	Islanded Bus No.	No. of Buses islanded	Time of Detection	Islanded Bus No.	No. of Buses islanded	Time of Detection	Islanded Bus No.	No. of Buses islanded	Time of Detection	Islanded Bus No.	No. of Buses islanded
Proposed GA Method	1.0495	4	23	1.083	3	27	1.078	2	32	1.0495	5	22
PSO [78]	1.05	4	23	1.084	2	32	1.0791	2	32	1.05	3	27

A representation of the formation of islands identified by the proposed HIDT-II, in 33 bus system with type-3 DGs at 120% of base load by different techniques is shown in Fig. 4.8.

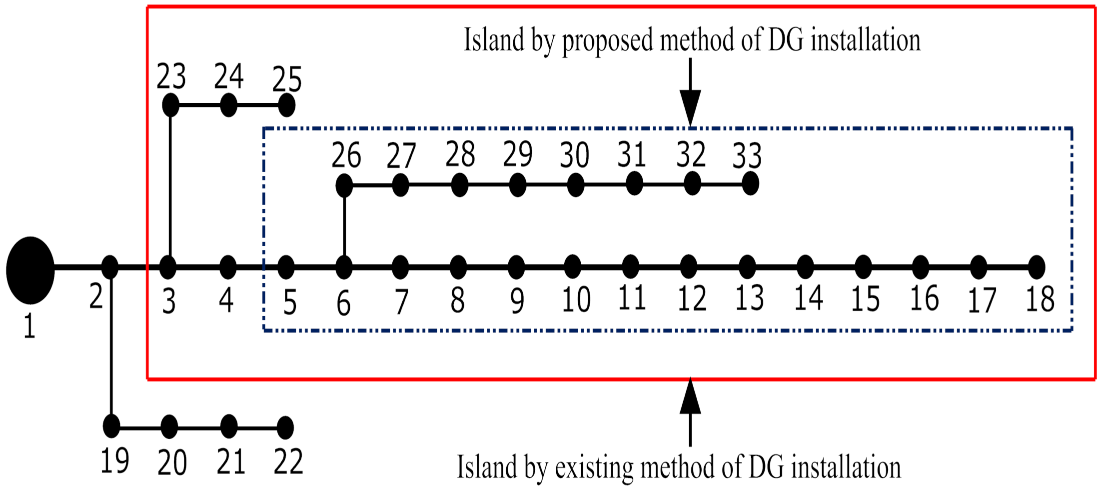

FIGURE 4.8: Formation of Island with type-3 DGs in 33 Bus System at 120% of Base Load

It can be seen from the table that, when DG units are installed by the proposed GA method, the system is islanded at bus 5 forming an island of 22 buses. When DG units are installed by existing technique proposed in [78] the system is islanded at bus 3 creating an island of 27 buses. The passive method-II utilizing the change in voltage, has high time of detection. The islanding is identified after 5 cycles are measured and averaged. The passive method-III utilizing the rate of change of active power, the NDZ is more and identifies the incorrect bus for islanding.

- **CASE 3: At 140% of Base Load**

The proposed HIDT-II is tested when the load demand is 140% of the base load. The TDS is performed by increasing the load from new base load to 130% of the new base load. The comparative results are shown in Table. 4.9.

Table 4.9: Islanding Analysis in 33 Bus System with type-3 DG (140% of Base Load)

DG Placement Technique	Islanding Detection											
	Passive Method-I			Passive Method-II			Passive Method-III			Proposed Method		
	Time of Detection	Islanded Bus No.	No. of Buses islanded	Time of Detection	Islanded Bus No.	No. of Buses islanded	Time of Detection	Islanded Bus No.	No. of Buses islanded	Time of Detection	Islanded Bus No.	No. of Buses islanded
Proposed GA Method	1.0412	3	27	1.083	3	27	1.083	2	32	1.0412	6	21
PSO [78]	1.042	4	23	1.0833	2	32	1.0833	2	32	1.042	3	27

It can be seen from the table that, when DG units are installed by the proposed GA method, the system is islanded at bus 6 forming an island of 21 buses. When DG units are installed by PSO method proposed in [78] the system is islanded at bus 3 creating an island of 27 buses. From the table it can be seen that with the increase in load, the passive method-I using ROCOF, is fast in identifying the islanding event. The δf_t triggers the HIDT-II for islanding event. However, the other passive IDTs have large time of detection of the islanding event or large NDZ. Since the Frequency-Reactive Power sensitivity is highly sensitive in the presence of type-3 DG unit, the false triggering of the islanding event is avoided. This also helps in early detection of the islanding event as the variation of frequency with increased loading condition becomes more sensitive.

A representation of the formation of islands in 33 bus system when a multi-objective function is considered for optimal siting and sizing of DGs by the proposed method and by existing techniques at 140% of base load is shown in Fig. 4.9.

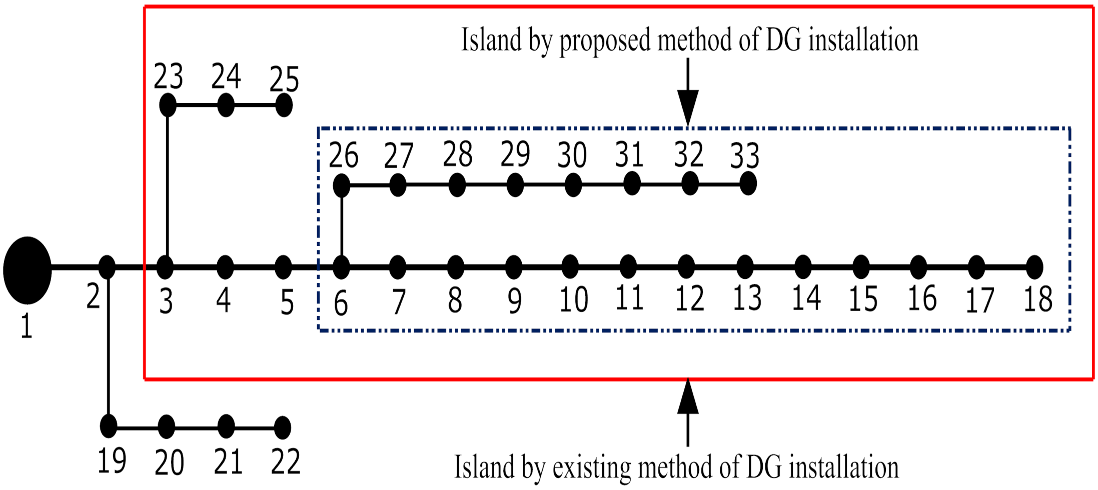

FIGURE 4.9: Formation of Island with type-3 DGs in 33 Bus System at 140% of Base Load

4.3.2 Test Results of IEEE 69 Bus System

The proposed HIDT-II is tested on IEEE 69 bus system in the presence of type-3 DG units and the results are compared with the existing passive IDTs. The results obtained for islanding by the proposed method of DG installation is compared with the existing technique of DG installation proposed in [78].

- **CASE 1: At Base Load**

  The proposed HIDT-II is tested on IEEE 69 Bus system at base load. The loads are increased from base load to 160% of base load. The time of islanding and the vulnerable bus for islanding is identified and compared with existing passive IDTs. A comparative analysis of results is shown in Table.4.10. When type-3 DG units are installed by the proposed GA method, the HIDT-II identifies bus 7 as the vulnerable bus for islanding. When DG units are placed by existing technique, the bus 6 is identified as islanded bus.

  It can be seen from the table that, the proposed HIDT-II is faster in identifying the vulnerable bus for islanding earlier than any other existing passive IDTs. The existing passive IDTs have either slow response in detecting the islanding event or high NDZ. The passive method-II identifies the wrong bus for islanding in the existing method of DG installation. The bus 10 is identified for islanding event. However, there is no DG available downstream from bus 10 to 27. It creates a blackout situation downstream in the buses from 10 to 27. The proposed method of DG installation also gives better voltage stability margin and loss reduction than the existing PSO method proposed in [78].

TABLE 4.10: Islanding Analysis in 69 Bus System with type-3 DG (Base Load)

DG Placement Technique	Islanding Detection											
	Passive Method-I			Passive Method-II			Passive Method-III			Proposed Method		
	Time of Detection	Islanded Bus No.	No. of Buses islanded	Time of Detection	Islanded Bus No.	No. of Buses islanded	Time of Detection	Islanded Bus No.	No. of Buses islanded	Time of Detection	Islanded Bus No.	No. of Buses islanded
Proposed GA Method	1.05	7	40	1.085	6	41	1.07457	6	41	1.05	7	40
PSO [78]	1.058	7	40	1.085	10	18	1.075	7	40	1.058	6	41

A representation of the islands formed in 69 bus system by the proposed method of DG installation and by existing technique of DG installation identified by the proposed HIDT-II is shown in Fig. 4.10.

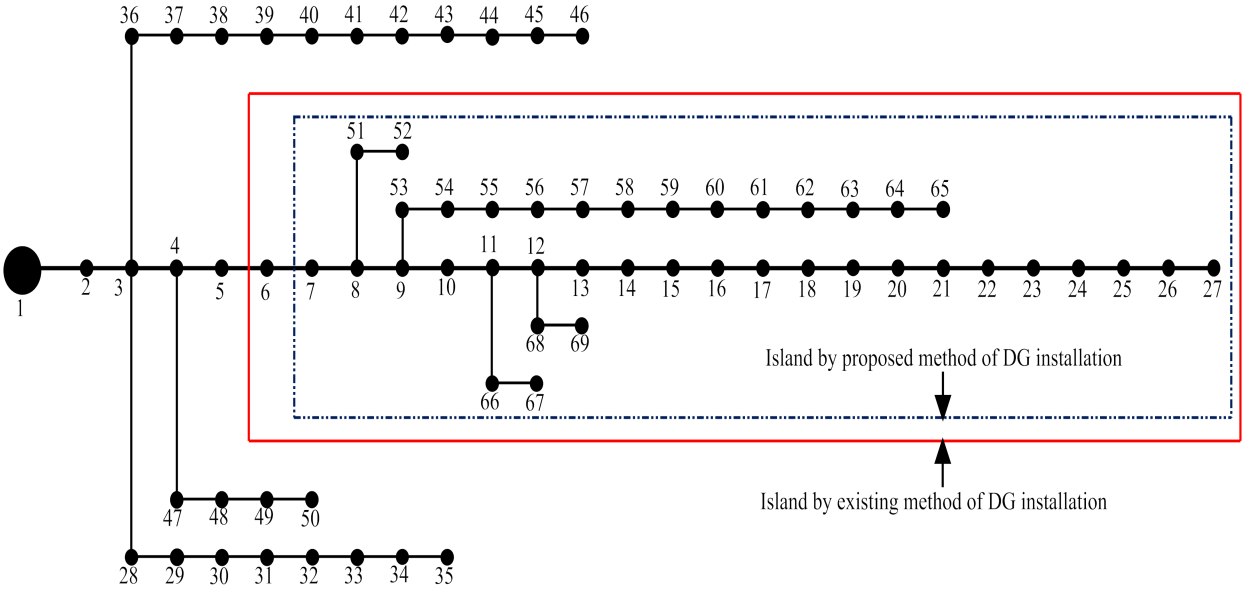

FIGURE 4.10: Formation of Island with type-3 DGs in 69 Bus System at Base Load

- **CASE 2: At 120% of Base Load**

The proposed HIDT-II is tested on the IEEE 69 Bus system with the minimum system load increased to 120% of base load. The loads are increased from the new base load to 150% of base load in TDS. The system gets islanded at bus 8 when DG units are installed by the proposed method of DG installation forming an island of

39 buses. In the existing methods of DG installation, the system gets islanded at bus 6 forming an island of 41 buses. A comparative analysis of results is shown in Table. 4.11.

Table 4.11: Islanding Analysis in 69 Bus System with type-3 DG (120% of Base Load)

DG Placement Technique	Islanding Detection											
	Passive Method-I			Passive Method-II			Passive Method-III			Proposed Method		
	Time of Detection	Islanded Bus No.	No. of Buses islanded	Time of Detection	Islanded Bus No.	No. of Buses islanded	Time of Detection	Islanded Bus No.	No. of Buses islanded	Time of Detection	Islanded Bus No.	No. of Buses islanded
Proposed GA Method	1.044	7	40	1.085	14	14	1.0791	7	40	1.044	8	39
PSO [78]	1.046	8	39	1.085	13	15	1.08	7	40	1.046	6	41

- **CASE 3: At 140% of Base Load**

The proposed HIDT-II is tested when the load demand is 140% of the base load. The TDS is performed by increasing the load from new base load to 130% of the new base load. A comparative analysis of results obtained at this loading level is shown in Table. 4.12. It can be observed from the table that the system gets islanded at bus 7 when DG units are installed by the proposed method of DG installation. It can be seen from the table that as the minimum load in the system is increased from base load, the time of detection of islanding is reduced. In the existing methods of DG installation, the system gets islanded at bus 6. The proposed HIDT-II is triggered by passive method-I using ROCOF. The passive method-II has low response time. The islanding is detected after 5 cycles of voltage measurement are averaged.

Table 4.12: Islanding Analysis in 69 Bus System with type-3 DG (140% of Base Load)

DG Placement Technique	Islanding Detection											
	Passive Method-I			Passive Method-II			Passive Method-III			Proposed Method		
	Time of Detection	Islanded Bus No.	No. of Buses islanded	Time of Detection	Islanded Bus No.	No. of Buses islanded	Time of Detection	Islanded Bus No.	No. of Buses islanded	Time of Detection	Islanded Bus No.	No. of Buses islanded
Proposed GA Method	1.0412	7	40	1.083	14	14	1.08	15	12	1.0412	8	39
PSO [78]	1.042	8	39	1.1162	12	16	1.1162	13	15	1.042	6	41

A representation of the formation of islands in 69 bus system with type-3 DGs by the proposed method and by existing technique at 120% of base load and 140% of base load is shown in Fig. 4.11.

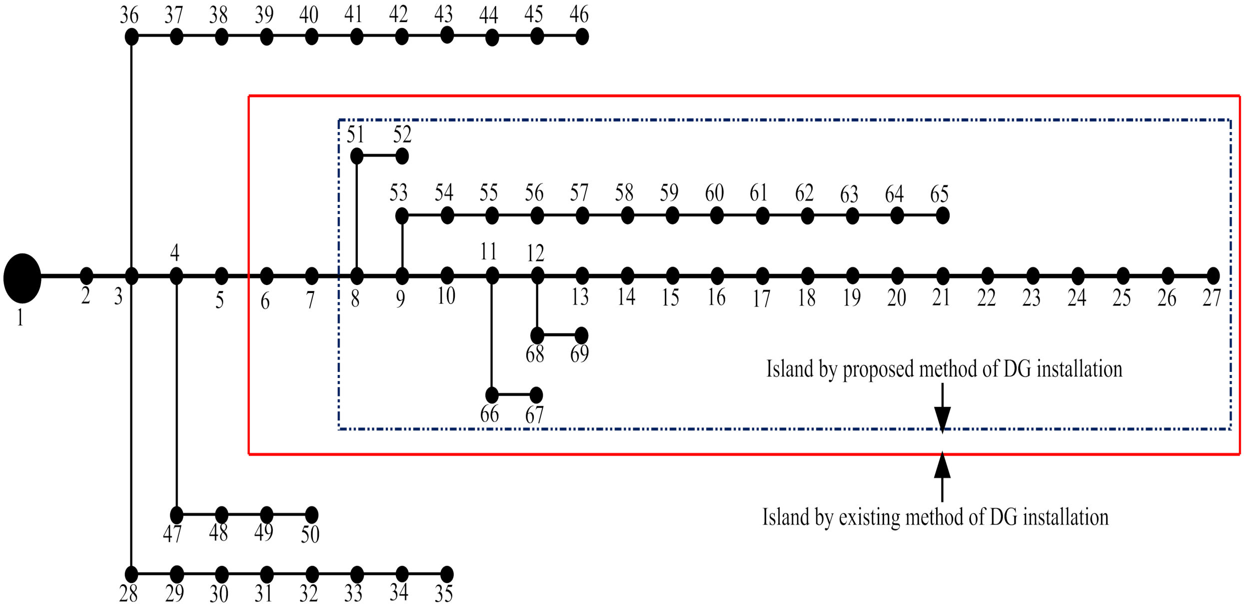

Figure 4.11: Formation of Island with type-3 DGs in 69 Bus System at overloaded condition

It can be seen that the proposed HIDT-II is capable of identifying the event early than existing passive IDTs. The Voltage-Active Power sensitivity and Frequency-Reactive Power sensitivity parameters are made robust by considering the variation of voltage with active power and frequency with reactive power to avoid false triggering of the islanding event. Moreover in the IEEE 69 Bus system, the system topology play a major role in the formation of islands along with location and size of DG units. The effect of the active and reactive power supplied by the installed type-3 DG units cannot be detected far away from the DG buses, the islanding has to be away from the main grid.

The following conclusions can be drawn from this section:

- The proposed HIDT-II is able to identify the islanding event earlier than existing passive IDTs based on voltage, frequency and active power deviation in the presence of type-3 DG units for various load conditions in the system.
- The NDZ is also reduced in the proposed HIDT-II as the variation of voltage with active power and variation of frequency with reactive power at each bus is calculated.
- The performance of the proposed HIDT-II is more satisfactory for any loading level of the system than the existing passive IDTs in identifying the vulnerable bus for

islanding early. The proposed HIDT-II takes the net effect of active and reactive power variations in each bus.

- As the loading is increased, the effect of installed DG units cannot be observed away from the DG buses. The islanded bus will be near DG units reducing the stress on the DG units in the system.

4.4 Summary

In this chapter, after the optimal placement of different DG units in IEEE 33 Bus and IEEE 69 Bus systems, TDS is performed for islanding detection. The results from this chapter can be summarized as follows:

1. In the presence of type-1 DGs in the distribution system, HIDT-I is proposed for islanding detection. An additional Voltage-Active Power sensitivity parameter is proposed along with voltage, frequency and Active Power measurements for early islanding detection effectively.
2. When the Voltage-Active Power sensitivity parameter violates the threshold limit along with either voltage, frequency and Rate-of-change of Active Power parameters, then it is classified as islanding event. The Voltage-Active Power sensitivity parameter which is variation of voltage with active power, takes into account the effect of voltage and active power at bus by the type-1 DG unit. This parameter ensures against false triggering of the islanding event.
3. HIDT-II is proposed for islanding detection in the presence of type-3 DGs in the distribution system. Two additional parameters, namely Voltage-Active Power sensitivity and Frequency-Reactive Power sensitivity parameters are utilized along with voltage, frequency, Active Power and Reactive Power measurements.
4. The Frequency-Reactive Power sensitivity parameter is variation of frequency with reactive power at each bus. The Frequency-Reactive Power sensitivity parameter is more sensitive than Voltage-Active Power sensitivity parameter as frequency deviations with variation in load is faster.

5. The introduction of additional parameters ensures the system against false triggering of islanding event and the threshold values set for each parameter is judiciously chosen after thorough simulations and are set to optimal values. The threshold values of HIDT-I is set at 10% and HIDT-II is set at 2% after thorough investigations at varying operating conditions. For values set lower than the proposed values, the islanding is falsely triggered and for higher values, some islanding conditions are not detected.

6. The performance of the proposed HIDT-I and HIDT-II with different loading conditions are better than existing passive IDTs as the time of detection of islanding is early in each case than any other existing passive IDTs.

7. The active power influences the frequency and reactive power influences the voltage. However, in the proposed parameters the measurements are sensitive since these parameters are cross-coupled. Hence the islanding event is not triggered due to sudden switching of loads or capacitor switching events.

8. As the loading level increases, the vulnerable bus for islanding moves away from the main grid as the effect of DG units cannot be effective in many buses. The size and topology of the system is also crucial for the detection of the vulnerable bus as the effect of variation of voltage, frequency, active power and reactive power (for type-3 DG units) are not significant near the grid. This is more prevalent in IEEE 69 Bus system than the IEEE 33 Bus system as the variation of frequency is spread more evenly throughout the system.

From this chapter it has been seen that, the existing islanding detection techniques tend to fail due to Non-Detection Zones or slow identification of islanding event in the presence of DG units in the system. The Active Power-frequency parameter and Reactive Power-Voltage parameter get triggered for non-islanding events as a result of direct coupling. The proposed HIDTs due to cross-coupling of the decision variables namely Voltage-Active Power and Frequency-Reactive Power significantly overcomes this disadvantage. The proposed parameters are utilized along with the existing parameters of passive IDTs. Since the parameters are cross-coupled these Voltage-Active Power sensitivity and Frequency-Reactive Power sensitivity parameters do not vary much during non-islanding events. However, only under actual islanding conditions, these parameters exhibit large variations and help in identifying the islanding event effectively. The inherent disadvantages of the existing methods like slow detection, large Non-Detection zones and false triggering of islanding event have been reduced considerably in the proposed schemes.

The next chapter discusses the operation of system in islanded mode. Emergency load shedding scheme for stable operation of islanded system and the reliability of the islanded system is evaluated before and after the proposed load shedding scheme.

CHAPTER 5

LOAD SHEDDING BASED EMERGENCY CONTROL OF ISLANDS

The operation of islands is a challenging task due to the power mismatch in the island. This arises due to limited power output from the DGs in the island. Most of the existing emergency control schemes utilize load shedding as a corrective measure for stable operation of the island. In the literature it was found that the majority of the schemes proposed in the literature for load shedding is based on frequency decline [125]-[131]. However, few voltage based schemes have also been proposed for load shedding in the literature. With emphasis on continuity of power supply and cost of investment on DG unit installation, reliability has become an important criteria for load shedding.

Quantitative reliability analysis is based on the failure statistics of the components in the system. The reliability analysis gives a comprehensive idea to the system planner to quantitatively evaluate the merits of investing in various reinforcements. Since the quantitative reliability analysis is based on the number of customers being affected, the effect of the load shedding can be measured through standard reliability indices. The reliability indices can also indicate the number of customers affected by the load shedding scheme.

5.1 Proposed Priority Based Load Shedding

In the priority based load shedding scheme if the power demand exceeds the power output of the DG sources in the island, load shedding process is initiated. The loads are ranked on the basis of rate of change of frequency and rate of change of voltage. The bus with largest variation of frequency is the most overloaded bus in the system hence more vulnerable for tripping. In this way, the buses with DG will not participate in load shedding. All the other buses are ranked and the loads are shed until the system frequency and voltage of the buses are brought back within threshold limits. The total amount of load shed in the system is calculated on the basis of the rank and the loads in the individual buses and can be expressed as:

$$Load\ shed = DPC_i * P_{Load,i} \tag{5.1}$$

where $P_{Load,i}$ is the load at bus 'i', DPC is the Decisive Participation Coefficient for a particular bus and is calculated as:

$$DPC = C_i * \zeta_f * \zeta_V \tag{5.2}$$

where ζ_f and ζ_V are the coefficient of frequency and voltage components respectively of the buses and are calculated as follows:

$$\zeta_f = \frac{f_{i,t}}{f_{init,0}} \tag{5.3}$$

$$\zeta_V = \frac{V_{i,t}}{V_{init,0}} \tag{5.4}$$

where $f_{i,t}$ is the frequency at bus 'i' when load shedding is initiated, $f_{init,0}$ is the frequency of the islanding bus when the islanding is detected. $V_{i,t}$ is the voltage at bus 'i' when load shedding is initiated, $V_{init,0}$ is the voltage of the islanding bus when the islanding is detected, C_i is the rank of each bus calculated as:

$$C_i = \begin{cases} 0, & if\ DG\ is\ present, \\ 1, & if\ DG\ is\ absent. \end{cases} \tag{5.5}$$

In the proposed load shedding since loads of the most vulnerable buses are shed, the amount of load being shed will be less than the total power demand in the island.

$$\sum_{i=1}^{z} P_{Load,i} < P_{L,island} \tag{5.6}$$

where 'z' is the total number of buses in the island, P_{island} is the total demand in the island. Since in distribution system the load shedding is discrete in each bus, the value of C_i is taken as either 0 or 1. The frequency, voltage and power flow limits also need to be within limits in the island.

$$f_{min} \leq f \leq f_{max} \tag{5.7}$$

$$V_{min} \leq V_i \leq V_{max} \tag{5.8}$$

$$P_{min} \leq P_i \leq P_{max} \tag{5.9}$$

A flowchart of the proposed scheme is shown in Fig.5.1.

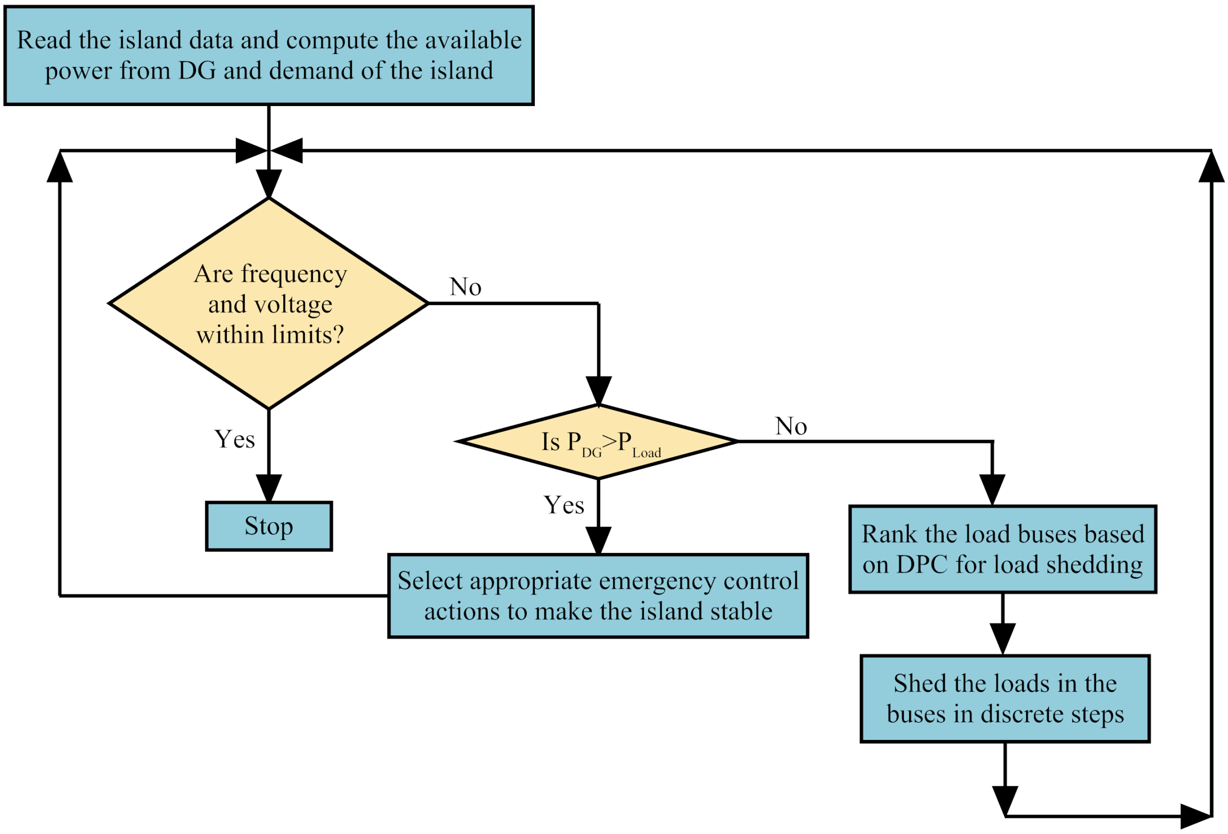

FIGURE 5.1: Flowchart of proposed priority based load shedding

Steps for implementation of Priority Based Load Shedding

1. Compute the DG power and load demand in the island.
2. Check whether the frequency variation and voltage variation are within tolerance limits and goto step 3.
3. If it is not within tolerance limit, check the power mismatch. If it is positive (i.e $P_{DG} > P_{load}$) regulate the DG output power to make frequency variation within limits, else goto step 4.
4. Rank the buses according to frequency deviation.
5. Shed the load in the higher ranked bus and goto step 2.

5.2 Reliability Analysis

The reliability of the islanded system is computed before and after load shedding to measure the effectiveness of the proposed load shedding scheme. The quantitative reliability analysis of the system gives a measure of the effect of the proposed load shedding scheme in the system. The reliability analysis is performed through standard reliability indices and from the failure rate and repair time of the lines in the system. The most commonly used reliability indices used are SAIDI, SAIFI, CAIDI, ENS and AENS. These indices are commonly obtained from the customer failure statistics [1] .

SAIDI is System Average Interruption Duration Index and expressed in terms of hours per customer.

$$SAIDI = \frac{Sum\ of\ customer\ interruption\ durations}{Total\ Number\ of\ customers} = \frac{\sum U_i N_i}{\sum N_i} \tag{5.10}$$

where U_i is the annual outage time and N_i is the number of customers of load point i.

SAIFI is System Average Interruption Frequency Index and expressed as interruptions per customer.

$$SAIFI = \frac{Total\ number\ of\ customer\ interruptions}{Total\ Number\ of\ customers\ served} = \frac{\sum \lambda_i N_i}{\sum N_i} \tag{5.11}$$

where λ_i is the failure rate and N_i is the number of customers of load point i.

CAIDI is Customer Average Interruption Duration Index and expressed as hours per customer interruption.

$$CAIDI = \frac{Sum\ of\ customer\ interruption\ durations}{Total\ Number\ of\ customer\ interruptions} = \frac{\sum U_i N_i}{\sum \lambda_i N_i} \tag{5.12}$$

ENS is Energy Not Supplied index and is measured as kWh.

$$ENS = Total\ Energy\ not\ supplied\ by\ the\ system = \sum L_{a(i)} U_i \tag{5.13}$$

where $L_{a(i)}$ is the average load connected to load point 'i'.

AENS is Average Energy Not Supplied index and is expressed in terms of kWh per customer.

$$AENS = \frac{Total\ Energy\ not\ supplied}{Total\ Number\ of\ customers\ served} = \frac{L_{a(i)} U_i}{N_i} \tag{5.14}$$

SIMULATION AND RESULTS

The proposed load shedding scheme is tested on IEEE 33 Bus System and IEEE 69 Bus System. The DGs are installed without dividing the system into zones as described in Chapter 3 and the islanding event is detected by the proposed HIDT-I for type-1 DG and by proposed HIDT-II for type-3 DG described in Chapter 4. The loads are assumed to be frequency and voltage sensitive. The proposed load shedding scheme is tested when the system is islanded. The reliability analysis is performed based on the failure indices and the failure data of the lines in the system. The reliability of the island is computed before and after the proposed priority based load is performed. The reliability is also checked without the effect of the proposed DPC.

5.3 Test Results of IEEE 33 Bus System

The proposed priority based load shedding is performed in the 33 Bus system in the presence of type-1 and type-3 DG units. The load shedding in the island is also performed without considering the proposed DPC parameter and the frequency and voltage of the island are measured. The reliability analysis is performed before and after the load shedding for each case.

5.3.1 With type-1 DG units

The type-1 DG units are installed in the system without dividing the system into zones and the islanding is identified by the proposed HIDT-I. The loads in the island are supplied by the type-1 DG units available in the island. The load shedding is performed without considering the proposed DPC. In this case, the loads are shed from the buses farther away from the DG units. The available power in the island from the DG units and the load demand for each case is shown in Table. 5.1.

TABLE 5.1: Load Shedding in 33 Bus System with type-1 DG

Load Shedding Technique	**Islanded Bus**	**Number of Buses in Island**	**Power Available (MW)**	**Load (MW)**	**Actual Load Shed (MW)**	**Amount of Load Shed (%)**
With DPC	5	22	1.531	2.535	0.45	17.75
Without DPC	5	22	1.531	2.535	0.81	31.95

It can be seen from the table that the amount of loads shed is more when the proposed DPC is not considered for the load shedding. The amount of loads being shed to regain the frequency and voltage stability is more without considering the DPC. The frequency and voltage variations of the islanded bus before and after load shedding with type-1 DG for different methods of DG installation is shown in Figs. 5.2 and 5.3 respectively.

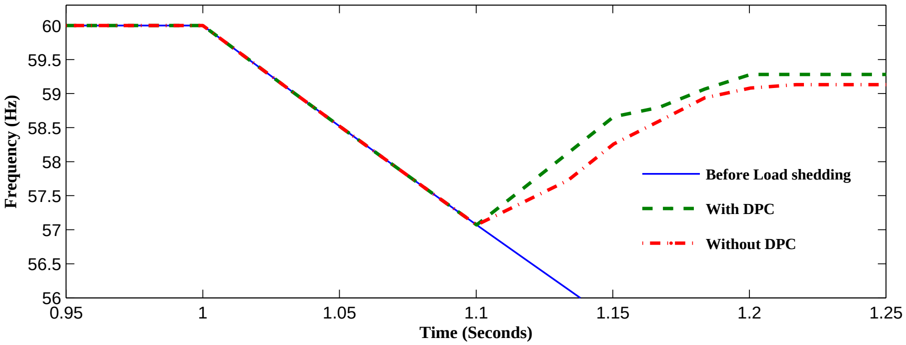

FIGURE 5.2: Comparison of Frequency at islanded bus in 33 Bus System with type-1 DGs before and after load shedding

From the figs. 5.2 and 5.3, it can be observed that the proposed load shedding scheme is effective in regaining the frequency and voltage within tolerance limits. Since the loads being shed are ranked at the first step, only vulnerable loads are shed. The buses with DG units do not participate in the load shedding when the proposed DPC is considered for load shedding.

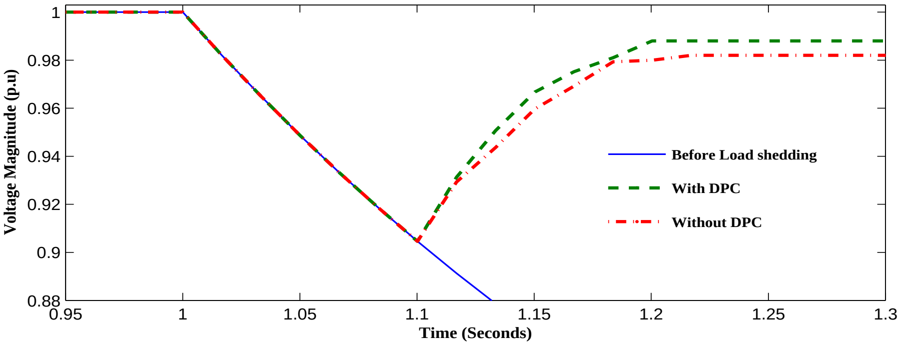

FIGURE 5.3: Comparison of Voltage at islanded bus in 33 Bus System with type-1 DGs before and after load shedding

The reliability of the islanded system is calculated before and after the proposed load shedding. The reliability of the system is calculated for load shedding without considering the proposed DPC and the results are shown in Table. 5.2.

TABLE 5.2: Reliability Analysis of 33 Bus System with type-1 DGs

Cases	**Before Load Shedding**					**After Load Shedding**				
	SAIDI	SAIFI	CAIDI	ENS	AENS	SAIDI	SAIFI	CAIDI	ENS	AENS
With DPC	0.3463	0.4090	0.8466	1.004	0.04563	0.3207	0.4	0.8017	0.45	0.02812
Without DPC	0.3463	0.4090	0.8466	1.004	0.04563	0.3403	0.3993	0.8522	0.81	0.05785

From the table it can be seen that, the reliability indices are improved when the proposed DPC is considered for load shedding. The SAIDI and SAIFI are based on the interruptions to the customer, the values obtained after the proposed load shedding are low with the effect of DPC. This implies that, the number of customers being affected by the proposed load shedding scheme is less as compared to when DPC is not considered for the load shedding.

5.3.2 With type-3 DG units

The type-3 DG units are installed in the system without dividing the system into zones and the islanding is identified by the proposed HIDT-II. The loads in the island are supplied by type-3 DG units installed. The load shedding without considering the proposed DPC is also performed. The available power in the island from the DG units and the load demand for each case is shown in Table. 5.3.

It can be observed from the table that, in the presence of type-3 DG unit in the island, the load shedding required by considering the proposed DPC is lesser than without considering the DPC parameter. The frequency and voltage are within limits with less amount of load shedding.

TABLE 5.3: Load Shedding in 33 Bus System with type-3 DGs at Base Load

Load Shedding Technique	Islanded Bus	Number of Buses in Island	Power Available (MVA)	Load (MVA)	Actual Load Shed (MVA)	Amount of Load Shed (%)
With DPC	4	23	1.86	2.9062	0.502	17.27
Without DPC	4	22	1.86	2.9062	0.9	30.97

The frequency and voltage variations of the islanded bus with and without the proposed DPC in the load shedding is shown in Figs. 5.4 and 5.5.

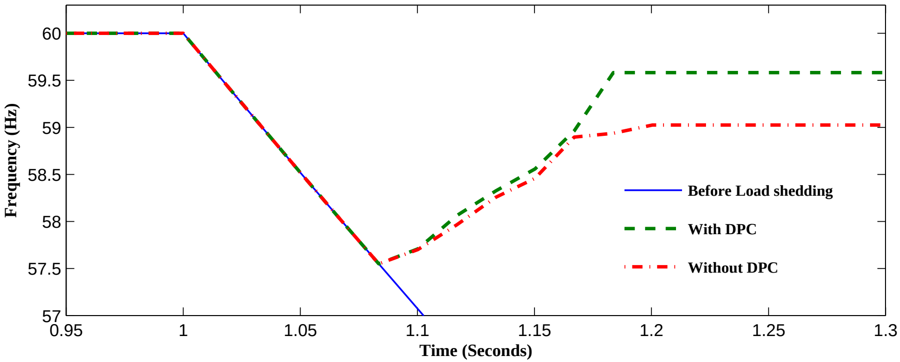

FIGURE 5.4: Comparison of Frequency at islanded bus in 33 Bus System with type-3 DGs before and after load shedding

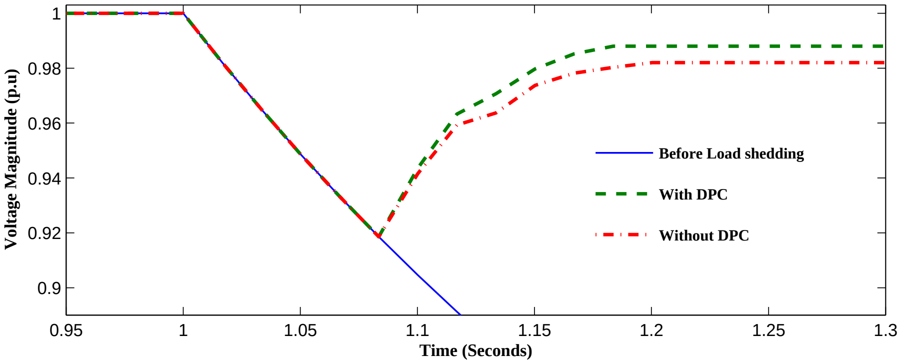

FIGURE 5.5: Comparison of Voltage at islanded bus in 33 Bus System with type-3 DGs before and after load shedding

The reliability of the island is calculated before and after the proposed priority based load shedding is performed. The reliability indices are also calculated before and after the load shedding without considering the proposed DPC. The results are shown in Table. 5.4.

Table 5.4: Reliability Analysis of 33 Bus System with type-3 DGs

Cases	**Before Load Shedding**					**After Load Shedding**				
	SAIDI	SAIFI	CAIDI	ENS	AENS	SAIDI	SAIFI	CAIDI	ENS	AENS
With DPC	0.3286	0.3817	0.8608	1.0462	0.0454	0.3159	0.3806	0.8300	0.502	0.0313
Without DPC	0.3286	0.3817	0.8608	1.0462	0.0454	0.3339	0.3856	0.8661	0.9	0.06

It can be seen that, after load shedding the quantitative indices indicate that the reliability of the islanded system has improved when load shedding is performed by considering the proposed DPC. The number of customers affected is higher when load shedding is performed without considering the DPC. This can be inferred from the SAIDI and SAIFI indices after load shedding. The values of SAIDI and SAIFI are low when the DPC parameter is considered for load shedding.

5.4 Test Results of IEEE 69 Bus System

The proposed priority based load shedding is performed in the 69 Bus system in the presence of type-1 and type-3 DG units. The effect of the proposed priority based load shedding scheme on the frequency and voltage of the islanded system is measured. The load shedding is performed without considering the proposed DPC parameter and the effect on the frequency and voltage of the island are measured. The reliability analysis is performed before and after the load shedding for each case.

5.4.1 With type-1 DG units

The type-1 DGs are installed in the 69 bus system and the vulnerable buses are identified for islanding by the proposed HIDT-I. The effect of the proposed DPC parameter on load shedding is also analyzed. The available power in the island from the DG units and the load demand for each case is shown in Table. 5.5.

Table 5.5: Load Shedding in 69 Bus System with type-1 DGs

Load Shedding Technique	**Islanded Bus**	**Number of Buses in Island**	**Power Available (MW)**	**Load (MW)**	**Actual Load Shed (MW)**	**Amount of Load Shed (%)**
With DPC	6	41	0.833	2.5569	1.244	48.65
Without DPC	6	41	0.833	2.5569	1.630	63.75

From the table it can be seen that, by considering the DPC parameter for load shedding, the amount of load shedding is less than when load shedding is performed without considering the DPC parameter. The load in bus 61 is 1.244 MW, which is sufficient to regain the stability within tolerance limits by considering the DPC parameter. However, when DPC is not considered the load at bus 61 is shed along with some more loads leading to higher amount of load shedding

The frequency and voltage variations of the islanded bus before and after load shedding for different types of DG installation is shown in Figs. 5.6 and 5.7. From the figs. it can be seen that, the load shed when DG units are installed by any method, the frequency and voltage are within specified limits.

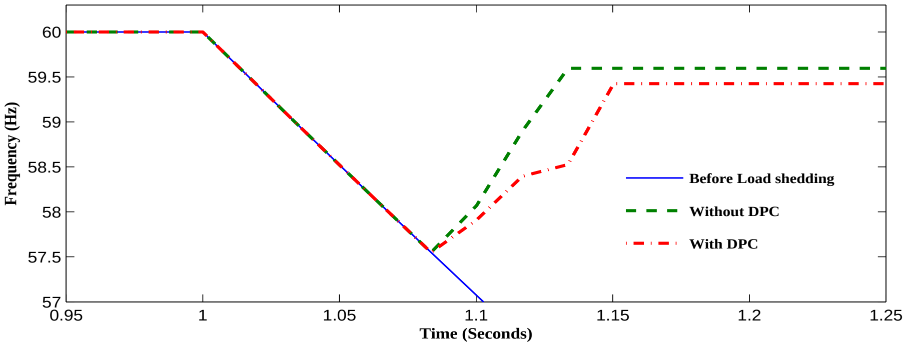

FIGURE 5.6: Comparison of Frequency at islanded bus in 69 Bus System with type-1 DGs before and after load shedding

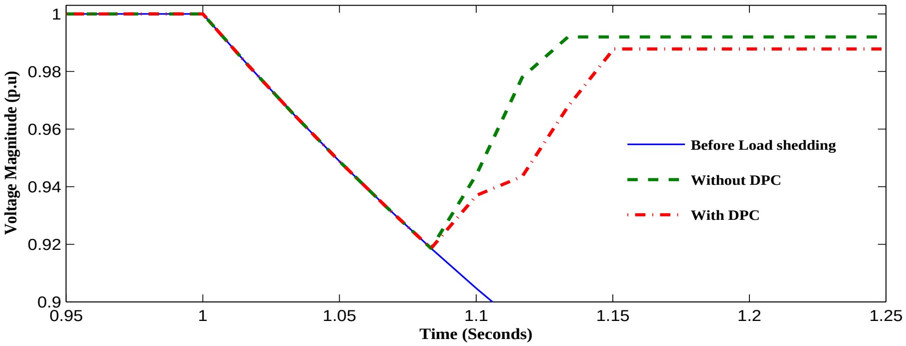

FIGURE 5.7: Comparison of Voltage at islanded bus in 69 Bus System with type-1 DGs before and after load shedding

The reliability analysis is performed before and after load shedding considering the effect of the proposed DPC parameter and the indices for each case are shown in Table. 5.6.

TABLE 5.6: Reliability Analysis of 69 Bus System with type-1 DGs at Base Load

Cases	**Before Load Shedding**					**After Load Shedding**				
	SAIDI	SAIFI	CAIDI	ENS	AENS	SAIDI	SAIFI	CAIDI	ENS	AENS
With DPC	0.1868	0.2544	0.7343	1.7239	0.042	0.1279	0.2146	0.5959	1.244	0.0311
Without DPC	0.1868	0.2544	0.7343	1.7239	0.042	0.1589	0.2529	0.7231	1.63	0.0509

From the table it can be seen that, by considering the DPC for load shedding, the number of customers affected is less after the load shedding is performed. Without considering the DPC in the proposed load shedding scheme, the number of customers affected are more. The failure indices are reduced by considering the proposed DPC in load shedding.

5.4.2 With type-3 DG units

The proposed priority based load shedding is performed after type-3 DG units are installed without dividing the system into zones and the vulnerable bus for islanding is identified by the proposed HIDT-II. The available power in the island from the DG units and the load demand is shown in Table. 5.7.

Table 5.7: Load Shedding in 69 Bus System with type-3 DGs at Base Load

DG Placement Technique	**Islanded Bus**	**Number of Buses in Island**	**Power Available (MVA)**	**Load (MVA)**	**Actual Load Shed (MVA)**	**Amount of Load Shed (%)**
With DPC	7	40	1.747	3.11	0.6153	19.78
Without DPC	5	22	1.747	3.11	1.0631	34.18

It can be seen from the table that, in the presence of type-3 DG unit in the island, the load shedding required by considering the DPC is lesser than without considering the DPC parameter. The frequency and voltage are within limits with less amount of load shedding by considering the DPC parameter. The frequency and voltage regain is faster by shedding less amount of load in the island.

The frequency and voltage variations of the islanded bus before and after load shedding for different types of DG installation are shown in Figs. 5.8 and 5.9.

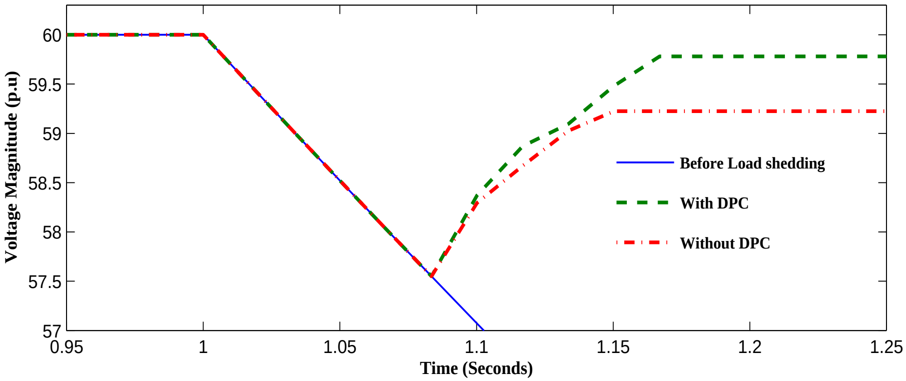

Figure 5.8: Comparison of Frequency at islanded bus in 69 Bus System with type-3 DGs before and after load shedding

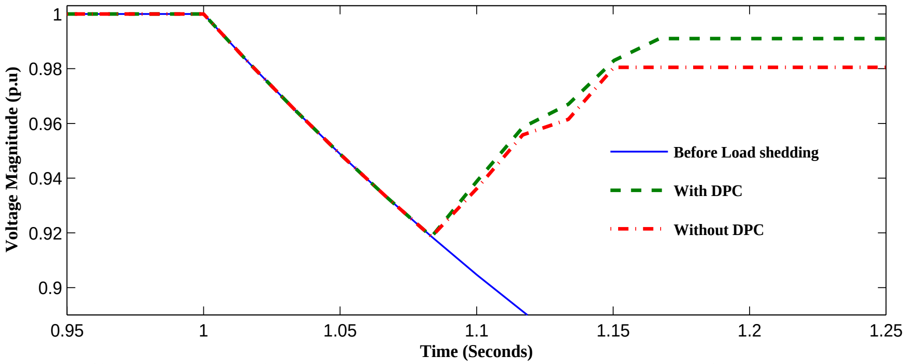

FIGURE 5.9: Comparison of Voltage at islanded bus in 69 Bus System with type-3 DGs before and after load shedding

The reliability analysis is performed before and after the load shedding process. The analysis is performed without considering the effect of proposed DPC and the indices are shown in Table. 5.8

TABLE 5.8: Reliability Analysis of 69 Bus System with type-3 DGs

Cases	**Before Load Shedding**					**After Load Shedding**				
	SAIDI	SAIFI	CAIDI	ENS	AENS	SAIDI	SAIFI	CAIDI	ENS	AENS
With DPC	0.1886	0.2551	0.7395	1.363	0.0340	0.1344	0.2542	0.5287	0.6153	0.02563
Without DPC	0.1886	0.2551	0.7395	1.363	0.0340	0.1357	0.2550	0.5321	1.0631	0.05062

The effect of DPC parameter can be seen on the SAIDI and SAIFI after load shedding. The DPC parameter is effective in identifying the most vulnerable buses for load shedding. The number of customers affected is less by considering the DPC parameter for load shedding.

5.5 Summary

The load shedding is performed after the different types of DG units are optimally installed in IEEE 33 Bus and IEEE 69 Bus Systems. The islanding event is identified by the proposed HIDTs and the load shedding is performed in the island. The results from this chapter are summarized as follows:

1. A priority based load shedding is proposed, to alleviate the power mismatch in the islanded system energized by the DGs. The proposed priority based load shedding is able to identify the most vulnerable buses to perform the load shedding.
2. The priority based load shedding uses a dynamic DPC parameter to identify the vulnerable buses for load shedding. The frequency and voltage stability in the island

is regained by shedding less amount of load. The proposed DPC parameter takes into account the availability of DG unit, frequency and voltage variations in a bus before identifying a bus for load shedding.

3. The load shedding scheme has been tested on systems with type-1 and type-3 DG units installed by the proposed GA method described in chapter 3. The islanded bus is identified by the proposed HIDT-I with type-1 DG units and HIDT-II with type-3 DG units described in chapter 4.
4. In the absence of DPC parameter more amount of load is shed to regain the frequency and voltage stability in the island. This is due to the load shedding without identification of the most vulnerable buses.
5. In both the test systems, in the presence of type-3 DG units, the proposed load shedding scheme is effective. Since both active and reactive power loads are shed, the effect on voltage and frequency is more. In the 69 Bus system the amount of load to be shed in the presence of type-3 DG is lesser than in the presence of type-1 DG units.
6. The quantitative reliability analysis of the islands, before and after the load shedding was performed. The reliability analysis with and without DPC parameter was performed for each case. The number of customers affected by the load shedding when DPC parameter is considered is less.
7. The reliability indices are improved by considering the proposed DPC parameter in the load shedding as the loads of only the vulnerable buses are shed. Since the reliability indices also depend on the number of customers being affected, the proposed DPC parameter is effective in improving the reliability of the island.

From this chapter it has been observed that under emergency conditions, shedding of the most vulnerable loads results in a significant improvement of frequency and voltage in the islands. However, identification of the vulnerable bus needs to be given careful consideration in the presence of DG units. The load shedding process cannot depend solely on the decay of frequency as it can be based on very rough estimations. The proposed load shedding scheme considers the variation of frequency and voltage along with the presence of DG units ensuring better identification of the vulnerable buses for islanding. The reliability indices are better when the proposed load shedding process is incorporated. The number of customers affected by the load shedding when DPC parameter is considered are less and the reliability indices are improved as the loads of only the vulnerable buses are shed.

CHAPTER 6

CONCLUSIONS

The objective of this chapter is to summarize the main contributions and findings of the work carried out in this thesis and to suggest scope for future research work in this area. In the deregulated market and competitive business environment, the operation of modern power systems has become complicated. With the increased emphasis on clean energy, usage of renewables and DG unit installation has found favour with utilities for utilizing the advantages offered by them optimally. However, the two way power flow has increased the complexity of operation of the system.

6.1 Important Findings

In Chapter 3, the optimal installation of different types of DG units have been performed by two different method. The DG installation is performed by two-stage GA method. In this the weaker possible solutions are eliminated in the first round and the best possible solution is achieved by fitter individuals. The quality of solutions obtained is better by this process. The method has been tested for achieving different objectives such as voltage stability margin improvement and increasing loss reduction.

In the first method, the entire system is divided into zones and atleast one DG unit is installed in each zone. The method has been tested on 33 Bus and 69 Bus systems. In both the systems, type-1 and type-3 DG unit were installed. The performance of the different DG units have been tested at base load and at 140% of base load condition. The performance of the DG units optimally installed by the proposed two-stage GA method was found to be better.

In the second method, the number of DG units to be installed is fixed the entire search space is explored for best possible solutions. The results obtained for type-1 DG unit installation is compared with two other existing methods described in [64] and [74]. The operation of the DG units has been tested under two different operating conditions namely at base load and at 140% of base load. The results obtained for type-3 DG unit installation is compared with a method described in [78]. The findings of the chapter are as follows:

1. Two methods of DG installation have been proposed in this chapter. In the first method, the system is divided into zones and one DG is optimally installed in each zone. In the second method, the number of DG units are fixed and optimal location and size is searched throughout the system. Both the methods have been tested by installing type-1 and type-3 DG units at base load condition on IEEE 33 Bus and IEEE 69 Bus systems.

2. A two-stage selection process is utilized for eliminating the weaker solutions and finding the optimal solution using GA. The two-stage GA ensures that the solutions achieved are better as the off-springs are produced from stronger individuals.

3. In the first method of DG installation by dividing the system into zones, better results are achieved when W_1 is considered as 0.75 for type-1 and type-3 DG installation in the IEEE 33 Bus system. This is achieved as a result of slightly higher sized DG units installed in the system. Since the DG units are not installed at the terminal nodes, the results achieved in terms of voltage stability maximization and loss minimization are better.

4. In 69 Bus system, the performance is better when W_1 is considered as 0.75 when the system is divided into 4 and 6 zones for type-1 and type-3 DG installation. When the system is divided into 5 zones better results are achieved when W_2 is considered as 0.75 for DG installation. The results achieved are due to the presence of type-1 DG unit at bus number 69 when the system is divided into 4 and 6 zones. In case of type-3 DG units, the DG units are installed at bus 67 when the system is divided into 4 and 6 zones. Since buses 67 and 69 are connected near the mid-point of the radial system.

5. The creation of zones with DG in each zone, the overall penetration level of DGs in the system is variable. With DG units installed at different parts of the system, the performance is improved with lesser power from individual DG units.

6. The increase in number of zones leads to better performance of the system. However, beyond the optimal number of divisions, the performance cannot be improved. Since, DG installation increases the initial investment cost, identification of the ideal number of zones is critical.

7. The creation of number of zones is system specific. Since, the load demand and number of buses in each radial branch varies from system to system, it is crucial to identify the ideal number of buses in each zone. The increase in number of zones does not effect much on the overall reduction of losses and improvement of voltage stability margin.

8. The optimal installation of DG unit without dividing the system into zones is more effective than by dividing the system into zones as the proposed method is not dependent on specific values of the weights in the objective function.

9. In the IEEE 33 Bus system for type-1 DG installation, results are better when W_1 is considered greater than W_2 as the sizes of the DGs installed are evenly distributed throughout the system. However for type-3 DG installation, considering W_1 lesser than W_2 is better as two DGs of almost same sizes are installed in the system.

10. In the IEEE 69 Bus system for type-1 DG installation, values $W_1, W_2 \notin \{0,1\}$, gives the same result. As only Active power is supplied by the DG units in the system the variation of weights do not affect the performance in terms of voltage stability maximization and loss reduction. For type-3 DG installation considering $W_1 > W_2$ gives better results as the supply of both active and reactive power is influenced by the location of DG units.

11. In both methods, the Type-3 DGs are effective in reducing the losses and improving the voltage stability margin as both active and reactive power is supplied at the same location.

12. As the size of the system increases, the variation in weights does not impact the performance of the system by the proposed algorithm. As the size of the system increases, the effect of DG is more evenly spread reducing the effect of variation of weights in the system.

13. The proposed methods were tested when the system operates at abnormal operating conditions (140% of base load). Even under overloaded condition, the performance of the proposed methods was better than existing methods of optimal DG installation.

In Chapter 4, islanding detection in the presence of DG units is described. A new method, HIDT-I is proposed for islanding detection in the presence of type-1 DG units and HIDT-II in the presence of type-3 DG units. The proposed method combines the advantages offered by the existing passive IDTs and overcomes the inherent disadvantages in the existing passive IDTs such as slow response or NDZ. The findings of the chapter can be summarized as:

1. In the presence of type-1 DGs in the distribution system, HIDT-I is proposed for islanding detection. An additional Voltage-Active Power sensitivity parameter is proposed along with voltage, frequency and Active Power measurements for early islanding detection effectively.
2. When the Voltage-Active Power sensitivity parameter violates the threshold limit along with either voltage, frequency and Rate-of-change of Active Power parameters, then it is classified as islanding event. The Voltage-Active Power sensitivity parameter which is variation of voltage with active power, takes into account the effect of voltage and active power at bus by the type-1 DG unit. This parameter ensures against false triggering of the islanding event.
3. HIDT-II is proposed for islanding detection in the presence of type-3 DGs in the distribution system. Two additional parameters, namely Voltage-Active Power sensitivity and Frequency-Reactive Power sensitivity parameters are utilized along with voltage, frequency, Active Power and Reactive Power measurements.
4. The Frequency-Reactive Power sensitivity parameter is variation of frequency with reactive power at each bus. The Frequency-Reactive Power sensitivity parameter is more sensitive than Voltage-Active Power sensitivity parameter as frequency deviations with variation in load is faster.
5. The introduction of additional parameters ensures the system against false triggering of islanding event and the threshold values set for each parameter is judiciously chosen after thorough simulations and are set to optimal values. The threshold values of HIDT-I is set at 10% and HIDT-II is set at 2% after thorough investigations at varying operating conditions. For values set lower than the proposed values, the islanding is falsely triggered and for higher values, some islanding conditions are not detected.

6. The performance of the proposed HIDT-I and HIDT-II with different loading conditions are better than existing passive IDTs as the time of detection of islanding is early in each case than any other existing passive IDTs.
7. The active power influences the frequency and reactive power influences the voltage. However, in the proposed parameters the measurements are sensitive since these parameters are cross-coupled. Hence the islanding event is not triggered due to sudden switching of loads or capacitor switching events.
8. As the loading level increases, the vulnerable bus for islanding moves away from the main grid as the effect of DG units cannot be effective in many buses. The size and topology of the system is also crucial for the detection of the vulnerable bus as the effect of variation of voltage, frequency, active power and reactive power (for type-3 DG units) are not significant near the grid. This is more prevalent in IEEE 69 Bus system than the IEEE 33 Bus system as the variation of frequency is spread more evenly throughout the system.

In Chapter 5, a priority based load shedding scheme is proposed for the islanded system. In this the vulnerable buses are identified for load shedding using a dynamic DPC parameter. The buses with DG units are not considered for load shedding. This scheme is tested in the presence of type-1 and type-3 DG units installed by the proposed GA method. The islanding is identified by the proposed HIDT-I for type-1 DG units and HIDT-II for type-3 DG units. The effect of the load shedding scheme is validated by quantitative reliability analysis of the islanded part of the system before and after the load shedding is performed. The load shedding in the island is performed without the effect of the DPC parameter. The findings of the chapter can be summarized as:

1. A priority based load shedding is proposed, to alleviate the power mismatch in the islanded system energized by the DGs. The proposed priority based load shedding is able to identify the most vulnerable buses to perform the load shedding.
2. The priority based load shedding uses a dynamic DPC parameter to identify the vulnerable buses for load shedding. The frequency and voltage stability in the island is regained by shedding less amount of load. The proposed DPC parameter takes into account the availability of DG unit, frequency and voltage variations in a bus before identifying a bus for load shedding.

3. The load shedding scheme has been tested on systems with type-1 and type-3 DG units installed by the proposed GA method described in chapter 3. The islanded bus is identified by the proposed HIDT-I with type-1 DG units and HIDT-II with type-3 DG units described in chapter 4.
4. In the absence of DPC parameter more amount of load is shed to regain the frequency and voltage stability in the island. This is due to the load shedding without identification of the most vulnerable buses.
5. In both the test systems, in the presence of type-3 DG units, the proposed load shedding scheme is effective. Since both active and reactive power loads are shed, the effect on voltage and frequency is more. In the 69 Bus system the amount of load to be shed in the presence of type-3 DG is lesser than in the presence of type-1 DG units.
6. The quantitative reliability analysis of the islands, before and after the load shedding was performed. The reliability analysis with and without DPC parameter was performed for each case. The number of customers affected by the load shedding when DPC parameter is considered is less.
7. The reliability indices are improved by considering the proposed DPC parameter in the load shedding as the loads of only the vulnerable buses are shed. Since the reliability indices also depend on the number of customers being affected, the proposed DPC parameter is effective in improving the reliability of the island.

From the work carried out, it has been understood that the optimal installation of DG units depends on the requirements of the system operator. By incorporating more decision variables and considering multiple objectives, the objective function becomes more complex necessitating the usage of more sophisticated algorithms and techniques to achieve the optimal solution. To make the system controllable and dispatchable in the presence of DG units, it is necessary to consider all available types of renewables and alternate energy sources.

With the system becoming more complex due to incorporation of different types of DG units, the existing islanding detection techniques trigger an islanding event even under non-islanding conditions. With the increase in complexity of the measurements, the decision parameters for islanding detection also needs to be more robust. Consideration of cross-coupled Voltage-Active Power parameter and Frequency-Reactive Power parameter significantly overcomes the disadvantage of Non-Detection Zones, slow response in identification of islanded bus and false triggering of islanding event in existing techniques. The performance of these parameters are satisfactory for different loading levels of the system and are able to identify the vulnerable bus for islanding earlier than existing passive techniques.

The power mismatch in the island may lead to a blackout situation in the island if timely counter measures are not initiated. Emergency control schemes need to be available to the operator if appropriate preventive control schemes are not available. In the identified island, the load shedding cannot be solely based on the frequency gradient as they are based on rough estimates. The identification of the vulnerable bus for load shedding, needs to consider the decay of frequency and voltage simultaneously taking into consideration the presence of DG units. This ensures minimum customer disruptions in the islanded part of the system.

The work carried out in the thesis may provide a comprehensive solution in planning the DG installation and reliable operation of the distribution systems in the presence of DG units. With more types of DG units being integrated into the system, islanded operation of the system has become a reality. With the system parameters becoming complex to be monitored, the system operator need to be made aware of any impending unintentional islanding condition in the system. Some emergency control schemes also need to be in place to manage the islanded part of the system. In the end of the thesis the future direction of the research work in context of the present work is discussed.

6.2 Future Research Scope

The following can be the future research direction from the present work:

1. With the increased emphasis on clean energy, the integration of renewable energy resources into the system on a large scale becomes crucial. The effect of varying penetration levels of different DG units needs to be investigated for smooth operation of the system.

2. The integration of many micro producers of renewable energy into the system needs to be explored carefully considering the operational constraints of the system.

3. The islanded operation of the system becomes critical to ensure reliable power supply to the customers. The effect of customer behaviour in the islanded mode of operation becomes vital. In such a scenario the evolution of smart appliances in the grid is important to avoid mal-operation of the protective devices.
4. In islanded condition, if the DG power available is more than the demand in the island, proper control action needs to be in place for the system operator to alleviate the power mismatch. More storage options for the power generated from the DG units in such scenarios need to be investigated.
5. The viability of effective online reconfiguration of the system under unintentional islanding is crucial and needs to be explored without violating the system constraints. Effective reconfiguration of system will reduce the need for load shedding and allow the customers to tap the energy resources available effectively.

Appendix A

IEEE 33 Bus System

This test distribution system and its data are referred from [74]. It is a 12.66kV distribution system having 32 sectionalizing lines and 5 tie-lines. The nominal active and reactive power loadings are 3715 kW and 2300 kVAr respectively.

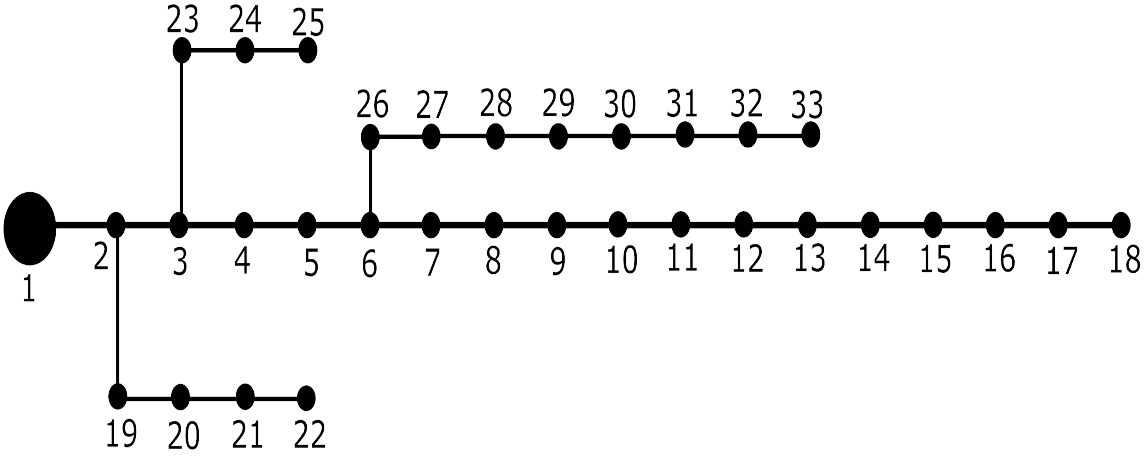

Figure A.1: IEEE 33 Bus Distribution System

Table A.1: IEEE 33 Bus System Bus Data

Bus No.	Bus Code	Voltage Magnitude (p.u)	Angle Degree	Load		Generator				Injected MVAr
				MW	MVAr	MW	MVAr	Qmin	Qmax	
1	1	1	0	0	0	0	0	0	0	0
2	0	1	0	0.1	0.06	0	0	0	0	0
3	0	1	0	0.09	0.04	0	0	0	0	0
4	0	1	0	0.12	0.08	0	0	0	0	0
5	0	1	0	0.06	0.03	0	0	0	0	0
6	0	1	0	0.06	0.02	0	0	0	0	0
7	0	1	0	0.2	0.1	0	0	0	0	0
8	0	1	0	0.2	0.1	0	0	0	0	0
9	0	1	0	0.06	0.02	0	0	0	0	0
10	0	1	0	0.06	0.02	0	0	0	0	0
11	0	1	0	0.045	0.03	0	0	0	0	0
12	0	1	0	0.06	0.035	0	0	0	0	0
13	0	1	0	0.06	0.035	0	0	0	0	0
14	0	1	0	0.12	0.08	0	0	0	0	0
15	0	1	0	0.06	0.01	0	0	0	0	0
16	0	1	0	0.06	0.02	0	0	0	0	0
17	0	1	0	0.06	0.02	0	0	0	0	0
18	0	1	0	0.09	0.04	0	0	0	0	0
19	0	1	0	0.09	0.04	0	0	0	0	0
20	0	1	0	0.09	0.04	0	0	0	0	0
21	0	1	0	0.09	0.04	0	0	0	0	0
22	0	1	0	0.09	0.04	0	0	0	0	0
23	0	1	0	0.09	0.05	0	0	0	0	0
24	0	1	0	0.42	0.2	0	0	0	0	0
25	0	1	0	0.42	0.2	0	0	0	0	0
26	0	1	0	0.06	0.025	0	0	0	0	0
27	0	1	0	0.06	0.025	0	0	0	0	0
28	0	1	0	0.06	0.020	0	0	0	0	0
29	0	1	0	0.12	0.07	0	0	0	0	0
30	0	1	0	0.2	0.6	0	0	0	0	0
31	0	1	0	0.15	0.07	0	0	0	0	0

32	0	1	0	0.21	0.1	0	0	0	0	0
33	0	1	0	0.06	0.04	0	0	0	0	0

BUS CODE
1 - slack bus
0 - load bus

Table A.2: IEEE 33 Bus System Line Data

Line No.	From Bus	To Bus	R (p.u)	X (p.u)	B (p.u)	line code =1 for lines >1 or <1 for tr.tap	Failure Rate (f/yr)	Repair time (h)
1	1	2	0.0922	0.0470	0	1	0.0500	1.00
2	2	3	0.4930	0.2512	0	1	0.3000	1.00
3	3	4	0.3661	0.1864	0	1	0.2200	1.00
4	4	5	0.3811	0.1941	0	1	0.2300	1.00
5	5	6	0.8190	0.7070	0	1	0.5100	1.00
6	6	7	0.1872	0.6188	0	1	0.1100	1.00
7	7	8	0.7115	0.2351	0	1	0.4400	1.00
8	8	9	1.0299	0.7400	0	1	0.6400	1.00
9	9	10	1.0440	0.7400	0	1	0.6500	1.00
10	10	11	0.1967	0.0651	0	1	0.1200	1.00
11	11	12	0.3744	0.1298	0	1	0.2300	1.00
12	12	13	1.4680	1.1549	0	1	0.9100	1.00
13	13	14	0.5416	0.7129	0	1	0.3300	1.00
14	14	15	0.5909	0.5260	0	1	0.3600	1.00
15	15	16	0.7462	0.5449	0	1	0.4600	1.00
16	16	17	1.2889	1.7210	0	1	0.8000	1.00
17	17	18	0.7320	0.5739	0	1	0.4500	1.00
18	2	19	0.1640	0.1565	0	1	0.1000	0.50
19	19	20	1.5042	1.3555	0	1	0.9300	0.50
20	20	21	0.4095	0.4784	0	1	0.2500	0.50
21	21	22	0.7089	0.9373	0	1	0.4400	0.50
22	3	23	0.4512	0.3084	0	1	0.2800	0.500
23	23	24	0.8980	0.7091	0	1	0.5600	0.50
24	24	25	0.8959	0.7071	0	1	0.5500	0.50
25	6	26	0.2031	0.1034	0	1	0.1200	0.50
26	26	27	0.2842	0.1447	0	1	0.1700	0.50

27	27	28	1.0589	0.9338	0	1	0.6600	0.50
28	28	29	0.8043	0.7006	0	1	0.5000	0.50
29	29	30	0.5074	0.2585	0	1	0.3100	0.50
30	30	31	0.9745	0.9629	0	1	0.6000	0.50
31	31	32	0.3105	0.3619	0	1	0.1900	0.50
32	32	33	0.3411	0.5302	0	1	0.2100	0.50
33*	8	21	2.0000	2.0000	0	1	1.2400	0.50
34*	9	15	2.0000	2.0000	0	1	1.2400	0.50
35*	12	22	2.0000	2.0000	0	1	1.2400	0.50
36*	18	33	0.5000	0.5000	0	1	0.3100	0.50
37*	25	29	.5000	0.5000	0	1	0.3100	0.50

* - Tie Line

Appendix B

IEEE 69 Bus System

This test distribution system and its data are referred from [74]. It is a 12.66kV distribution system having 68 sectionalizing lines and 5 tie-lines. The nominal active and reactive power loadings are 3801.5 kW and 2694.6 kVAr respectively.

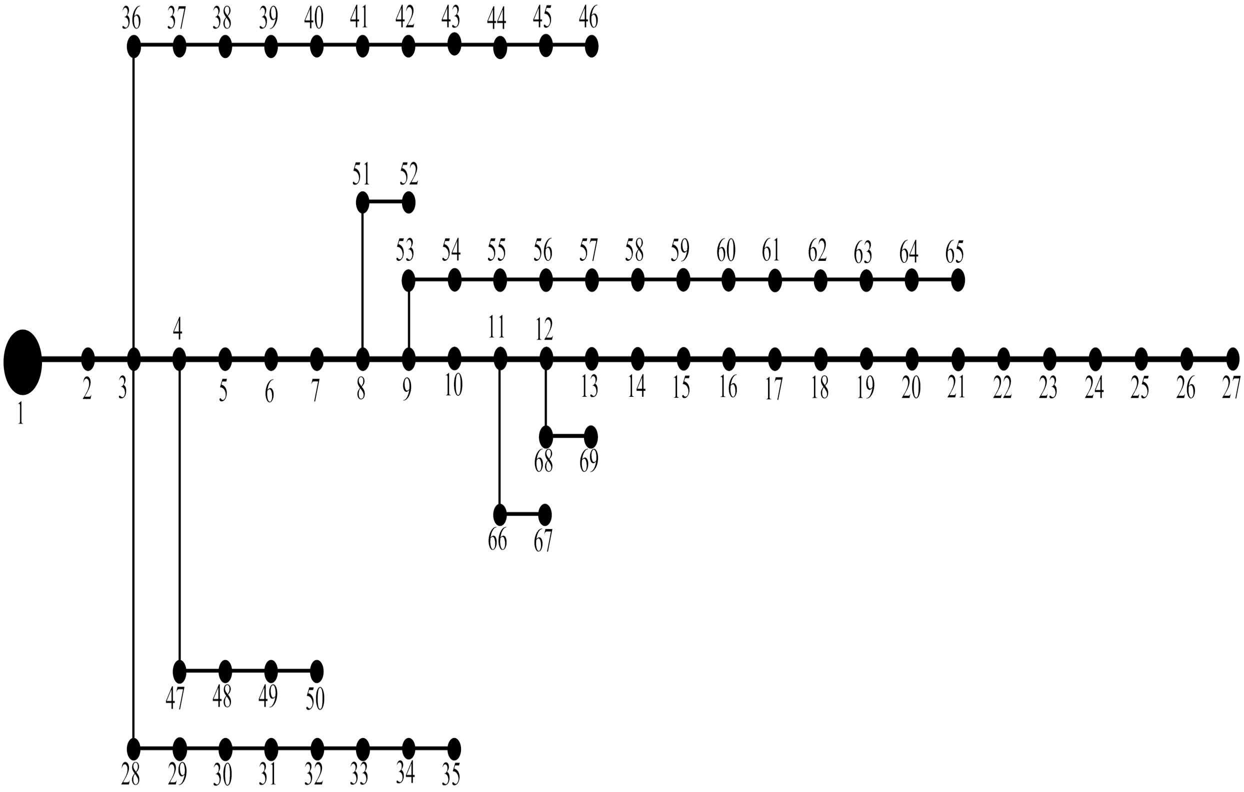

FIGURE B.1: IEEE 69 Bus Distribution System

Table B.1: IEEE 69 Bus System Bus Data

Bus No.	Bus Code	Voltage Magnitude (p.u)	Angle Degree	Load		Generator				Injected MVAr
				MW	MVAr	MW	MVAr	Qmin	Qmax	
1	1	1	0	0	0	0	0	0	0	0
2	0	1	0	0	0	0	0	0	0	0
3	0	1	0	0	0	0	0	0	0	0
4	0	1	0	0	0	0	0	0	0	0
5	0	1	0	0	0	0	0	0	0	0
6	0	1	0	0.0026	0.0022	0	0	0	0	0
7	0	1	0	0.0404	0.0030	0	0	0	0	0
8	0	1	0	0.0075	0.0054	0	0	0	0	0
9	0	1	0	0.0030	0.0022	0	0	0	0	0
10	0	1	0	0.0028	0.0019	0	0	0	0	0
11	0	1	0	0.145	0.104	0	0	0	0	0
12	0	1	0	0.145	0.104	0	0	0	0	0
13	0	1	0	0.008	0.0055	0	0	0	0	0
14	0	1	0	0.008	0.0055	0	0	0	0	0
15	0	1	0	0	0	0	0	0	0	0
16	0	1	0	0.0455	0.0030	0	0	0	0	0
17	0	1	0	0.060	0.035	0	0	0	0	0
18	0	1	0	0.060	0.035	0	0	0	0	0
19	0	1	0	0	0	0	0	0	0	0
20	0	1	0	0.001	0.0006	0	0	0	0	0
21	0	1	0	0.114	0.081	0	0	0	0	0
22	0	1	0	0.00530	0.0035	0	0	0	0	0
23	0	1	0	0	0	0	0	0	0	0
24	0	1	0	0.02800	0.0200	0	0	0	0	0
25	0	1	0	0	0	0	0	0	0	0
26	0	1	0	0.01400	0.0100	0	0	0	0	0
27	0	1	0	0.01400	0.01000	0	0	0	0	0
28	0	1	0	0.026	0.01860	0	0	0	0	0
29	0	1	0	0.026	0.01860	0	0	0	0	0
30	0	1	0	0	0	0	0	0	0	0
31	0	1	0	0	0	0	0	0	0	0

32	0	1	0	0	0	0	0	0	0	0
33	0	1	0	0.01400	0.01000	0	0	0	0	0
34	1	1	0	0.01950	0.01400	0	0	0	0	0
35	0	1	0	0.00600	0.00400	0	0	0	0	0
36	0	1	0	0.02600	0.01855	0	0	0	0	0
37	0	1	0	0.02600	0.01855	0	0	0	0	0
38	0	1	0	0	0	0	0	0	0	0
39	0	1	0	0.02400	0.01700	0	0	0	0	0
40	0	1	0	0.02400	0.01700	0	0	0	0	0
41	0	1	0	0.00120	0.00100	0	0	0	0	0
42	0	1	0	0	0	0	0	0	0	0
43	0	1	0	0.00600	0.00430	0	0	0	0	0
44	0	1	0	0	0	0	0	0	0	0
45	0	1	0	0.03922	0.02630	0	0	0	0	0
46	0	1	0	0.03922	0.02630	0	0	0	0	0
47	0	1	0	0	0	0	0	0	0	0
48	0	1	0	0.07900	0.05640	0	0	0	0	0
49	0	1	0	0.38470	0.27450	0	0	0	0	0
50	0	1	0	0.38470	0.27450	0	0	0	0	0
51	0	1	0	0.04050	0.02830	0	0	0	0	0
52	0	1	0	0.00360	0.00270	0	0	0	0	0
53	0	1	0	0.00435	0.00350	0	0	0	0	0
54	0	1	0	0.02640	0.01900	0	0	0	0	0
55	0	1	0	0.02400	0.01720	0	0	0	0	0
56	0	1	0	0	0	0	0	0	0	0
57	0	1	0	0	0	0	0	0	0	0
58	0	1	0	0	0	0	0	0	0	0
59	0	1	0	0.100	0.0720	0	0	0	0	0
60	0	1	0	0	0	0	0	0	0	0
61	0	1	0	1.2440	0.8880	0	0	0	0	0
62	0	1	0	0.0320	0.0230	0	0	0	0	0
63	0	1	0	0	0	0	0	0	0	0
64	0	1	0	0.2270	0.1620	0	0	0	0	0
65	0	1	0	0.0590	0.0420	0	0	0	0	0
66	0	1	0	0.0180	0.0130	0	0	0	0	0
67	0	1	0	0.0180	0.0130	0	0	0	0	0

68	0	1	0	0.02800	0.02000	0	0	0	0	0
69	0	1	0	0.02800	0.02000	0	0	0	0	0

BUS CODE
1 - slack bus
0 - load bus

Table B.2: IEEE 69 Bus System Line Data

Line No.	From Bus	To Bus	R (p.u)	X (p.u)	B (p.u)	line code =1 for lines >1 or <1 for tr.tap	Failure Rate (f/yr)	Repair time (h)
1	1	2	0.0005	0.0012	0	1	0.0003	0.50
2	2	3	0.0005	0.0012	0	1	0.0003	0.50
3	3	4	0.0015	0.0036	0	1	0.0009	0.50
4	4	5	0.0251	0.0294	0	1	0.0156	0.50
5	5	6	0.3660	0.1864	0	1	0.2269	0.50
6	6	7	0.3811	0.1941	0	1	0.2363	0.50
7	7	8	0.0922	0.0470	0	1	0.0572	0.50
8	8	9	0.0493	0.0251	0	1	0.0306	0.50
9	9	10	0.0819	0.2707	0	1	0.5078	0.50
10	10	11	0.1872	0.0691	0	1	0.1161	0.50
11	11	12	0.7114	0.2351	0	1	0.4411	0.50
12	12	13	1.0300	0.3400	0	1	0.6386	0.50
13	13	14	1.0440	0.3450	0	1	0.6473	0.50
14	14	15	1.0580	0.3496	0	1	0.6560	0.50
15	15	16	0.1966	0.0650	0	1	0.1219	0.50
16	16	17	0.3744	0.1238	0	1	0.2321	0.50
17	17	18	0.0047	0.0016	0	1	0.0029	0.50
18	18	19	0.3276	0.1083	0	1	0.2031	0.50
19	19	20	0.2106	0.0690	0	1	0.1306	0.50
20	20	21	0.3416	0.1129	0	1	0.2118	0.50
21	21	22	0.0140	0.0046	0	1	0.0087	0.50
22	22	23	0.1591	0.0526	0	1	0.0986	0.50
23	23	24	0.3463	0.1145	0	1	0.2147	0.50
24	24	25	0.7488	0.2745	0	1	0.4643	0.50

25	25	26	0.3089	0.1021	0	1	0.1915	0.50
26	26	27	0.1732	0.0572	0	1	0.1074	0.50
27	3	28	0.0044	0.0108	0	1	0.0027	1.00
28	28	29	0.0640	0.1565	0	1	0.0397	1.00
29	29	30	0.3978	0.1315	0	1	0.2466	1.00
30	30	31	0.0702	0.0232	0	1	0.0435	1.00
31	31	32	0.3510	0.1160	0	1	0.2176	1.00
32	32	33	0.8390	0.2816	0	1	0.5202	1.00
33	33	34	1.7080	0.5646	0	1	1.0590	1.00
34	34	35	1.4740	0.4673	0	1	0.9139	1.00
35	3	36	0.0044	0.0108	0	1	0.0027	1.00
36	36	37	0.0640	0.1565	0	1	0.0397	1.00
37	37	38	0.1053	0.1230	0	1	0.0653	1.00
38	38	39	0.0304	0.0355	0	1	0.0188	1.00
39	39	40	0.0018	0.0021	0	1	0.0011	1.00
40	40	41	0.7283	0.8509	0	1	0.4515	1.00
41	41	42	0.3100	0.3623	0	1	0.1922	1.00
42	42	43	0.0410	0.0478	0	1	0.0254	1.00
43	43	44	0.0092	0.0116	0	1	0.0057	1.00
44	44	45	0.1089	0.1373	0	1	0.0675	1.00
45	45	46	0.0009	0.0012	0	1	0.0006	1.00
46	4	47	0.0034	0.0084	0	1	0.0021	1.00
47	47	48	0.0851	0.2083	0	1	0.0528	1.00
48	48	49	0.2898	0.7091	0	1	0.1797	1.00
49	49	50	0.0822	0.2011	0	1	0.0510	1.00
50	8	51	0.0928	0.0473	0	1	0.0575	1.00
51	51	52	0.3319	0.1114	0	1	0.2058	1.00
52	9	53	0.1740	0.0886	0	1	0.1079	1.00
53	53	54	0.2030	0.1034	0	1	0.1259	1.00
54	54	55	0.2842	0.1447	0	1	0.1762	1.00
55	55	56	0.2813	0.1433	0	1	0.1744	1.00
56	56	57	1.5900	0.5337	0	1	0.9858	1.00
57	57	58	0.7837	0.2630	0	1	0.4859	1.00
58	58	59	0.3042	0.1006	0	1	0.1886	1.00
59	59	60	0.3861	0.1172	0	1	0.2394	1.00
60	60	61	0.5075	0.2585	0	1	0.3146	1.00

61	61	62	0.0974	0.0496	0	1	0.0604	1.00
62	62	63	0.1450	0.0738	0	1	0.0899	1.00
63	63	64	0.7105	0.3619	0	1	0.4405	1.00
64	64	65	1.0410	0.5302	0	1	0.6454	1.00
65	11	66	0.2012	0.0611	0	1	0.1247	1.00
66	66	67	0.0047	0.0014	0	1	0.0029	1.00
67	12	68	0.7394	0.2444	0	1	0.4584	1.00
68	68	69	0.0047	0.0016	0	1	0.0029	1.00
69*	11	43	0.5000	0.5000	0	1	0.3100	1.00
70*	13	21	0.5000	0.5000	0	1	0.3100	1.00
71*	15	46	1.0000	1.0000	0	1	0.6200	1.00
72*	50	59	2.0000	2.0000	0	1	1.2400	1.00
73*	27	65	1.0000	1.0000	0	1	0.6200	1.00

* - Tie Line

Appendix C

Publications

The following research papers have been published, accepted for publications and communicated out of this thesis work.

International Journals

1. Narayanan. K, Shahbaz A. Siddiqui and Manoj Fozdar, ***"Optimal Placement of Distributed Generators in Radial Distribution System for reducing the effect of Islanding"***, Journal of Electrical Engineering & Technology, Vol. 11, No. 3, pp 551-559, 2016; Available Online- DOI: 10.5370/JEET.2016.11.3.551.
2. Narayanan. K, Shahbaz A. Siddiqui and Manoj Fozdar, ***"Operation of Islanded Distribution System in the Presence of different types of DG units"***, Accepted for Publication in IET Generation, Transmission & Distribution. DOI: 10.1049/iet-gtd.2016.0437.
3. Narayanan. K, Shahbaz A. Siddiqui and Manoj Fozdar, ***"An Unified Scheme for DG Placement to Reduce Impact of Islanding and Detection of Islanding Event"***, Under review in Journal of Modern Power Systems and Clean Energy.

International Conferences

1. Narayanan. K, Shahbaz A. Siddiqui and Manoj Fozdar, ***"Identification and Reduction of Impact of Islanding Using Hybrid Method with Distributed***

Generation", *IEEE PES, General Meeting, Denver, Colorado, USA*, pp. 1-5, 26-30 July, 2015. Available Online - www.ieeexplore.org. DOI: 10.1109/PESGM.2015.7286467. Electronic ISBN: 978-1-4673-8040-9. Print ISSN: 1932-5517.

2. Narayanan. K, Shahbaz A. Siddiqui and Manoj Fozdar, ***"An Improved hybrid method to reduce the Effect of Islanding in the presence of Optimally Located DGs"***, *IEEE INDICON 2015, Jamia Millia Islamia, India*, pp. 1-5, 17-20 December 2015. Available Online - www.ieeexplore.ieee.org. DOI: 10.1109/INDICON.2015.7443690. Electronic ISSN 2325-9418.

National Conferences

1. Narayanan. K, Shahbaz A. Siddiqui and Manoj Fozdar, ***"An Improved Islanding Detection Technique and Priority Based Load Shedding for Distribution System with multiple DGs"***, Accepted for presentation in 19^{th} National Power Systems Conference-2016, IIT Bhubaneswar, India.
2. Narayanan. K, Shahbaz A. Siddiqui and Manoj Fozdar, ***"A Robust Islanding Detection Technique and Rank Based Load Shedding for Distribution System with single DG"***, Accepted for presentation in 19^{th} National Power Systems Conference-2016, IIT Bhubaneswar, India.

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