Distribution System Expansion Planning Considering Distributed Generation Integration

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CANDIDATE’S DECLARATION

I hereby certify that the work which is being presented in the Dissertation entitled **“Distribution System Expansion Planning Considering Distributed Generation Integration”,** in partial fulfillment of the requirements for the award of the **Degree of Master of Technology** and submitted in the **Department of Electrical Engineering**, Malaviya National Institute of Technology Jaipur, is an authentic record of my own work under the supervision of **Dr. Prerna Jain**, Assistant Professor, Department of Electrical Engineering, Malaviya National Institute of Technology Jaipur.

The matter presented in this dissertation embodies the results of own work and studies carried out by me and have not been submitted for the award of any other degree of this institute or any other institute.

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This is to certify that the above statement made by the candidate is correct to the best of my knowledge.

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ABSTRACT

Distribution System Expansion Planning (DSEP) answers the services to be mounted and/or reassembled so that the distribution system fulfils the predicted load requirement at the lower cost and satisfy all operational and technical constraints in the particular planning horizon while ensuring the consumer reliability and power quality standards. Distributed Generation (DG) is the newest options to deal with the DSEP. The operating characteristics of modern power system modify due to the integration of DGs, and have noteworthy economic and technical benefits such that DGs can reduce the complications in expansion planning of distribution system, reduction in losses, improve voltage profile, flattering of peak and increase reliability.

This dissertation work presents an algorithm for the Expansion planning of distribution system with incorporating DG in the existence of the price and load uncertainties. The main motive of the expansion planning is the minimization of the investment and operation cost of distribution network equipment which considers the installation/reinforcement cost of the substation, feeders, and Distribution Generation. In this paper, price and load uncertainties are taken into expansion planning which gives the robust and reliable expansion planning. These uncertainties are molded as Normal Probability Distribution Function. By using Monte Carlo Simulation, uncertainties are added into planning. A 9 bus and 72 bus (Kian-pars Ahvaz 11 KV a practical distribution network in Iran) distribution network are used for a case study of expansion planning. This multistage dynamic expansion planning problem is resolved by the Quantum Particle Swarm Optimization. The proposed algorithm is compared with the standard Particle Swarm Optimization and results shows the superiority of proposed algorithm over PSO.

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LIST OF ABBREVIATIONS

DSEP	Distribution System Expansion Planning
DG	Distributed Generation
PDF	Probability Distribution Function
MCS	Monte Carlo Simulation
PSO	Particle Swarm Optimization
QPSO	Quantum Particle Swarm Optimization

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

The electrical distribution system is a central portion of the extremely complex electrical power system. In total investment cost of the whole power system, distribution system investment cost has a major portion of total cost. Thus, an effective configuration and efficient operation of the distribution system is becoming a very challenging job. Electrical power distribution network is joining point between the electrical transmission system and electricity transfer to the customers. In the modern era, due to increasing load demand, a distribution company must have to fulfill the demand growth, for that these companies consider capital investment into installing of new equipment or reinforcement/upgradation of existing equipment in existing distribution network. The primary motive of any electric utility enterprise in the new competitive atmosphere of deregulated market is that it can provide the electricity to the consumers at lower cost, a good amount of reliability and reduce the cost of maintenance, construction, and operation of new facilities. To fulfill these objective planning for distribution network is an important concern in present power system scenario.

The primary objective of the Distribution System Expansion Planning (DSEP) is the minimization of the total cost of the operation, maintenance and investment for the installing the new facilities or reinforcement of the existing facilities i.e. substations, feeders and distributed generation (DG) at right amount of reliability, while satisfying the all technical and operational constraints. In DSEP problem, we find the optimal location, size and proper time to install new facilities or upgrade the existing facilities. To deal with the DSEP problem, two methodology can be adopted: (a) stage by stage approach in which these stages are executed one after another. In this methodology, the operation and investment cost of the facilities for each single stage are individually optimal but for the whole planning period is not optimum. (b) The multistage approach of planning, in which all stages are considered together, simultaneously. In this approach, all stages depend on one another so that investment and operation cost of a single stage cannot be optimum but the total cost for all planning period will be optimum.

Expansion planning of the distribution system is explained in two types:

- Static methodology that considers one planning perspective and decides the type, place and size of novel apparatus which should be extended or/and connected to the distribution network. In a simple way, All expansion planning necessities are decided in one scheduling time duration.
- Multistage methodology which describes the optimum position, type, and volume of investment/ upgradation, as well as the best suitable time period to perform this type of investment expenses, so that the growing load requirement is always adapted to the distribution network in an ideal manner. Multistage method states to enlargement of the power system in succeeding strategies over a number of phases, demonstrating the regular way of progress in enlargement

In the recent era, due to the scarcity of the fuel for power generation in power plants, the movement towards the development of the green and clean energy technologies is only an option, in which renewable resources of energy are more suitable for the distribution system companies. So we integrate the renewable and non-renewable DG as an alternative in distribution network expansion planning due to their inexhaustible and non-polluting characteristics. The main problem of long-term DSEP is due to its Sensitivity towards the system considerations like forecasted load, quality management, uncertainties of load, price, and DG, and economical constraints.

1.2 MOTIVATION

A distribution network may have several nodes which are related to the load points and other switching and protection equipment point. Continuously increasing load demand is the main problem to maintain and operate the distribution network with demand satisfaction, power quality standards and a right amount of reliability. Therefore, an economic design of the distribution system should be such that no network reconfiguration or extension is required for a couple of years. To deal with increasing demand, reinforcement or expansion of the distribution system is an extremely low -cost solution which leads towards distribution system expansion planning.

Distribution System Expansion Planning (DSEP**)** answers the services to be mounted and/or reassembled so that the distribution system fulfills the predicted load requirement at the lower cost and satisfy all operational and technical constraints in the particular planning horizon while ensuring the consumer reliability and power quality standards. The main tasks of distribution companies for DSEP is to fulfill electricity load increment at the lowermost cost and consumers' reliability desires with a level of satisfaction. The size, place and proper time of the reconfiguration and/or integration of power distribution system apparatus are determined by the DSEP problems.

Distributed Generation (DG) is the newest options to deal with the DSEP. The operating characteristics of modern power system modify due to the integration of DGs and have noteworthy economic and technical benefits such that DGs can reduce the complications in expansion planning of distribution system, reduction in losses, improve voltage profile, flattering of peak and increase reliability. Distributed generation technologies are generally flexible regarding size, operation, and expandability, besides, their use in a distribution network clues to elasticity in the charges of power and the effectiveness of power system.

In previous research papers, the DSEP problem is solved by many heuristic and mathematical optimization techniques which were solved with and without DG integration, with and without uncertainties of DGs, load, and price. In proposed paper this expansion problem is answered by the Quantum Particle Optimization (QPSO), which provides the better expansion solutions for the distribution system in comparison to other optimization techniques in terms of high convergence speed, less controlling parameters, and less complexity. QPSO has only one tuning parameter to converge to the solution to the global optimum, so QPSO is used in the present paper to provide an effective, economical and optimal expansion planning by considering price and load uncertainties with DG incorporation. In proposed problem, DG (renewable) uncertainties i.e. penetration level, solar radiation, wind speed, etc. Because if we consider DG uncertainties, then the problem becomes more complex and difficulties in obtaining optimal planning solutions.

In this paper, DG integrated DSEP by taking price and load uncertainties is described. The main motive of this planning is the minimization of the total cost of the investment and operation. This planning is conveyed in two phases. In the first phase, planning is conveyed without taking DG units. For that, we have considered the three levels of load profile as low, medium and high. In the second phase, proposed planning is conveyed in the existence of the DGs. In this planning price and load, uncertainties are molded as Normal Probability Distribution Function (PDF) to provide robust and flexible planning. Uncertainties are inserted into planning with the help of Monte Carlo Simulation (MCS). The proposed expansion planning optimization problem is solved by the QPSO. A 9 bus and 72 buses (Kian-pars Ahvaz 11 KV a practical distribution network in Iran) distribution network are used for a case study of expansion planning.

1.3 THESIS OUTLINES

Chapter 1: A brief introduction of Distribution System Expansion Planning problem and advantages of the DG integration in the distribution system to solve DSEP problem is discussed in this chapter, It summarizes motivation regarding this work and organization of the thesis.

Chapter 2: In this chapter, the literature review and objectives of the work (Distribution System Expansion Planning) is discussed in this chapter. is discussed.

Chapter 3: A brief description of DG Types, available DG technologies, impacts of DG integration in the distribution system to solve DSEP problem is evaluated in this chapter.

Chapter 4: A brief introduction of uncertainties in regulated and deregulated power system and Monte Carlo Simulation are described in this chapter.

Chapter 5: Problem formulation for DSEP is discussed in this chapter. Objective function along with operational and technical constraints for Substation, Feeders and DG are discussed. Problem formulation with price and load uncertainties consideration is also discussed in this chapter.

Chapter 6: Methodology is proposed for DSEP and DG placement using PSO and QPSO in the distribution system is discussed in this chapter.

Chapter 7: Simulation results obtained from programming in MATLAB for the proposed method are presented in this chapter. Results of expansion planning for 9 bus, and 72 bus (Kian-pars Ahvaz 11 KV a practical distribution network) with and without DG integration, with and without uncertainties consideration are discussed. The obtained results from QPSO are also compared with the conventional PSO results to show the superiority of QPSO over PSO in this chapter.

Chapter 8: Conclusions and future scope are discussed.

CHAPTER 2
LITERATURE SURVEY

2.1 Literature Review

A literature review of research problems and models of the distribution network is presented in [2]. For finding out the DG equivalence to a distribution facility, a reliability model is presented in [3] for planning in a competitive environment. In [4] ant colony system (ACS) algorithm is tied with conventional distribution network load flow algorithm to resolve the planning problems. A literature survey of DGs types, technologies, and their application are reported in [5], and dynamic programming genetic algorithm is used to solve the expansion problem in [6].

Multistage expansion planning by integrating DGs is solved with the help of a genetic algorithm and optimum power flow method in [7]. The investment and operating cost of the feeders, substation, and DGs are consider in [7,9,11,12,14], which have the main objective of total cost minimization. In [8] unit commitment (UC) and multistage expansion planning for distribution network using Artificial Bee Colony (ABC) is reported. A multi-objective framework for distribution system expansion planning using Hybrid PSO and Shuffled Frog leaping (SFL) is explained in [9]. Dynamic behavior of the system with the help of Imperialist competitive algorithm for multistage expansion planning is explained in [10].

OPF using fuzzy satisfying method & global based harmony search algorithm (HSA) are described in [9, 11, 12, 14]. By implementing DGs in DSEP in the existence of price of and load uncertainties is presented [12]. Considering uncertainties, islanding condition, & all alternatives in distribution system planning are presented in [13] using GA. In [14], integrated dynamic DSEP along with renewable & non-renewable DGs is presented. A dynamic mathematical model for long term DSEP is presented in [15] which gives the optimal value of all distribution network designs parameters.

Integration of DGs of peak cutting in expansion planning is described in [16] which focus on the minimization of total cost of investment and operation. Significance and comparison of quantum PSO and conventional PSO are described in [17,18]. In [19] a mathematical model is described for expansion planning which contains distributed power using QPSO. A new method to determine optimal values of switched and fixed capacitors in distribution network based on real-coded genetic algorithm (RCGA) is explained in [20].

In [21], a better description of quantum PSO and its improved version with memory and single-step searching strategy for continuous optimization problems is given which shows it's superiority on PSO. A dynamic multi-objective model with incorporating DGs is described in [22] which optimizes the cost and fulfillment of technical constraints. The optimal sizing and placement schemes for DG installation are given in [22, 23] and binary decision variables are used to give optimal planning decisions in the optimization technique. In [24] a dynamic expansion planning methodology for an active distribution network in the presence of demand and DG's uncertainties is described by using GA. A new DSEP methodology with incorporating renewable DGs solar photovoltaic, wind, biomass and their uncertainties with intermittent and schedulable power production patterns is described in [25].

By considering DGs and storage units with the help of modified PSO algorithm is explained in [26] for DSEP. Feeder reconfiguration for a distribution system with incorporating different models of renewable DGs solar photovoltaic panels, wind turbines, fuel cells, etc. is proposed in [27] and solved by decimal coded QPSO. A new reactive power optimization model is explained in [28] with incorporating DG penetration with the help of QPSO and differential evolution QPSO. A new dynamic methodology for DSEP with DG integration and Total capital cost of network planning minimization is given in [29]. A long term practical eco-environmental DSEP model with fuel cell and non-renewable DG is presented in [30].

In [31] a new model for electric distribution system expansion with incorporating DG Micro Gas turbines by using Dynamic Ant Colony Search Algorithm (DACSA). In [32] a dynamic prototypical of DG in the smart grid environment is proposed, which is based on traditional DG capacity cost, environmental costs of compensation, maintenance and operation costs of DG, purchased electricity cost, and system losses cost. The proposed model in [32] can replicate the environment-friendly structures of DG, including load growth, the expansion planning problem is separated into different stages which can be resolved with the help of dynamic programming method. In [33] a probabilistic technique is presented to estimate the influence of wind turbines (WTs) integration into distribution network with help of combined Monte Carlo simulation (MCS) method and optimal power flow (OPF) based on market to make the most of the social welfare scheme seeing different combinations of wind power generation and load demand of a year and with integrating demand side management (DSM) is presented in [34]. An overview of the models and methodology used in the modern DSEP problem, investigating and categorizing present and future research developments in this field is described in [35].

A new optimization algorithm, written in C-language for application of DG to radial distribution feeder, with greatly overloaded with non-uniformly distributed load considering low power factor for single DG and the multi-DG system is explained in [36]. A new model for optimal sizing and placement of DG considering time sequence characteristics of DG and load is presented in [37] with an objective of minimization of investment and operation cost of DG and electricity purchased from the grid with in voltage limit using Non-dominated Sorting Genetic Algorithm. A time-based model for DSEP considering DG with minimization of investment and operation cost with the help of Modified Integer-coded Harmony Search (MIHS) to obtain the ideal network expansion planning and Enhanced Gravitational Search Algorithm (EGSA) to enhance the operational costs is explained in [38]. A single DG placement algorithm is proposed in [39] for identification of optimal DG locations and evaluation of the voltage profile using the Newton-Raphson method. Present paper discourses the problem of DG penetration with a Monte Carlo Simulation technique is addressed in [40] which consider the intrinsic variability of electric power consumption and a comparison is given between the outcomes of the deterministic load flow and probabilistic load flow studies.

In [41] a hybrid module is described for optimal size and location of the substation considering new constructed substation and capacity extension and load assignment by using Geographic Information System for data collection. This problem is solved by improved QPSO depend on the reliability and economic constraints with three layer model. A modified PSO algorithm is offered in [42] for DSEP problem and some techniques are also proposed for DG and storage units operation for optimal planning. Operating and Reserve MV lines, HV/MV substations, DG and storage units are considered as solution for multistage dynamic DSEP. In [43] a new adaptive particle swarm optimization (APSO) algorithm is offered and applied to voltage control and reactive power in power systems.

A new multi-objective Tabu search (NMTS) algorithm is proposed [44] for optimal DSEP using a multi-objective fuzzy model which have three objective functions as level of fuzzy reliability, maximization of robustness and fuzzy economic cost including optimal location and size of reserve feeders to maintain a right amount of reliability at lower cost. A dynamic expansion planning of distribution network with DG integration considering the Solar and wind DG uncertainties due to intermittent nature is given in [45]. The objective of this is to the maximization of the returns of the distribution network using the benefit-cost analysis with punishment and promising functions and to find the optimal planning strategy for DG units a Covariance Matrix Adaptation Evolutionary approach and Monte-Carlo simulation for uncertainties consideration is implemented.

A new method is proposed in [46] for Integrated Generation and Primary–Secondary Distribution System Expansion Planning (IGDSEP) considering retail and wholesale market and objective of IGDSEP is the minimization of operational and investment cost with a right amount of reliability. IGDSEP is solved by a scenario driven Mixed Integer Non-Linear Programming. In [47] DSEP is solved by the creation of construction plan and network reconfiguration including load demand growth of large consumers in which proposed methodology at first attempts to reconstruct the objective system by varying switch status for minimization of loss and evaluating the security of the objective network by contingency analysis**.** A new module for multistage smart distribution network expansion planning (MSDNEP) is presented with the integration of fault passage indicator (FPI) and vehicle to grid (V2G) in a multi-objective agenda and Distribution system should be extended to fulfill the load growth in an optimal way.

Objectives of DSEP are the minimization of total cost throughout the planning perspective and maximization of reliability index and solved by a non-dominated sorting genetic algorithm (NSGA-II). A mixed-integer quadratically-constrained programming (MIQCP) module is presented in [49] to solve the DSEP problem which considers the erection/reinforcement of substations, circuits and optimal location of fixed capacitors banks and the radial topology adjustment. A new module to solve the DSEP problem is addressed in [50] with an objective of minimization of the total value of installation/upgradation of the substation, feeders, maintenance and operation cost and network losses and this nonlinear is solved by using standard mathematical programming.

2.2 Objectives of Thesis

The main motive of the expansion planning is the minimization of the investment and operation cost of distribution network equipment which considers the installation/reinforcement cost of the substation, feeders, and Distribution Generation. Distribution System Expansion Planning (DSEP) answers the services to be mounted and/or reassembled therefore the distribution network fulfills the predicted load requirement at the lower cost and satisfy all operational and technical constraints in the particular planning horizon while ensuring the consumer reliability and power quality standards. The objective of the present work are:

- Growing the capability of the existing substations or mounting the new substation to meet the load demand.
- Expanding the capacity of the existing feeders up to their power transfer capacity.
- Representing the capacity and optimal place of the new feeders that should be mounted to meet the load demand.
- Indicating the capacity (size) and the optimal location of DGs that should be mounted on buses at the period of increasing load demand.
- Representing the optimal connection (installation) period of the new apparatuses i.e., Substations, feeders, DG with regard to the planning period.
- Consider the price and load uncertainty for robust planning and use Monte Carlo Simulation technique to insert them in planning problem.
- To investigate the performance of proposed algorithm on 9 bus and 72 buses (Kian-pars Ahvaz 11 KV a practical distribution network in Iran) distribution systems.

CHAPTER 3

DISTRIBUTED GENERATION

Distributed generation (DG) is an electrical source of power, which directly linked to the customer side of the meter or the distribution system to supply power to a small area i.e., apartment, factory offices, etc. we can say in a simple way as small-scale power generation system. The explanation of DG is given in a different way according to their input by different organization according to their utilization of DG in a different field. In general form, DG can be any type of static inverter or electrical generator generating alternating current which (i) has the proficiency of parallel operation integrated with the distribution network, or (ii) is considered to work independently from distribution network and can meet a load demand which may also be served by the utility owned electrical distribution network. A DG is occasionally denoted in simple words as “generator”.

DG term originates from the idea of power generation at the power consumption point linked in the distribution system. International Energy Agency (IEA) explains DG as a small generating plant, granting sustenance to a distribution system or feeding a customer on-site, coupled to the grid network at the voltage level of the distribution system. CIGRE describes DG as the power generation which is neither dispatched nor centrally scheduled generally coupled to the distribution system and is lesser than 100 MW.

The term DG is occasionally used as replaceable with the word Distributed Resources (DR), but DR is projected to incorporate non-producing technologies like that energy storage devices i.e. flywheels and batteries in accumulation to generators, although DG is restricted to minor scale (a lesser amount of 20 MW) electrical generation situated near to the load point. Unlike principal electrical power plant generation, DG frequently employs the unused heat from the generation procedure as supplementary usage of power for space or process warming, or for refrigerating over and done with absorption cooling.

DG can arise from non- renewable or renewable energy sources, via both conventional and modern machinery. DG technologies comprise small gas turbines, internal combustion engines, wind turbines, micro-turbines, fuel cells, small combined cycle gas turbines, solar panel and the photovoltaic cell, small geothermal and biomass energy generating plants. According to the source of generation of active power or reactive power or both, DGs can be characterized in following types:

- Type I DG: which can deliver only active power
- Type II DG: which can deliver only reactive power
- Type III DG: which can deliver both powers (active and reactive)
- Type IV DG: which can deliver active power but absorbs reactive power

Fuel Cells and Photovoltaic are the noble instances of type I DG. Synchronous Compensator, capacitors, KVAr compensators, etc. come under the type II DG. Instances of III type DG is synchronous machines. As type IV DG, induction generators are mostly used.

The organization of current conventional power system is revealed in fig 1. The distribution system is disturbed due to the existence of the local generation (DG) in a distribution network. For example, DG will change the power drift direction in the distribution network, and now it cannot be reflected in a network with unidirectional power flow.

DG can effect distribution system in many probable means, e.g. voltage profile improvement or system loss reduction but also some difficulties may arise due to their integration in system i.e. instance voltage increase problems, rise in levels of network fault and protection problems. In the weak system the size of associated generator is generally restricted by a rise in voltage impacts. In the modern era, DG is generally reflected as the negative load in distribution network configuration and expansion problem, the quantity of DG is restricted on the basis of dangerous conditions of maximum load/minimum generation limit and minimum load/maximum generation limit. It is supposed that DG cannot contribute to the regulation of distribution system in any way.

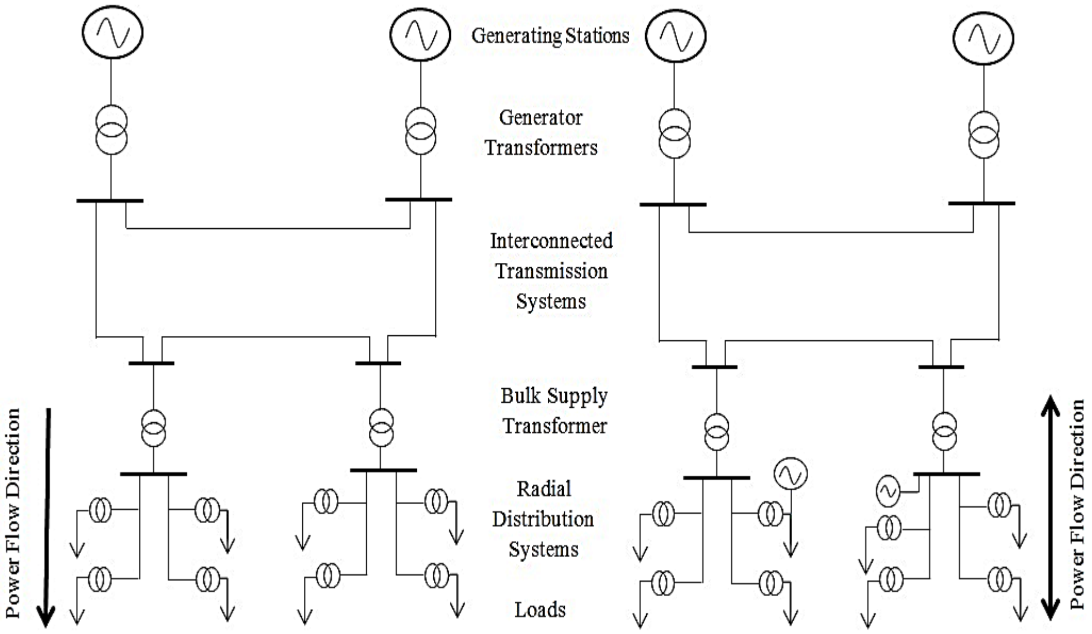

Fig. 4.1 Conventional power system in left and DG integrated electric power system in right

3.1 DG Types:

There are many types of DG technologies existing. DGs can be classified on the basis of several primary energy sources. DG may be classified according to either renewable or fossil fuels.

- DG technologies which need a supplied fuel:
  1. Micro-turbines:
  2. Fuel Cells
  3. Sterling Engines
  4. Internal Combustion Reciprocating Engines
- DG technologies which do not need a Supplied Fuel
  1. Solar or Photovoltaic
  2. Wind

A. Reciprocating Internal Combustion Engines:

Reciprocating internal combustion engines (ICEs) transform heat from incineration of fuel into rotating motion which, in results, energies a generator. These are considerably the most frequent power production apparatus under 1 MW capacity. There are two kinds of combustion engines which are: (i) Gas-driven combustion engines are mostly worked with natural gas, while landfill gas or biogas may be used.

(ii) Diesel engines use diesel as fuel, but these can also be worked on extra petroleum fuels i.e. biodiesel or heavy fuel oil.

B. Gas Turbines

A combustor, compressor and turbine-generator association are the main parts of Gas turbines, which transforms the revolving energy input into electrical power output. There are many types of different size gas turbines broadly used in the electrical energy generation. In combined heat and power (CHP) application, minor industrial gas turbines are normally used with a capacity of 1-20MW. Air is mixed into mix fossil fuel in Gas turbines, such as IC engines to produce thermal energy. High-pressure air, high- temperature is the heat transmission environment & air is permitted to amplify in the turbine. Thus the heat energy is transformed into mechanical energy which rotates a shaft. This shaft is linked with a reduction gears series which rotate a synchronous generator directly coupled to the electrical power house.

C. Micro-turbines

Micro-turbines spread the gas-turbine machinery to a minor level. Micro-turbines are 25- 500 kW power output minor combustion turbines. The widely held commercial equipment usage natural gas as the primary fuel. A range of fuels, containing gasoline, kerosene, diesel, natural gas, alcohol, digester gas, methane, propane, and naphtha can be burned into Micro-turbines. A permanent magnet generator (PMG) with a high-speed is generally used in the generator and develops high-frequency power. Therefore, we cannot directly connect a generator to the grid. To rectify the high-frequency AC to the DC and then transform the DC to AC, the interface is used which is attuned with the concerning power system.

D. Fuel Cells

This cell is a device which uses the electro-chemical reaction to produce electricity. Hydrogen and oxygen are merged to produce water, to generate electricity. Several different forms of fuel cells are presently available containing a solid oxide, molten carbonate, proton exchange membrane and phosphoric acid. Fuel cells generate electric power with negligible harmful emissions at high efficiencies, up to 40 to 60%, and operate so silently that Fuel cell has efficient use in residential regions. Fuel cells harvest DC power, which needs a power electronic interface to transform DC to AC, which is attuned with the power system.

D. Photovoltaic Systems

These system also entitled as photovoltaic electric power system, solar array, solar PV system or PV system. It includes the direct transformation of heat energy of sunlight into power without any contribution of the heat engine. Photovoltaic systems have mainly usage in small scale applications like for remote buildings, water pumping, calculators and watches, communications, for megawatt-scale power plants as well as satellites and space vehicles as the power source. PV modules contain numerous PV cells, which are semiconductor devices able to transform instance solar heat energy into DC power. PV cell panels also require a power electronic interface to transform DC to AC, which is attuned with the power system.

E. Wind Systems

Wind turbines transform the kinetic or mechanical energy of the wind into electrical energy (power). There are three basic kinds of wind turbine machinery, presently used for communicating with power systems: doubly-fed induction generator (DFIG), standard induction machine, and a synchronous generator with a permanent magnet.

F. Hydro-generation

Hydro-generation or Hydro-power systems usage the fluid water energy to generate electrical or mechanical energy. In hydro-generation mechanical energy is transformed into electrical energy and directly coupled to the grid for power generation without any other interfaces.

3.2 DG Applications

There are a lot of causes for a consumer to select a DG to install in the power system to meet the load demand. DGs may be used to produce a consumer’s complete electricity load demand, for peak cutting (producing a percentage of a consumer’s electricity requirement onsite to decrease the volume of electricity bought at higher rate in peak load condition); for reserve power source or emergency electricity producer as a backup power supply); for enlarged reliability; as a green power source (by means of renewable

DG). In some faraway places, DG can be a less costly because it removes the necessity for the costly building of distribution system and transmission feeders.

Different types of DG technologies are employed to achieve the necessities of a large number of applications. These applications modify conferring to the electricity load requests. As a consequence, these depend on the kinds of DGs used. Following DG applications are discussed below:

1) **Stand-alone system:** Generally, isolated remote regions considers the DGs as a power supplier in place of linking to the grid supply. These remote regions have many geographical complications, which creates it too costly to be coupled with the grid.
2) **Backup power source**: DGs are also used as a backup power source to meet the requisite power requirement for necessary load demand, like during grid failure, process industries, and hospitals.
3) **Peak load cutting:** The electricity cost changes according to the corresponding existing generation and the load demand curves at that same time. Therefore, DGs are also used to meet some amount of load demand at peak times, decrease the volume of electricity bought at a higher rate in peak load condition, which decrease the electricity price for large industrial consumers who have to pay time-of-use tariffs (TOU).
4) **Provide combined heat and power (CHP):** DG delivering CHP as a cogeneration have a great total energy consumption efficiency. The generated heat energy, from the transforming fuel into electrical energy procedure, is used for a broad range of applications in hospitals, large commercial zones, and manufacturing factories.
5) **Remote and rural areas Applications:** DG can deliver the standby power to remote applications to meet the load demand. These applications contain heating, lighting, communication, cooling and manufacturing procedures. DG can regulate and support the voltage in rural and remote applications (delicate loads) associated with the grid.
6) **Base load:** DGs preserved by the utility are generally used as a base load supplier to deliver some portion of the main load demand and provide sustenance to the grid by refining the voltage outline, decreasing the energy losses and enhancing the power quality level.

3.3 Advantages of DG Systems

DG application in the distribution network has many advantages. Some DGs advantages are discussed following:

3.3.1 Economical advantages:

- DG can offer the necessary load growths by mounting them in optimal sites so that they can decrease or escape the necessity for constructing new transmission and distribution feeders, expand the present power systems configuration and decrease transmission and distribution system capacity throughout the planning period.
- DG are not limited by the concentration of the power because they can be located anyplace. So, DGs position elasticity has an excessive influence on electricity rates. Renewable DG like wind, hydro, and solar units need definite geographical circumstances.
- DG can be accumulated easily anyplace as segments (MT-batteries and FC-MT) that have numerous benefits as:
  a) DGs can be mounted in a very short time at anyplace. Each module can be worked instantly and independently after its connection.
  b) The entire capacity of DGs can be enlarged or reduced by addition or elimination of more units, individually.
- DG have desired small sized to be installed to meet increments in required consumer load demand.
- DGs can decrease the comprehensive electricity rate by delivering electricity to the grid; that traces to decrease the load demand needed.
- Stand-alone CHP or remote DG can be more inexpensive. CHP DG usage their unused heat energy for cooling, warming or refining their proficiency by producing extra power that is not appropriate in the condition of only centralized power generation.
- DGs increase the transformers and system equipment lifetime and offer fuel reserves.
- Installing DGs decrease the manufacture agendas of mounting generating stations. Therefore, the system can trace and monitor the market's price variations and/or increment in the load demand in peak time.

3.3.2 Operational advantages:

- DGs can decrease the distribution system energy losses, load demand by providing some part of the load demand and decrease power run through the transmission system to satisfy the definite constraints and improve the voltage profile of the system.
- DGs provide support in load management courses and peak load cutting.
- DGs can help in improvement of system reliability and continuity.
- DGs may be used as on-site backup power source to supply power in system outages and crisis conditions.
- DGs preserve power system stability and meet the spinning reserve requirement.
- DG have the many capacity sizes so that DG can easily mount on low and/or medium voltage distribution system which provide elasticity for sizing of DG units integrated into the distribution system.
- DG offer transmission capacity relief.
- Renewable DG removes or decrease the output procedure radiation which is beneficial for environment and society.
- DGs has a lesser capital investment cost due to the small sizes of the DGs (by the way, the installation cost per kVA of a DG is ample greater than that of a large generating station).
- DG can decrease the requirement for large groundwork erection or advancements because that the DG can be fabricated at the load point.
- DG may decrease pressure on distribution and transmission feeders If the DG supply power for local use.
- Some DG technologies like solar, the wind, produces zero or near-zero pollutant radiations over working period.
- Some DG technologies like solar, wind, DG is a usage of renewable energy.
- DG can improve power system reliability and work as a stand-by or back-up power source to consumers.
- DG provides a choice for consumers in meeting their load demand.

3.4 Challenges with DG integration

- No uniform national interconnection standards are available talking about safety.
- The present procedure for interconnection of DG into grid is not identical among provinces.
- DG interconnection with power system may include communication with numerous different societies.
- Some DG projects become uneconomical because of the environmental guidelines and certification process established for bigger DG projects.
- Contractual obstructions exist like obligation insurance necessities, charges, and fees.

CHAPTER 4

POWER SYSTEM UNCERTAINTIES AND MONTE CARLO SIMULATION

4.1 POWER SYSTEM UNCERTAINTIES

Uncertainty is a word which is used in slightly different means in many fields, containing information science and physics statistics economics engineering. It relates to estimation of future occasions, to physical amounts that are previously done, or to be the unknown. Uncertainty occurs in moderately noticeable in different environments.

Uncertainty and risk are terms which are commonly addressed in the power system literature review. These terms do not have any fixed definitions to explain. Thus, some consider that these both are the same, some consider that one is the outcome of another term and some believe that these are quite independent terms. Although, we consider that these uncertainties may result into risk. For example, as expansion planning of Generator, substation and distribution network is done on the basis of forecasted load and any uncertainties in estimated load get results into risk because of that the system scheduled may be not able to achieve its occupations accurately (i.e. to meet load demand). Modeling of the uncertainties in planning is one of the most difficult tasks because there are several kinds of these uncertainties like that controllable or uncontrollable, technical or economic; measurable or unmeasurable and stochastic or non-stochastic. Whatever the type of uncertainties is, these may be molded by some methodologies based on circumstances. Although, these uncertainties interrupt all long-term and short-term planning decisions. However, these uncertainties are differentiated concerning the deregulated and the regulated power system environments in below sections [1].

a) **Uncertainty Measurement**: A group of possible conditions or results where probabilities are allotted to every possible state or result, and this also consist of the application of a probability density function (PDF) to a continuous variable.

b) **Risk Measurement**: A group of determined uncertainties where some probable results are losses, and their magnitudes and this also consist of loss functions consisting continuous variables.

For understand uncertainties, an example to calculate the area of a rectangle with and without uncertainties which has one lateral as a length of 2.5 ± 0.3 m and the another lateral as width of 2.4 ± 0.2 m,

Now, the area of a rectangle without uncertainties would be:

Area = Length * Width = 2.5 * 2.4 = 6.0 m^2

Area in the presence of Uncertainties

The minimum area would be with the "minimum" dimensions

Length = 2.5-0.3=2.2 m

Width =2.4-0.2= 2.2 m

Now "minimum' area is A_{min} = 2.2*2.2 = 4.84 m^2

Like that for the maximum area, Length = 2.5 + 0.3 = 2.8 and Width = 2.4 + 0.2 = 2.6

So the Maximum area is A_{max} = 2.8 * 2.6 = 7.28 m^2

We can say that uncertainty in Area is ¥ = ± (0.3)*(0.2) = ±0.6 the area is A = 6.0 ± 0.6 m^2

4.1.1 Uncertainties in a Regulated Power System

Power system planning is done on the basis of load forecasting (LF) and consists of expansion planning of Generator, substation, reactive power and distribution network; each has its own input parameters. Due to the dependency of input parameters on each other, the research is conceded for many years in the future time. As an outcome, input parameters in the power system expansion planning sections may face some uncertainties that clearly disturb our judgments. The distinct individual selects, on which place and in which way assign transmission and/or generation services. The installation and the operating prices and a proper level of revenue to the holders are rewarded by planned charges enforced on the consumers.

Few of these input constraints are following:

- Economic input parameters such as depreciation, interest rates and inflation rate.
- Economic growth

- Fuel cost (directly depend on Generation expansion planning and indirectly depend on expansion planning of substation and distribution network and RPP because of its influence on the price of system losses).
- Investment costs
- Electricity price
- Maintenance and Operation costs.
- Social factors (like population growth rate)
- Resource (like fuel and water) availability.

It is observable that the uncertainties convoluted in overhead or related parameters are event dependent for every electrical power industry.

4.1.2 Uncertainties in a De-regulated Power System

Power system de-regulating has caused in looking novel self-regulating bodies like that GenCos, TransCos, DisCos, etc., each targeting at achieving, the extreme return (revenues minus costs) from its possessions. A network operator attempts to manage the market players' activities in such a manner that the system is worked efficiently and reliably. Each body now should take its individual judgments. Apparently it should, anyhow, consider the other players' behaviors into consideration. The electricity rate is calculated on the basis of supply–demand law in the new situation. Right now it does not give any guarantee of recoveries of investment costs. On another side, the de-regulating is still working on in in many countries across the world. New guidelines and lawful acts are constantly performing. Furthermore, any international or even national economic judgment and/or crunch impacts directly or indirectly on the electric power industry. The single-player market environment has now exchanged by a multi-player market environment, with its uncertainties and risks considered.

4.1.3 Advantages of uncertainties consideration in power system planning

- Reduced the risk and error in planning problem.
- Give more accuracy measurements for planning.
- Provide robust power planning.

- Provide more reliability for short and long term planning of power system.

4.2 MONTE CARLO SIMULATION (MCS)

Monte Carlo simulation (MCS) is a kind of simulation technique that be dependent on Recurrent (repeated) unplanned statistical and sampling investigation to calculate the outcomes. This simulation technique is much thoroughly linked to random experimentations, which specific results are unknown in advance or we can say that the outcomes of that experiment are not to be calculated by hand. In this perspective, a logical way of finding solutions termed as *what-if* analysis is also called Monte Carlo simulation. We will focus on this opinion throughout this chapter, that MCS is one of the simplest methods to solve uncertainty related problems in any field of the science and other fields.

We use many mathematical representations in social sciences, natural sciences, and engineering field to define the relations in a system with the help of a mathematical terminologies. These mathematical representations usually be subject to a large number of input variables, which are treated with the help of these mathematical formulations, in the model, give outcomes in one or more outputs. An efficient model should have to take the risks related with numerous input parameters. Experimenters invent many forms of a model in most of the cases, which can also consider the base case, worst probable consequence, and the best probable consequence for the input parameters.

MCS provide a platform for an experimenter to examine logically the whole range of risk parameters linked with each and every *risky* input. In MCS, we distinguish a numerical distribution using that we can take as the source for every input variable. Then, we fetch random trials from the every distribution, after it which signify the data of the input parameters. We obtain a group (set) of output parameters, for every set of input variables, When we run the simulation, each obtained value is the individually an output result scenario and collect these output data after a number of the simulation run.

In the end, we execute statistical analysis on the obtained output data values, to make decisions about the task for which it has done. We can also usage the sampling information of the obtained output data to illustrate the output distinction.

4.2.1 Terminology used in MCS

- **Statistical distributions:** Probability distributions or Statistical distributions defines the results of changing a random parameter, and give the possibility of happening of those results. Probability distributions are known as discrete probability distributions if the random variable considers only discrete data values. For examples of this statistical distribution are the hypergeometric distribution, binomial distribution, and Poisson distribution. When the random parameters consider the continuous data, the equivalent probability distributions is known as continuous probability distributions, i.e. normal, gamma and exponential distributions.
- **Random sampling:** A determinate subset of particular variables from a populace is known as a sample in statistics. The samples (trial) are fetched randomly from the population in random sampling, which indicates that each particle or data of population has the same chance of being involved in the drawn sample from the population.
- **Random number generator (RNG):** It is a physical or computational device which is made to produce an order of numbers that seem to be autonomous fetch from a population, and which also transfer sequences of statistical trials. These are also known as Pseudo-random number generators. RNG’s produce random numbers from 0 to 1 that is also entitled as uniform RNG’s.

4.2.2 METHODOLOGY USED IN MCS

The below described steps are generally accomplished for the MCS of a physical progression.

- **Static Model Generation:** Every MCS ended with emerging a deterministic model, which look like as the real situation, we usage the best near around value (base case) of the input variables in the deterministic model. After it, we put on mathematical interactions which take considering the data of the input parameters and convert these data into the wanted output.

- **Input Distribution Identification:** When the deterministic model fulfills our requirement then we insert the risk factors to the model. As described earlier, the risks initiate from the stochastic behavior of the input parameters, we attempt to detect the essential distributions, if any of them, rule the input parameters. This stage requires previous historic data for the input parameters. There are an ordinary statistical techniques to detect input distributions.
- **Random Variable Generation:** After identifying the essential distributions for the input parameters, we produce a group of random numbers (variates or random samples) from the distributions. One group or set of random samples, containing one data value for every input parameters, will be considered in the deterministic model to give one set or group of output data values. After it, this process is repeated by producing further more random samples, each one for every input distribution, and gather dissimilar sets of probable outcomes. This is the main part of MCS.
- **Decision Making and Analysis:** After collecting a sample set of output data values from the simulation, we execute those values in statistical analysis. This step delivers us the solutions for the decisions with statistical confidence, which we can make this decision after executing the simulation.

CHAPTER 5

PROBLEM FORMULATION

DSEP problem is an optimization procedure in which the optimal location and class (voltage level, conductor type, the number of conductors) of new components with their required optimal times for installation are indicated. Usually in a simple way, in DSEP the problem is to decide the conduction paths between both new and existing substations and their physical characteristics, i.e., voltage level, conductor type, the number of conductors, etc. We have to solve DSEP problem so that

- The investment cost of network equipment should be minimized.
- The operational cost of network equipment should be minimized.
- Several constraints (limitations) should be satisfied during normal and contingency conditions.

We can explain in the simplest way that the investment cost includes the cost of connecting new network elements like a substation, feeders, and DG. Furthermore, the operational cost comprises the cost of power losses and cost of the electricity bought from the grid during the planning horizon. The constraints of the DSEP are the power transfer capability limit of a component that should not be violated. The contingency in system is an outage arising on a single component like that a transformer, a line, a power generation source or some other components.

The distribution system expansion planning problem with a long-term planning perspective has been sculpted explaining the subsequent issues into description:

- The distribution system is consists of nodes on that nodes, sources and loads are connected, and branches making contacts between these nodes, demonstrating the lines;

- The expansion planning period is separated into phases of known time interval, along with the variables in the proposed problem being linked with each phase.
- Two continuous variables are related with every node: among them one is the complete worth of nodal voltage, and the other variable is the injection of current; one continuous variable, current flow, is linked with every system branch;
- In every phase of the planning period, nodes are adjusted by growing the capacity of existing substation and mounting new substations; branches are also reformed by conductors substituting.
- Possible alternative solutions to the system branches and nodes contain a group of investment substitutes which are used to solve the DSEP problem.
- Every alternative investment solution during the phases is related to the execution of solutions, the planning alternatives have binary variables, which have one if the proposed alternative is selected, otherwise, zero if the alternative is not selected in expansion planning.
- Every kind of alternatives have investment costs linked with exchanging one branch in the network by another branch, with the addition of a new branch conductor, and by expanding the capability of substation and mounting a new alternative substation at near to the load node.
- Available network branches are alternatives for DSEP problem, The planning alternatives have binary variables, which have one if the proposed alternative is selected, otherwise zero if the alternative is not selected in expansion planning at that stage.
- All associated network branches have their operational and maintenance costs.
- DG is the best alternative option to solve the DSEP problem in an efficient way.
- In every phase, nodal voltages, current injections, current flows fulfill Kirchhoff's rules requirement.
- In DSEP load is characterized by the known magnitude of current injections for every phase.
- Limitation of substation capacities, conductor capacities, and available DG power output are considered in every phase.
- In distribution network voltage drops are determined as the multiplication of branch impedance and branch current;

- The objective function of DSEP is the minimization of the net current value of operational and investment costs.

The primary objective of the Distribution System Expansion Planning (DSEP) is the minimization of the total cost of the operation, maintenance and investment for the installing the new facilities or reinforcement of the existing facilities i.e. substations, feeders and distributed generation (DG) at right amount of reliability, while satisfying the all technical and operational constraints. In DSEP problem, we find the optimal location, size and proper time to install new facilities or upgrade the existing facilities. To deal with the DSEP problem, two methodology can be implemented: (a) stage by stage approach in which these stages are executed one after another. In this methodology, the operation and investment cost of the facilities for each single stage are individually optimal but for the whole planning period is not optimum. (b) Multistage approach of planning, in which all stages are considered together, simultaneously. In this approach, all stages depend on one another so that investment and operation cost of a single stage cannot be optimal but the total cost for all planning period will be optimum.

Expansion planning of the distribution system is explained in two types:

- **Static methodology** that considers one planning perspective and decides the type, place and size of novel apparatus which should be extended or/and connected to the distribution network. In a simple way, all expansion planning necessities are decided in one scheduling time duration.
- **Multistage methodology** which describes the optimum position, type and volume of investment/ upgradation, as well as the best suitable time period to perform this type of investment expenses, so that the growing load requirement is always adapted to the distribution network in an ideal manner. Multistage method states to enlargement of the power system in succeeding strategies over a number of phases, demonstrating the regular way of progress in enlargement.

5.1 Problem Formulation

Distribution network planning and design are facing prime changes in prototype due to the deregulation of the power system environment with quick penetration of DG units. Distribution network planning and design are key topographies for finding out the most optimal expansion planning approaches to offer economic and reliable services to the consumer. In traditional expansion planning, the load demand increment is normally fed by the addition of a novel substation or expanding the capacity of the current substation as well as feeders. In the modern era, quick improvements in DG technologies and their several profits have made DGs an attractive alternative for the distribution system companies, power system operators and planners, energy policy regulators and makers, as well as developers.

5.1.1 Objective Function

The core motive of the distribution system expansion planning in this research paper is the minimization of the whole cost of investment and operation. The proposed objective function of the DSEP targets to minimizing the net capital value of the investment and operating cost of the substation, feeders, DG and electricity purchased from the grid. This expansion planning problem is nonlinear, constrained and mix integer optimization programming which can be described in objective function as follows:

$$Min\ TC = C_{inv} + C_{opr} \tag{5.1}$$

where TC is the total cost which is the summation of the C_{inv} and C_{opr}. Term C_{inv} denotes the yearly investment cost of the new components should be installed /expanded and it is described as:

$$C_{inv} = \lambda\Big(\sum_{l\in s} IC_l^{ss} + \sum_{m\in F} IC_m^{FD} + \sum_{n\in G} IC_n^{DG} \times S_{n-cap}^{DG}\Big) \tag{5.2}$$

where 'λ' is the capital recovery factor which convert all cost in to per year, IC_l^{ss} shows the fixed cost of the l_{th} substation in "$", IC_m^{FD} represents the installation cost of the m_{th} feeder in "$", IC_n^{DG} represents the installation cost of the n_{th} in "$/MVA", S_{n-cap}^{DG} demonstrates the total capacity of the n_{th} in "MVA".

'λ' is described as follows:

$$\lambda = \frac{\alpha(1+\alpha)^k}{(1+\alpha)^k - 1} \tag{5.3}$$

where 'α'is interest rate and "k" is the lifetime of the projects in year. Another term in total cost represents the operating cost of distribution network which mainly varies the power that bought from the system and the power produced by DGs. It is defined as:

$$C_{opr} = \sum_{t \in T} T_t (\sum_{n \in G} OC_n^{DG} \times P_{n-t}^{DG} + \sum_{l \in S} EC_{l-t}^{SS} \times P_{l-t}^{SS}) \tag{5.4}$$

where T_t represents the time period of the load level in hours, OC_n^{DG} shows the operating cost of n_{th} DG in "\$/MWh", P_{n-t}^{DG} is the power generated by the n_{th} in "MW" during load level 't', EC_{l-t}^{SS} represents the electricity market price at l_{th} substation at load level 't' in "\$/MWH", P_{l-t}^{SS} shows the real transmitted from l_{th} substation during load level 't' in "MW".

5.1.2 Constraints

The proposed expansion planning is subjected to following constraints:

a) **Voltage limit constraint:**

The voltages on the buses in the distribution network should be in the standard limits. It should not be violated in any condition, and the deviation in voltage is not more than ±5%.

$$V_{min} \leq V \leq V_{max}$$

where V_{min} is the minimum voltage and V_{max} is the maximum voltages limit of the buses.

b) **Substation Capacity limit:**

Substation capacity constraints certify that the net power supplied by the substation through the outgoing distribution feeders and the total transferred power by the substation have to be within the substation capacity limit. These capacity limit constraints take into concern in the new investments in substation upgradation.

$$0 \leq S_l^{ss} \leq S_{l-cap}^{ss}$$

where S_{l-cap}^{ss} the maximum power transfer capacity of the substation is, so power supplied to the load by a substation should be below its maximum capacity.

c) **Feeder Power Transfer Capacity Limit:**

Power flow from any distribution feeder must fulfill the thermal capacity limit of that distribution feeder. This capacity limit also takes into concern in the new investments in feeder upgradation.

$$S_m^{FD} \le S_{m-cap}^{FD}$$

where S_{m-cap}^{FD} is the thermal limit of maximum power transfer of the feeders.

d) **DG capacity constraint:**

The power produced by a DG unit must be below than its maximum capacity.

$$S_n^{DG} \le S_{n-cap}^{DG}$$

where S_{n-cap}^{DG} is the maximum power generation capacity of the DG.

e) **Radial structure constraint**:

The radial condition of the network should be satisfied otherwise proposed planning is discarded. In this planning, DGs are owned by the utility, not by the independent power producers.

5.2 Power Flow Formulation using DGs

The DG integration problem can be expressed including several objectives, comprising minimization of system losses, improvement in voltage profile, economical returns, environmental influence reduction, and enhancement of reliability features, etc. In this thesis work, backward forward power flow method is used for radial distribution load flow analysis.

DG integration in DSEP is the procedure of optimizing DG size, type and/or optimal place of installation, in order to accomplish a set of goals and subjected to the constraints. DG integration problem has nonlinear equality constraints like power flow constraints. It also comprises some nonlinear optimization objectives of minimization of line loss.

In this problem installed buses with DGs is demonstrated as PQ or PV buses. For modeling of PV buses compensation techniques are required and PQ buses are considered as the negative load in the problem, power flow formulation described in [15] integrating DGs is used in given expansion planning problem.

5.3 Backward-Forward power flow method

Backward-Forward power flow method is used for the load flow analysis of the radial distribution network. This method executed in two stages: the forward sweep and the backward sweep. In backward sweep step, voltage and currents are calculated with the help of KVL and KCL from the outermost node to the source node. The downstream voltage is determined beginning from the source node, in a forward sweep. The input data for this method is specified by line-bus oriented data which required data are, active and reactive powers, resistance, the reactance of sending and receiving end line-buses.

Backward-Forward power flow method is used in this planning, which contains two steps backward swept and forward swept. In backward swept the transferred power over the lines and bus voltages are calculated by following equation (5) and (6) respectively.

$$Sb_i^j = Sn_n^j + Sl_i + Loss_i^j \tag{5.5}$$

$$Sn_M^j = \sum_{i \in M} Sb_i^j \tag{5.6}$$

In first iteration losses are not considered, and transferred power through lines and ending buses are presented. Where Sb_i^j denotes the transmitted power by the ith branch at jth iteration, Sn_n^j shows the injected power to the nth bus at jth iteration, Sl_i is the load demand on ith branch, $Loss_i^j$ denotes the losses of the ith branch at jth iteration.

In forward swept the current in first bus and branches are indicated, and after it currents in branches are calculated by (7):

$$I_i^i = \left(\frac{Sb_i^j}{V_i^j} \right) \tag{5.7}$$

where I_i^j denotes the ith branch current at jth iteration and V_i^j is ith bus voltages at jtj iteration. After it bus voltages are calculated as:

$$V_n^j = V_n^j - (Z_n \times I_i^j) \tag{5.8}$$

$$Loss_i^j = (V_i^j - V_n^j) \times I_i^j \tag{5.9}$$

$$e = \max \left| \left(V_n^j - V_n^{j-1} \right) \right| \tag{5.10}$$

where Zn represents the n_{th} branch impedance and ‘e’ denotes the convergence criteria for the algorithm.

In this problem installed buses with DGs is demonstrated as PQ or PV buses. For modeling of PV buses compensation techniques are required and PQ buses are considered as the negative load in the problem, power flow formulation described in [15] integrating DGs is used in given expansion planning problem.

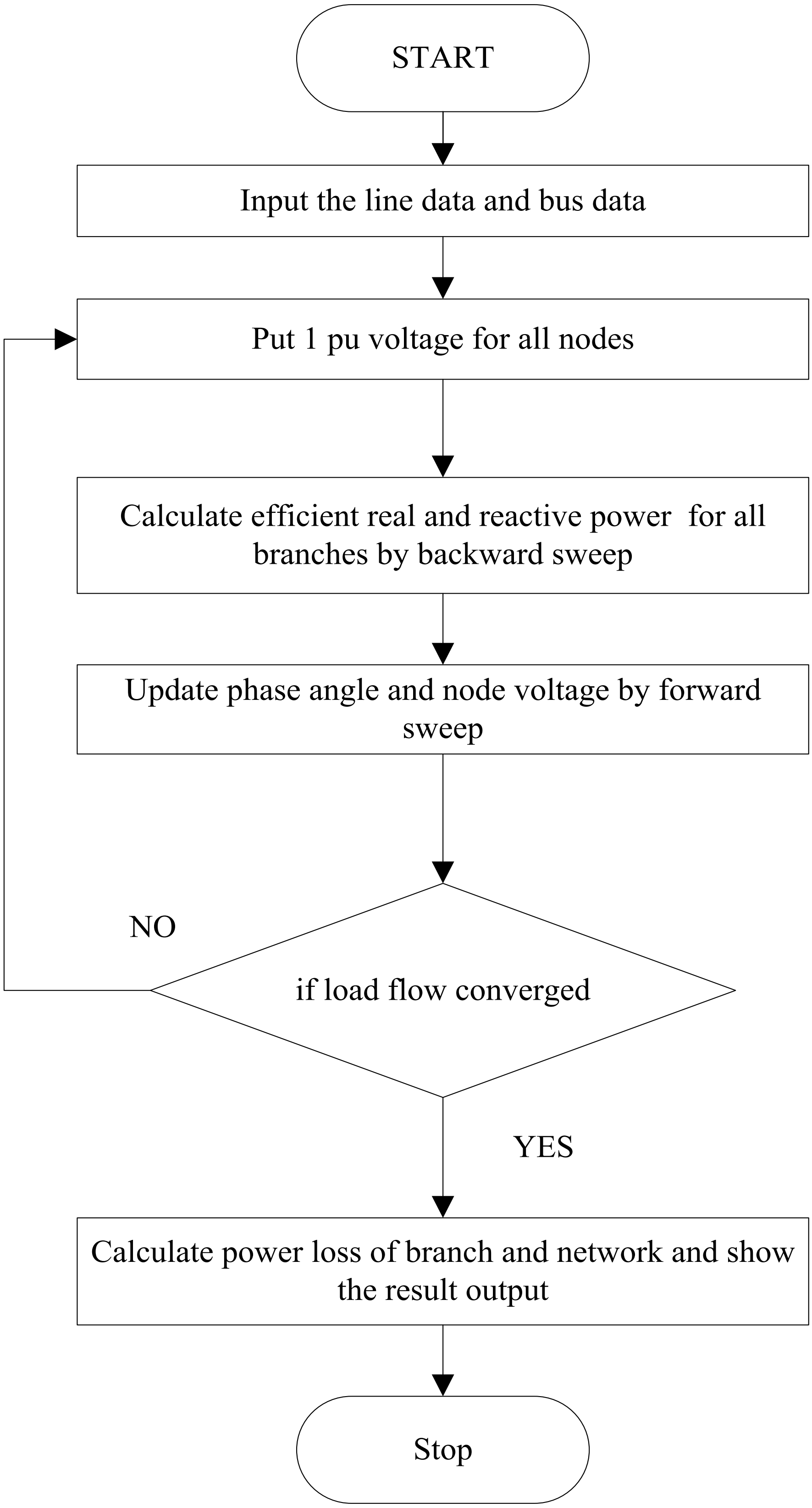

Fig 5.1: Flow chart of Backward-forward power flow method

CHAPTER 6

PROPOSED METHODOLOGY

In this work methodology is proposed to find out the optimal and efficient expansion planning schedule for the distribution network incorporating distributed generation. The chief motive of this expansion planning is the minimization of the whole cost of investment and operational of the substation, feeders, and DGs, while meeting the operational and technical constraints with the fulfillment of load demand. This planning is a multistage dynamic planning which carried out in two phases.

- In the first phase, an optimal planning in which all equipment required for demand fulfillment are installed and planning horizon is denoted, dividing it into periods.
- In the second phase, new loads are connected to the network which is considered as demand growth and new component are mounted in the system to supply new loads.
- The proposed planning is solved by the PSO and QPSO for all planning horizon to represent the finest proposal to supply the load demand with minimum cost to consumers.

In power system, the load and prices are variable in nature due to their uncertainties, which mostly effect the planning. So for flexible and robust planning, we considered the Price and load uncertainties which are molded as normal PDF and inserted into the planning problem using MCS.

6.1 Particle Swarm Optimization

PSO algorithm is motivated by the animal's behavior. In PSO, swarm uses for the population; particle denotes each participant of the population. Every particle explores over the whole search space by casually stirring in altered directions and think of the earlier best position of that particle and locations of its neighbors. Each particle in population changes its position and velocity by collaborating best positions of every particle in a swarm with each other. This process is running continuously until particle finds its optimal solution. Therefore, because of its simple implementation and capability to attain fast convergence speed, PSO algorithm is very popular in every field of optimization. Furthermore, PSO considers only basic mathematical formulation based on newton’s mechanic's principles.

Kennedy and Eberhart offered an explanation to complex and non-linear optimization problems by noticing the swarm’s behavior and invented the idea of optimizing the problem function using particle’s population. Assume a function of n dimension explained by

$$(x_1, x_2, x_3.......x_n) = (x_i) \tag{6.1}$$

Where x_i is the variable of population which have to optimize, denotes a set of variables for a certain objective function f(x). Now, our aim to find an optimum value x*, by which the objective function f(x*) give the optimum solution for maximization or minimization problem.

PSO algorithm is an analogous search tool which uses multi-particles (population). Each particle in the population denotes a solution for the individual particle. Every particle explores over the whole search space by casually stirring in altered directions and think of the earlier best position of that particle and locations of its neighbors. Each particle in population changes its position and velocity by collaborating best positions of every particle in a swarm with each other. Thus, in PSO technique, all agents are randomly initialized, and fitness value is computed by updating the personal best (best value of each agent) and global best (best value of all agents in the entire swarm). The loop starts by assuming initial values of the position of the particles as personal best and then updates every particle position by using the updated velocity. When the stopping criterion is met, the loop will be ended.

Therefore, we notice that P_{best} is the personal best of each particle and G_{best} is the global best of all particles in the whole population. Velocity and position of a particles are updated by:

$$\begin{gathered} v_{id}(t+1) = w(t) + c_1.rand\left(p_{best_{i,d}}(t) - p_{id}(t)\right) + c_2.rand\left(g_{best_d}(t) - x_{id}(t)\right) \\ p_{id}(t+1) = p_{id}(t) + v_{id}(t+1) \end{gathered} \tag{6.2}$$

w(t) is the inertia factor which is linearly decreased;
$V_{id}(t)$ is the velocity of particle;

$P_{id}(t)$ is the current position of particle;

$P_{best}(t)$is the is the personal best of each particle;

$G_{best}(t)$,is the global best position of all particles in the whole population;

c1 and $c2$ are the cognitive and social components respectively; and 'rand' are random values in the range of [0,1].

6.2 Proposed Quantum Particle Swarm Optimization Algorithm

In previous research papers, the DSEP problem is solved by many heuristic and mathematical optimization techniques which were solved with and without DG integration, with and without uncertainties of DGs, load and price. In proposed paper this expansion problem is answered by the Quantum Particle Optimization (QPSO), which provides the better expansion solutions for the distribution system in comparison to other optimization techniques regarding high convergence speed, less controlling parameters, and less complexity. QPSO has only one tuning parameter to converge to the solution to the global optimum, so QPSO is used in the present paper to provide an effective, economical and optimal expansion planning by considering price and load uncertainties with DG incorporation. In proposed problem, DG(renewable) uncertainties i.e. penetration level, solar radiation, wind speed, etc. Because if we consider DG uncertainties, then problem becomes more complex and difficulties in obtaining optimal planning solutions

In 1995, Kennedy and Eberhart suggested PSO whose key idea is imported from the birds swarm behavior's study. PSO cannot congregate to a global optimum solution, but it is easy to implement to solve the optimization problem. Therefore, to improve the PSO convergence speed, quantum behavior features have been presented in PSO update approach which derived from the quantum potential well model. QPSO [19,21] uses only one displacement update formula and not use any velocity updating formula, so QPSO reduces the complexity of the PSO algorithm with better convergence speed. The QPSO is superior to PSO in terms of global searching performance because in quantum space particle searches all feasible solutions.

In QPSO procedure, the wave function Ψ (x,t) denotes the particle's state, and solution of Schrodinger equation in the space of PDF at some point gives the position equation particle using the MCS.

$$X(t) = P \pm \frac{L}{2}\ln(\frac{1}{r}) \tag{6.3}$$

$$L(t+1) = 2\alpha\left|M_{best} - X(t)\right| \tag{6.4}$$

QPSO evolution equations are following:

$$M_{best} = \frac{1}{M}\sum_{n=1}^{M} P_n(t) = [\frac{1}{M}\sum_{n=1}^{M} P_{n1}(t), \frac{1}{M}\sum_{n=1}^{M} P_{n2}(t) .... \frac{1}{M}\sum_{n=1}^{M} P_{nd}(t)] \tag{6.5}$$

$$PP_{nd} = \Phi \times P_{nd}(t) + (1-\Phi) \times P_{gd}(t) \tag{6.6}$$

$$X_{nd}(t+1) = P_{nd}(t) + rand(t).\beta(t).\left|M_{best}(t) - X_{nd}(t)\right|.\ln\left(\frac{1}{r(t)}\right) \tag{6.8}$$

where r is a random number which gives a value between [0,1], ‘d’ shows the particle dimension and ‘M’ denotes the particles’ number in the population. $P_n(t)$, $P_{gd}(t)$ shows the current best position and global best position respectively at t iteration, of particle n. M_{best} denotes the average of all best position in a population of particles, α is the contraction expansion coefficient, that is governing factor for the convergence speed of QPSO algorithm. α Varies according to the situations and it is calculated as following:

$$\beta(t) = m - (m-l) \times \frac{t}{T_{\max}} \tag{6.9}$$

where β decrease from m to l linearly iterative and $T_{\max}$ denotes a maximum number of iteration. The function rand() is allotted at a definite probability 1 or -1.

QPSO algorithm is used to solve real continuous optimization problems and does not provide a better solution for discrete space optimization problems. By using the behavior and specific memory function of quantum particle swarm to trace the current position and regulate the search approach dynamically.

6.3 Flow Chart of Proposed Distribution System Expansion Planning

The proposed QPSO algorithm considers the price and load uncertainties into the planning which is shown in fig 7.1 for each stage of planning. The planning stages are solved one after another, all stages are not resolved at same time period.

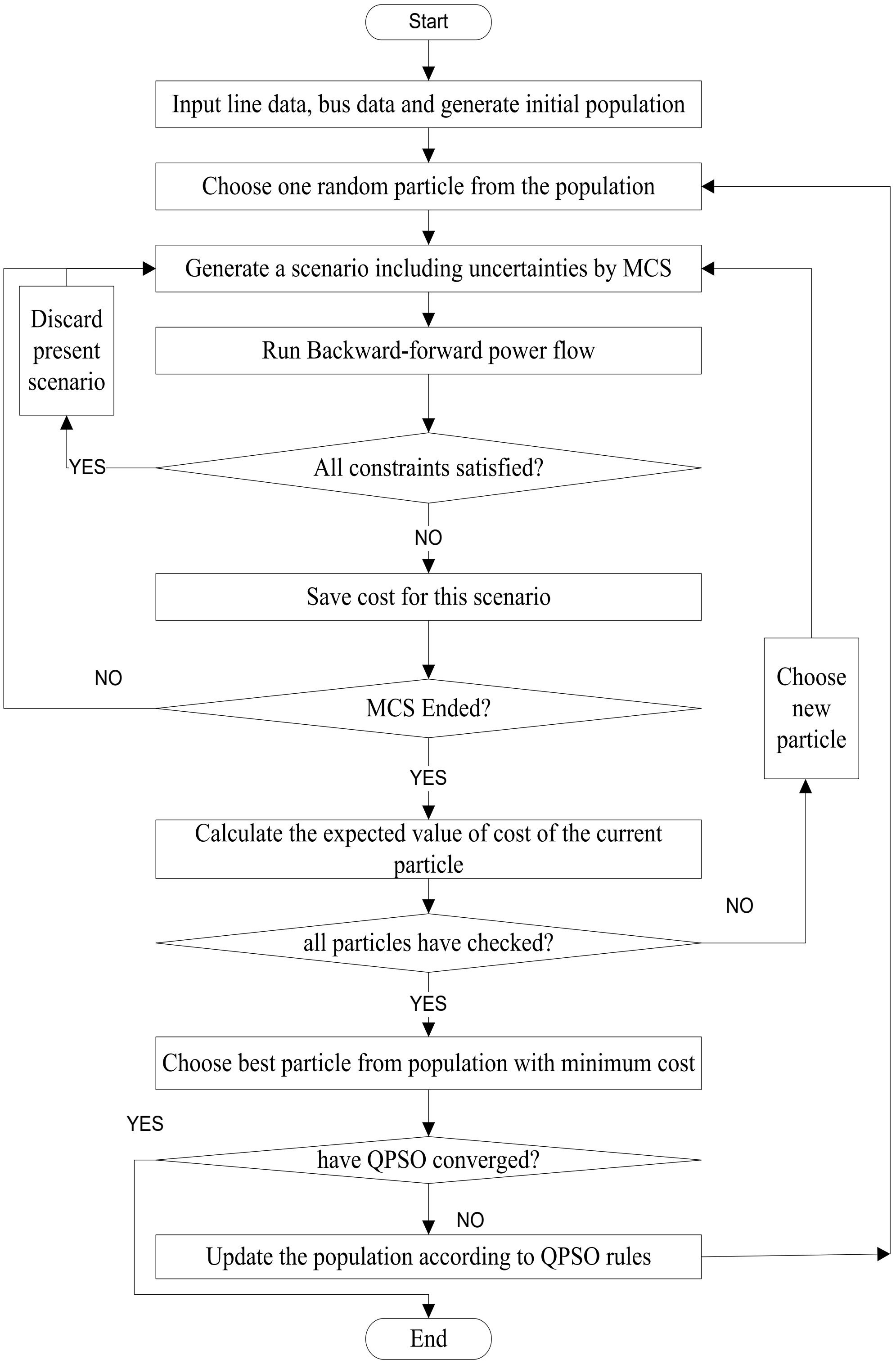

Fig. 6.1 Flow Chart of proposed expansion planning

The data for next stage is depend on the previous stage, so it's not possible to solve all stage together at same time. So after solving the first stage, transfer first stage data to the second stage, after solving the second stage, all data of the second stage will be transfer to the third stage and so on. This procedure will be continue until the last stage has been solved. So due to the dependency of next stage on the previous stage, this approach is called pseudo-dynamic approach. The proposed optimization algorithm is a constrained optimization programming. At first in fig 7.1, the population is randomly generated for QPSO technique. In the second stage, one particle is selected from the population and after it, a scenario is generated considering load and price uncertainties with the help of MCS. Backward-forward power flow is used for load analysis for this scenario. In next stage all constraints are checked, if any constraint violated then, this scenario would be discarded otherwise the cost is calculated for this scenario using the objective function. MCS is run, and constraints are checked for all scenario, and if MCS is conversed then, the final calculated cost is the final revenue for the current scenario. After calculating the cost for all feasible scenario, a scenario with minimum cost is nominated as the best particle. After it, the convergence of QPSO is tested, if stopping criteria is fulfill then the best particle is reflected as optimal results of planning otherwise particle position is updated in a population based on QPSO rules.

CHAPTER 7

RESULTS OF EXPANSION PLANNING

To estimate the effectiveness of the proposed technique, investigations have been performed out on 9 bus and 72 bus (Kian-pars Ahvaz 11 KV a practical distribution network in Iran) distribution network. In this chapter, results of expansion planning for different-2 scenario such as planning with and without, planning with and without uncertainties consideration are presented.

7.1 Illustrative Test Systems

7.1.1 Illustrative 9 Bus Distribution Network

9 bus distribution network is considered to evaluate the QPSO algorithm, which contains 9 buses, among these one bus is picked as distribution substation and remaining are load points. System line data and bus data is provided in Table A.4 and A.3 respectively in Appendix. There are six existing lines in the system and seven candidate solutions for a line extension. The proposed expansion planning perspective is carried in two stages, and load growth rate for each stage is 10%. Three load level are considered which are given in Table A.1. We can install the DGs on all load points and capacities of DGs are 1,2,3 or 4 MW, which are modeled in planning as PQ load. The other data related to planning cost parameters are given in Table A.2. Load information for 9 bus distribution network is given in Table A.5. Load and price uncertainties are considered as normal PDF with a standard deviation of 15%. The rate of interest is taken as 12.5%.

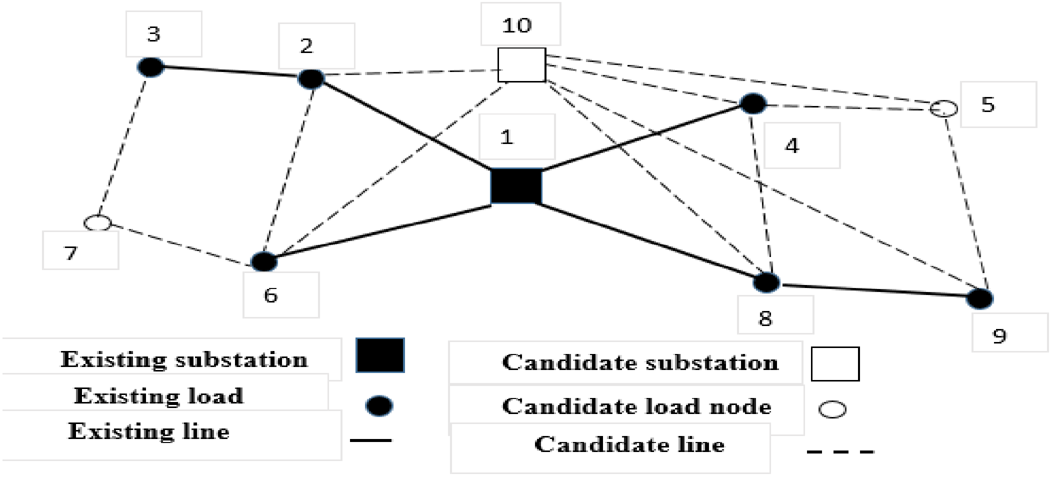

Fig.7.1 9 bus distribution network

7.1.2 Kian-Pars Ahvaz 72 Bus Distribution Network

The proposed method is evaluated on a practical and large distribution network, the Kian-pars Ahvaz 11 KV network (a practical distribution network in Iran) for a case study which is shown in Fig 7.2. System line data and bus data is provided in Table A.6 and A.7 respectively in Appendix. The proposed practical network consists a substation, 72 buses and 72 feeders among which feeder no 1 to 24 are the double circuit lines and remaining feeders 25 to 72 are the single circuit lines. These single circuit feeders can be expanded to the double circuit lines in expansion planning. The capacities of DGs are taken as 1,2,3 or 4 MW, which can be installed on the buses according to the load demand at the black dotted points assumed as candidate points shown in the fig 7.2. The five new buses 73 to 77 are considered new load points which are taken as a demand growth and these are added to the existing network over three time period of 10 years each. The 72 bus data is given in the [20] and other data for new feeders and loads is given in Table A.8 and A.9. The rate of interest on the planning cost is taken as 12.5%.

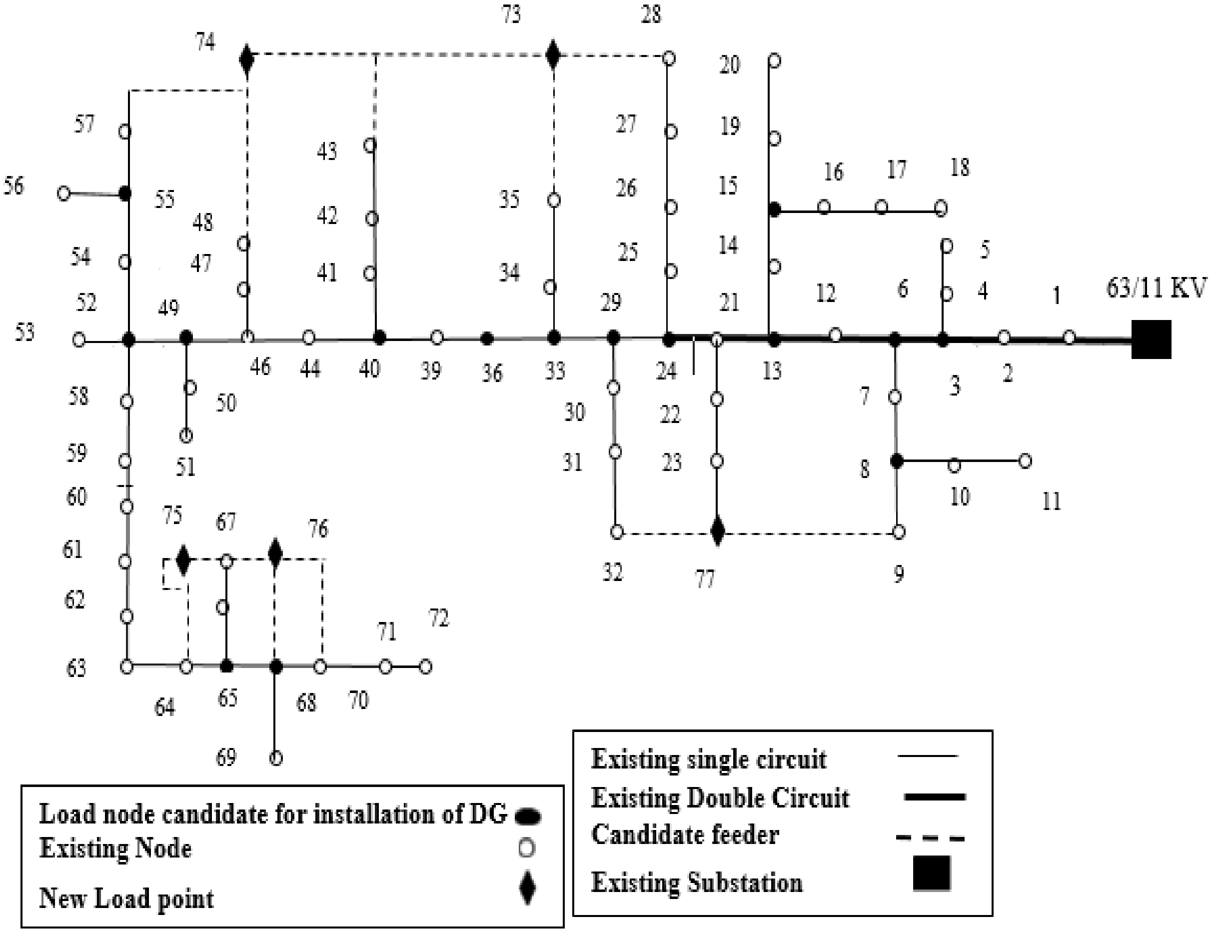

Fig. 7.2 63/11 KV Kian pars Ahvaz 72 Bus distribution network

7.2 Results of Planning

7.2.1 Bus 9 Distribution Network

The expansion planning carried out in two phases for comparison purpose and to understand the effect of uncertainties and DGs on planning. In first phase planning without considering uncertainties and in next phase planning with uncertainties consideration is performed. These each phase are further performed without and with DGs. The load information of 9 bus network is given in Table A.5, and the standard deviation is 10% of normal PDF. The QPSO factors are a number of particle=50; signal to noise ratio=20; the number of bit=10. The proposed algorithm repeatedly run until it can find a global optimal solution and best solution is picked up as an absolute solution.

7.2.1.1 Expansion planning without considering uncertainties

In this phase, planning accomplished by not considering uncertainty. Planning executed in two phases; in first phase bus no. 7 is connected to the network and in second phase bus no. 5 is connected to the 9 bus network. Table 7.1 shows the resulted expansion planning for with and without DGs & without uncertainties respectively. Table 7.3 represents the voltages of the buses for without uncertainties. The result shows the positive influence of the DGs on planning that improve the voltage profile. The standard deviation of bus voltages is decreased by 24% and 16% for the first and next second stage individually. The expansion planning cost is shown in Table 7.5 for without uncertainties by the PSO algorithm. The graphical representation of expansion planning cost without uncertainty using PSO is demonstrated in fig 7.3. The expansion planning cost is shown in Table 7.7 for without uncertainties by the QPSO algorithm. The graphical representation of expansion planning cost without uncertainty using QPSO is demonstrated in fig 7.5. The expansion planning cost shows that by integration of DGs in planning reduce the annual expansion cost by 3.36% and 2.74%, for the first and next second stage individually. The annual energy loss cost is also decreased by incorporating the DGs in planning, which is clearly shown in the results.

7.2.1.2 Expansion planning with uncertainties consideration

In this step price and load uncertainties are taken into account of the expansion planning and expansion planning performed in two steps like previous section ”expansion planning without uncertainty”. Table 7.2, Table 7.4 represents the resulted planning, bus voltages of planning respectively. The results show the importance of

DGs in planning and the standard deviation is reduced by 23% and 25% in the presence of DGs for the first and next second stage individually.

TABLE 7.1

RESULTED EXPANSION PLANNING WITHOUT UNCERTAINTY

New Feeders/DGs	**Without Considering Uncertainties**			
	Phase 1		phase 2	
	Without DGs	With DGs	Without DGs	With DGs
New connected Feeders	N6-7	N6-7	N4-5 N1-2 N1-8 N1-6	N4-5
Added DGs	-	At B3, 2 MW At B7, 1 MW At B9, 2 MW		At B2, 3 MW At B3, 1 MW At B4, 2 MW At B5, 3 MW At B6, 2 MW At B7, 2 MW At B8, 3 MW At B9, 2 MW

*B3=At bus no 3, *N6-7=between node 6 and 7

TABLE 7.2

RESULTED EXPANSION PLANNING WITH UNCERTAINTY

New Feeders/DGs	**With Considering Uncertainties**			
	phase 1		phase 2	
	Without DGs	With DGs	Without DGs	With DGs
New connected Feeders	N6-7 N1-2 N1-6	N6-7	N4-5 N2-3 N1-4	N4-5 N1-2 N1-4
Added DGs		At B3, 4 MW At B7, 1 MW At B9, 2 MW		At B2, 2 MW At B4, 3 MW At B5, 2 MW At B6, 1 MW At B7, 2 MW At B8, 1 MW At B9, 2 MW

TABLE 7.3

VOLTAGES OF BUSES WITHOUT UNCERTAINTY

Bus Number	**Without Considering Uncertainties**			
	Phase 1		Phase 2	
	Without DGs	With DGs	Without DGs	With DGs
1	1	1	1	1
2	0.9948	0.9374	0.9980	0.9562
3	0.99552	0.9968	0.9918	0.9258
4	0.9956	0.9376	0.9999	0.9907
5	0	0	0.9986	0.9961
6	0.9410	0.9494	0.9982	0.9258
7	0.9518	0.9916	0.9941	0.9402
8	0.9966	0.9986	0.9862	0.9288
9	0.9206	0.9941	0.9978	0.9774

TABLE 7.4

VOLTAGES OF BUSES WITH UNCERTAINTY

Bus Number	**With Considering Uncertainties**			
	Phase 1		Phase 2	
	Without DGs	With DGs	Without DGs	With DGs
1	1	1	1	1
2	0.9999	0.9986	0.9960	0.9992
3	0.9808	0.9997	0.9862	0.9936
4	0.9944	0.9860	0.9911	0.9932
5	0	0	0.9860	0.9996
6	0.9866	0.9972	0.9969	0.9909
7	0.9989	0.9972	0.9983	0.9975
8	0.9916	0.9955	0.9979	0.9938
9	0.9900	0.9986	0.9910	0.9909

The expansion planning cost is shown in Table 7.6 for with uncertainties by the PSO algorithm. The graphical representation of expansion planning cost with uncertainty using PSO is demonstrated in fig 7.4. The expansion planning cost is shown in Table

7.8 for with uncertainties by the QPSO algorithm. The graphical representation of expansion planning cost with uncertainty using QPSO is demonstrated in fig 7.6.

TABLE 7.5

EXPANSION PLANNING COST BY PSO WITHOUT UNCERTAINTY

Cost	**Without Considering Uncertainties**			
	Phase 1		Phase 2	
	Without DGs	With DGs	Without DGs	With DGs
Investment cost of Feeders (M$)	1.21	1.20	4.89	1.61
Investment cost of Substation (M$)	0.00	0.01	0.81	0.01
Investment cost dgs (M$)	0.00	1.59	0.00	4.14
Operation cost of dgs (M$/year)	0.01	1.02	0.00	5.92
Purchased electricity cost (M$/year)	9.65	8.15	11.82	5.11
Losses cost (M$/year)	0.39	0.34	0.50	0.49
Total cost of expansion (M$/year)	9.82	9.55	12.39	12.05

TABLE 7.6

EXPANSION PLANNING COST BY PSO WITH UNCERTAINTY

Cost	**With Considering Uncertainties**			
	Phase 1		Phase 2	
	Without DGs	With DGs	Without DGs	With DGs
Investment cost of Feeders (M$)	3.68	1.21	5.77	3.20
Investment cost of Substation (M$)	0.00	0.01	0.80	0.01
Investment cost dgs (M$)	0.00	2.22	0.00	4.13
Operation cost of dgs (M$/year)	0.00	1.81	0.01	4.62
Purchased electricity cost (M$/year)	9.91	7.78	12.12	6.24
Losses cost (M$/year)	0.42	0.41	0.51	0.49
Total cost of expansion (M$/year)	10.38	10.00	12.91	11.87

TABLE 7.7

EXPANSION PLANNING COST BY QPSO WITHOUT UNCERTAINTY

Cost	**Without Considering Uncertainties**			
	Phase 1		Phase 2	
	Without DGs	With DGs	Without DGs	With DGs
Investment cost of Feeders (M$)	1.02	1.02	4.25	1.65
Investment cost of Substation (M$)	0.00	0	0.81	0.00
Investment cost dgs (M$)	0.00	2.15	0.00	4.14

Operation cost of dgs (M$/year)	0.00	0.72	0.00	5.52
Purchased electricity cost (M$/year)	9.322	7.293	10.825	4.956
Losses cost (M$/year)	0.18	0.12	0.50	0.45
Total cost of expansion (M$/year)	9.454	9.288	11.572	11.212

TABLE 7.8

EXPANSION PLANNING COST BY QPSO WITH UNCERTAINTY

Cost	**With Considering Uncertainties**			
	Phase 1		Phase 2	
	Without DGs	With DGs	Without DGs	With DGs
Investment cost of Feeders (M$)	3.20	1.06	5.03	2.90
Investment cost of Substation (M$)	0.00	0.00	0.80	0.00
Investment cost dgs (M$)	0.00	1.90	0.00	3.33
Operation cost of dgs (M$/year)	0.00	1.81	0.00	3.93
Purchased electricity cost (M$/year)	9.253	7.102	10.396	5.925
Losses cost (M$/year)	0.41	0.38	0.32	0.26
Total cost of expansion (M$/year)	9.666	9.29	11.142	10.624

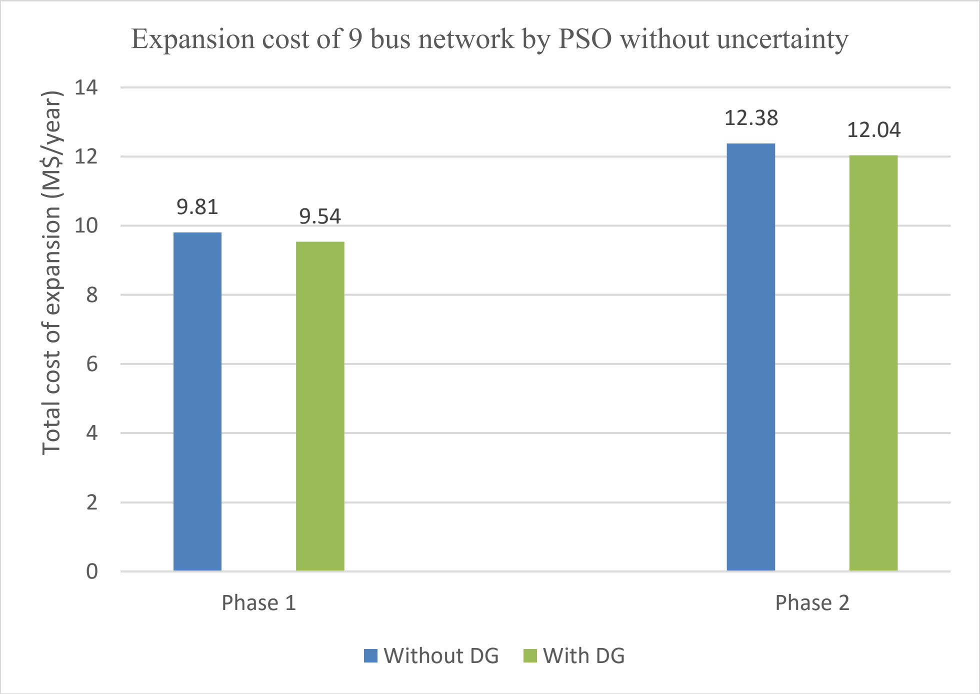

Fig 7.3: Expansion cost of 9 bus network by PSO without uncertainty

The annual cost of energy loss is reduced by integration of DGs. The annual expansion cost of expansion is greatly reduced by 3.67% and 8.05% by the application of DGs for first and second stage respectively.

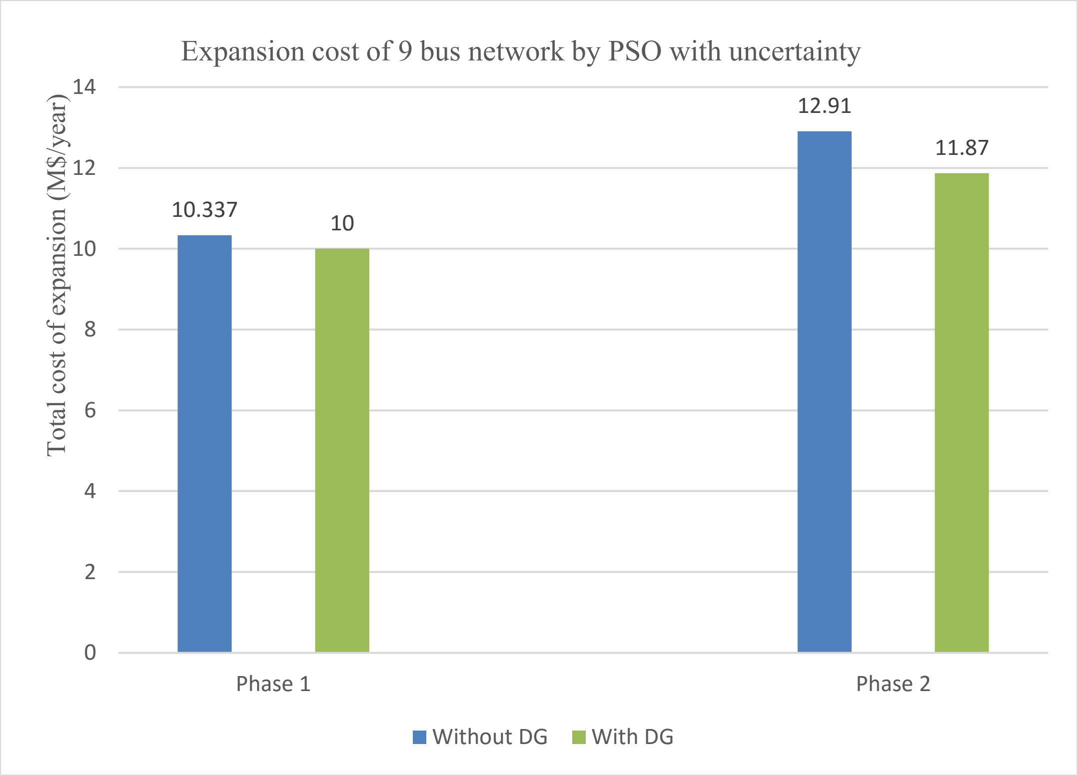

Fig 7.4. Expansion cost of 9 bus network by PSO with uncertainty

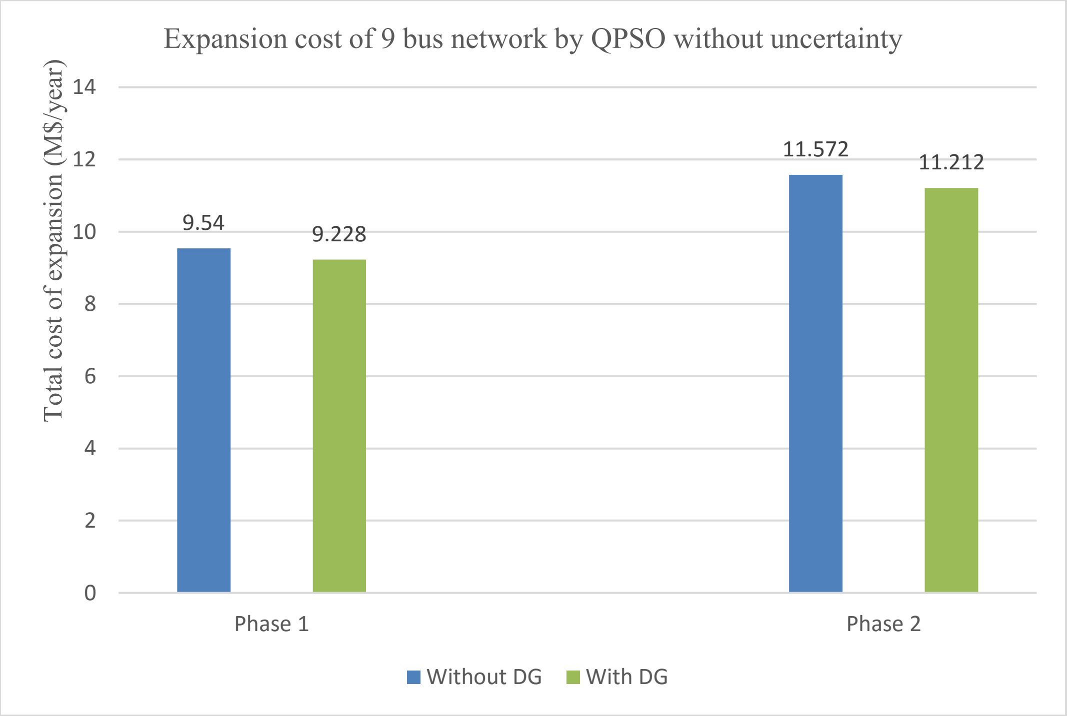

Fig 7.5 Expansion cost of 9 bus network by QPSO without uncertainty

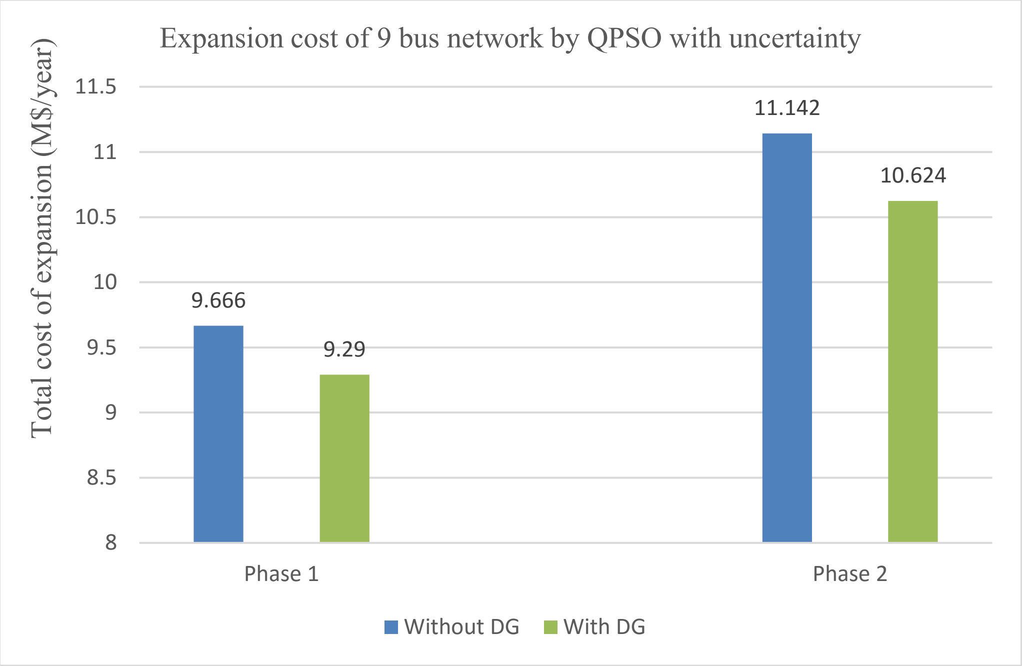

Fig 7.6. Expansion cost of 9 bus network by QPSO with uncertainty

7.2.1.3. Evaluation of the expansion planning Outcomes

In order to exhibit the effectiveness and ability of the QPSO algorithm, the comparison is carried out with other research papers. The comparison shows the superiority of QPSO algorithm over standard PSO and other research references [10] and [19] which is displayed in Table 7.9 and Table 7.10 with 20% load increment and 20% load decrement respectively. The effect of uncertainties on planning is clearly compared in Table 7.5 over QPSO and PSO algorithm which shows that by considering uncertainties the annual expansion cost and losses are minimized, and the violation of the constraints are also reduced.

TABLE 7.9

COMPARISON OF THE UNCERTAINTY EFFECTS ON THE EXPANSION PLANNING OF LOAD INCREMENT

	20% Increment in Load			
	EC (M$/year)	Losses (pu)	No. of violation in voltage constraints	No. of violation in line flow constraints
Proposed QPSO plan with uncertainties	10.624	0.0042	0	0
Proposed QPSO plan without uncertainties	11.212	0.0054	0	1

PSO plan with uncertainties	11.8742	0.0062	0	0
PSO plan without uncertainties	12.0442	0.0072	1	1
Ref. [19]	12.3856	0.0086	1	2

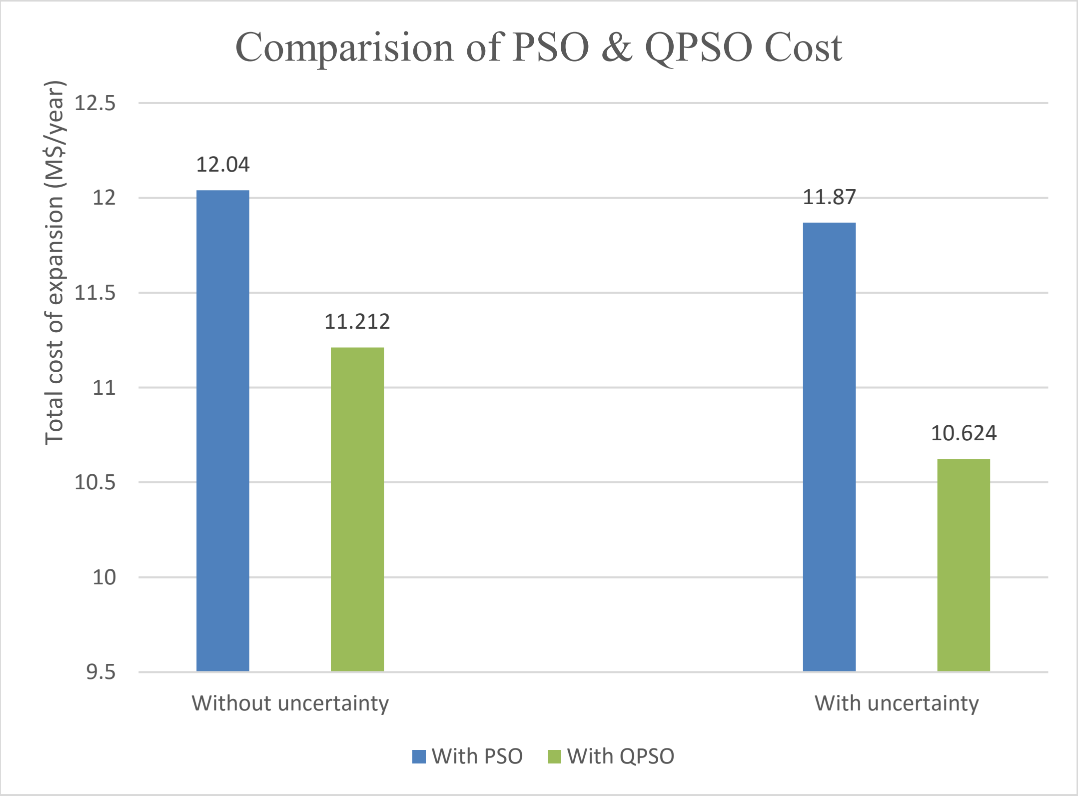

Fig. 7.7 Comparison of expansion cost obtained by PSO and QPSO for 9 bus network

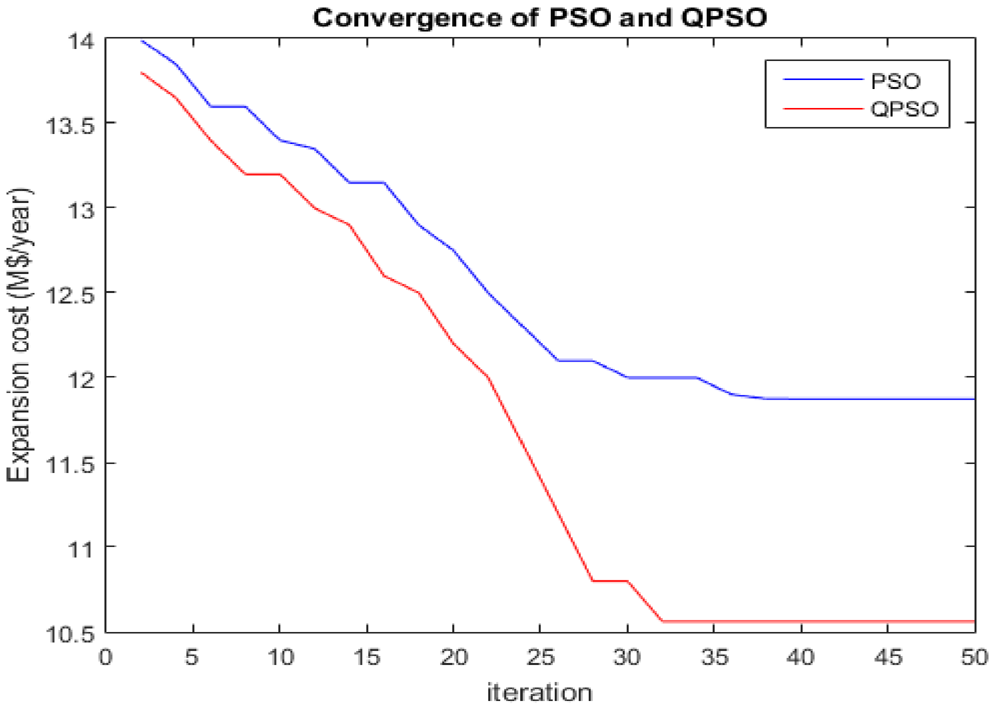

Fig.7.8 Convergence graph of PSO and QPSO for 9 bus network

TABLE 7.10

COMPARISON OF THE UNCERTAINTY EFFECTS ON THE EXPANSION PLANNING OF LOAD DECREMENT

	20% Decrement in Load			
	EC (M$/year)	Losses (pu)	No. of violation in voltage constraints	No. of violation in line flow constraints
Proposed QPSO plan with uncertainties	10.624	0.0014	0	0
Proposed QPSO plan without uncertainties	11.212	0.0016	0	0
DG PSO plan [10] with uncertainties	11.8742	0.0028	0	0
DG PSO plan [10] without uncertainties	12.0442	0.00139	0	0
Ref. [19]	12.3856	0.0042	0	0

The effect of uncertainties is tested on 20% load increment and 20% load decrement, in both cases, the recommended expansion planning does not interrupt the line flow and voltage limit constraints while other planning violates these constraints. The graphical representation of a comparison of expansion planning cost obtained by PSO and QPSO is shown in fig 7.7. Convergence graph of PSO and QPSO is shown in fig 7.8, which shows that QPSO gives the optimal solution in less number of iteration and lower cost of planning than PSO algorithm.

7.2.2 Kian-Pars Ahvaz 72 Bus Distribution Network

7.2.2.1 Expansion planning without considering uncertainties

In this section, price and load uncertainties into planning are not considered. Proposed planning is performed into three phases. In the first phase the bus no 72 &73 are connected to the existing network, bus no 74 & 75 are connected into the system and at the last bus, no 77 is added to the network in second and third phase respectively. This planning is performed with and without DG which is shown in Table 7.11. Voltages of buses are shown in Table 7.13 for without uncertainty. The expansion planning cost is shown in Table 7.15 for without uncertainties by the PSO algorithm. The graphical representation of expansion planning cost without uncertainty using PSO is demonstrated in fig 7.9.The expansion planning cost is shown in Table 7.17 for without uncertainties by the QPSO algorithm. The graphical representation of expansion planning cost without uncertainty using QPSO is demonstrated in fig 7.11. The results show that by integration of DGs, voltage profile and the system performance is greatly enhanced. The cost results demonstrate that DG can reduce the expansion cost and the cost of the network losses. Expansion planning results show the significance reduction in expansion cost and losses cost with DGs in comparison to without DGs.

7.2.2.2. Expansion planning with uncertainties consideration

This segment of the planning is carried out with uncertainties consideration under the same circumstance as described in the previous section. The planning is performed in three phases like the previous section with and without DGs. The resulted planning and the voltages of the buses are shown in Table 7.7 and Table 7.8 respectively.

TABLE 7.11

EXPANSION PLANNING FOR 72 BUS DISTRIBUTION SYSTEM WITHOUT UNCERTAINTY

New Feeders/DGs	**Without Considering Uncertainties**					
	Phase 1		Phase 2		Phase 3	
	Without DG	With DG	Without DG	With DG	Without DG	With DG

New connected Feeders	28-73	28-73	67-76	67-76	9-77	23-77
	57-74	57-74	64-75	64-75	-	-
Upgraded feeders			36-39		24-29	
			40-44		29-33	
			44-46		33-36	
			49-52		46-49	
ADDED DGs		2MW B65		2MW B52		1MW B52
						1MW B49

The expansion planning cost is shown in Table 7.16 for with uncertainties by the PSO algorithm. The graphical representation of expansion planning cost without uncertainty using PSO is demonstrated in fig 7.10. The expansion planning cost is shown in Table 7.18 for with uncertainties by the QPSO algorithm, which describes that with DGs integration the voltage profile and system performance is improved and planning cost & network losses are reduced.

TABLE 7.12

Expansion planning for 72 bus Distribution System with uncertainty

New Feeders/DGs	**With Considering Uncertainties**					
	Phase 1		Phase 2		Phase 3	
	Without DG	With DG	Without DG	With DG	Without DG	With DG
New connected Feeders	28-73	28-73	67-76	67-76	9-77	23-77
	57-74	57-74	64-75	64-75		-
Upgraded feeders	24-29	-	36-39	-	60-61	
	29-33		40-44		61-62	
	33-36		44-46		62-63	
	39-40		46-49		63-64	
	62-63		49-52		65-68	
			58-89		68-70	
			59-60		70-71	
			64-65		71-72	

Added DGs		2MW B65		2 MW B52		

The graphical representation of expansion planning cost with uncertainty using QPSO is demonstrated in fig 7.12. The cost of planning and losses with DGs is lower than the without DGs. The superiority of QPSO over PSO in terms of Cost and loss reduction is compared in Table 7.10. These results of planning signify the advantages of the DGs in distribution network in terms of system performance, voltage profile improvement, reliability, etc.

TABLE 7.13

VOLTAGES OF BUSES WITHOUT UNCERTAINTY

Phases	**Without Considering Uncertainties**			
	Without DG		With DG	
	V_{min}(pu)	Bus No.	V_{min}(pu)	Bus No.
Phase 1	0.9502	69	0.9542	11
Phase 2	0.9570	76	0.9582	11
Phase 3	0.9584	76	0.9598	11

TABLE 7.14

VOLTAGES OF BUSES WITH UNCERTAINTY

Phases	**With Considering Uncertainties at High Loading Circumstance**			
	Without DG		With DG	
	V_{min}(pu)	Bus No.	V_{min}(pu)	Bus No.
Phase 1	0.9544	69	0.9520	11
Phase 2	0.9596	76	0.9520	11
Phase 3	0.9544	76	0.9576	11

TABLE 7.15

EXPANSION PLANNING COST BY PSO WITHOUT UNCERTAINTY

Cost	Without Considering Uncertainties					
	Phase 1		Phase 2		Phase 3	
	Without DG	With DG	Without DG	With DG	Without DG	With DG
Investment cost of Feeders (M$)	0.06	0.06	0.06	0.03	0.14	0.01
Investment cost of DGs (M$)	0.00	0.64	0.00	0.32	0.00	0.64
Operation cost of DGs (M$/year)	0.00	0.52	0.00	0.77	0.00	1.29
Purchased electricity cost (M$/year)	3.41	2.81	3.73	2.83	4.01	2.52
Losses cost (M$/year)	0.09	0.06	0.10	0.06	0.11	0.06
Total cost of expansion (M$/year)	3.42	3.41	3.74	3.47	4.03	3.88

TABLE 7.16

EXPANSION PLANNING COST BY PSO WITH UNCERTAINTY

Cost	With Considering Uncertainties					
	Phase 1		Phase 2		Phase 3	
	Without DG	With DG	Without DG	With DG	Without DG	With DG
Investment cost of Feeders (M$)	0.10	0.06	0.09	0.03	0.13	0.01
Investment cost of DGs (M$)	0.00	0.64	0.00	0.64	0.00	0.00
Operation cost of DGs (M$/year)	0.00	0.52	0.00	1.03	0.00	1.03
Purchased electricity cost (M$/year)	3.48	2.80	3.85	2.50	4.02	2.78
Losses cost (M$/year)	0.08	0.06	0.10	0.06	0.11	0.06
Total cost of expansion (M$/year)	3.50	3.41	3.86	3.62	4.04	3.81

TABLE 7.17

EXPANSION PLANNING COST BY QPSO WITHOUT UNCERTAINTY

Cost	Without Considering Uncertainties					
	Phase 1		Phase 2		Phase 3	
	Without DG	With DG	Without DG	With DG	Without DG	With DG
Investment cost of Feeders (M$)	0.033	0.033	0.032	0.06	0.047	0.08
Investment cost of DGs (M$)	0.000	0.636	0.000	0.32	0.000	0.64

Operation cost of DGs (M$/year)	0.000	0.515	0.000	0.77	0.000	1.29
Purchased electricity cost (M$/year)	3.319	2.717	3.641	2.74	3.918	2.42
Losses cost (M$/year)	0.069	0.040	0.084	0.04	0.086	0.04
Total cost of expansion (M$/year)	3.326	3.321	3.649	3.38	3.935	3.79

TABLE 7.18

EXPANSION PLANNING COST BY QPSO WITH UNCERTAINTY

Cost	**With Considering Uncertainties**					
	Phase 1		Phase 2		Phase 3	
	Without DG	With DG	Without DG	With DG	Without DG	With DG
Investment cost of Feeders (M$)	0.005	0.033	0.002	0.06	0.040	0.08
Investment cost of DGs (M$)	0.000	0.636	0.000	0.64	0.000	0.00
Operation cost of DGs (M$/year)	0.000	0.517	0.000	1.03	0.000	1.03
Purchased electricity cost (M$/year)	3.395	2.714	3.757	2.41	3.934	2.69
Losses cost (M$/year)	0.064	0.040	0.083	0.04	0.088	0.04
Total cost of expansion (M$/year)	3.407	3.320	3.768	3.52	3.951	3.72

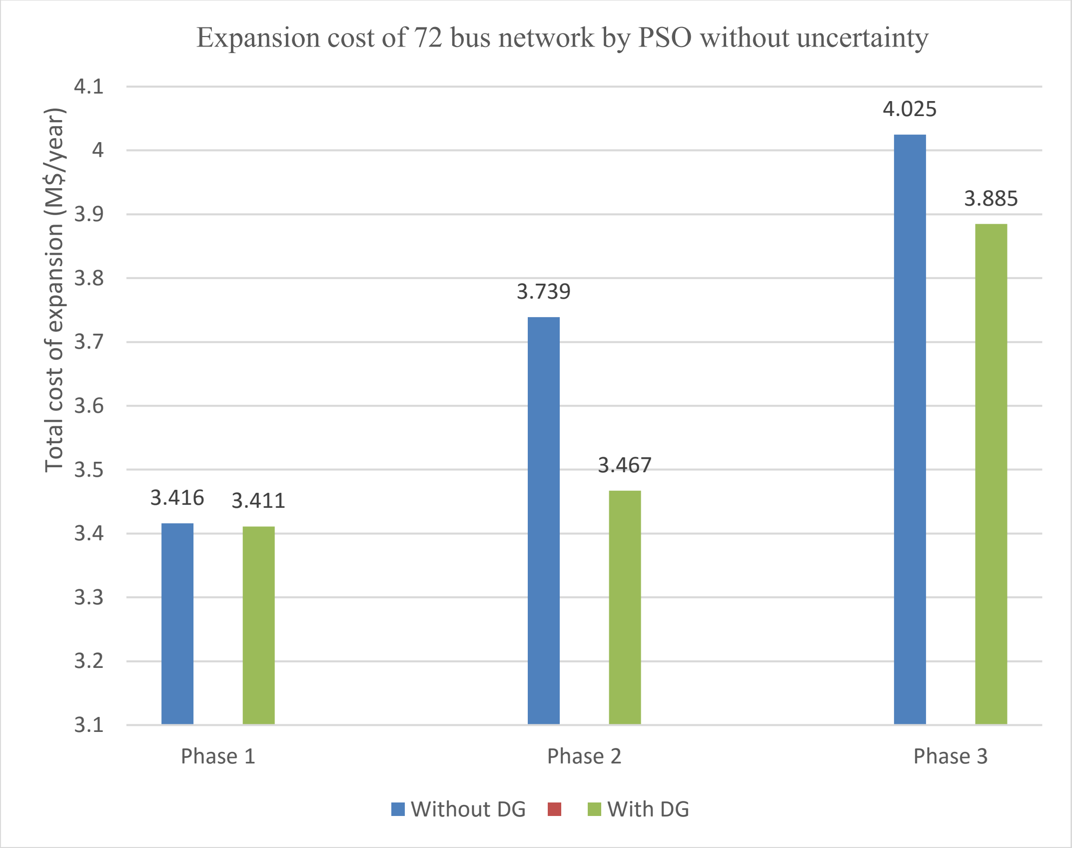

Fig 7.9. Expansion cost of 72 bus network by PSO without uncertainty

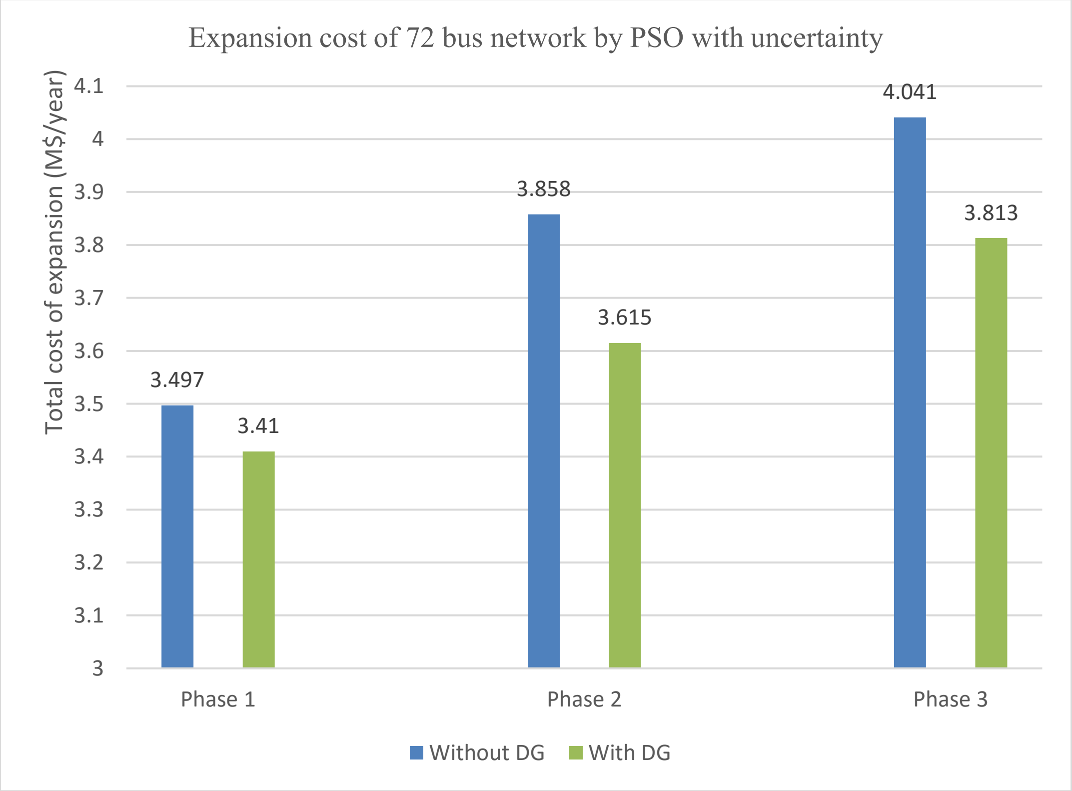

Fig 7.10. Expansion cost of 72 bus network by PSO with uncertainty

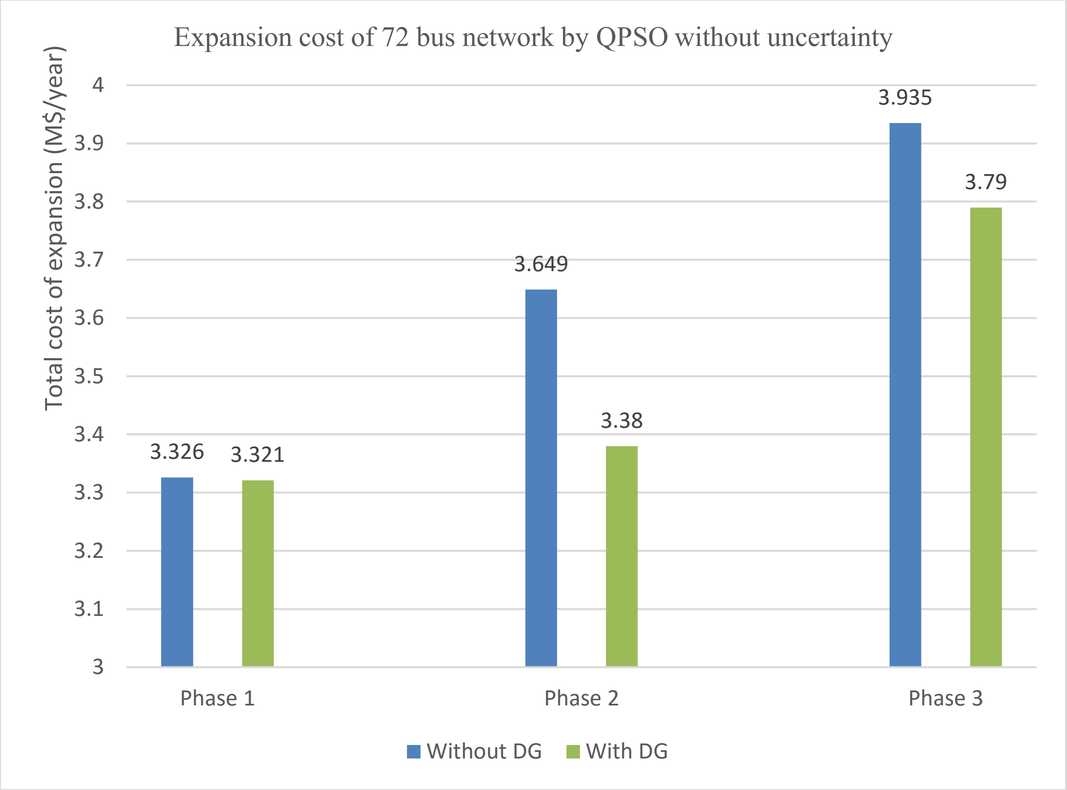

Fig 7.11. Expansion cost of 72 bus network by QPSO without uncertainty

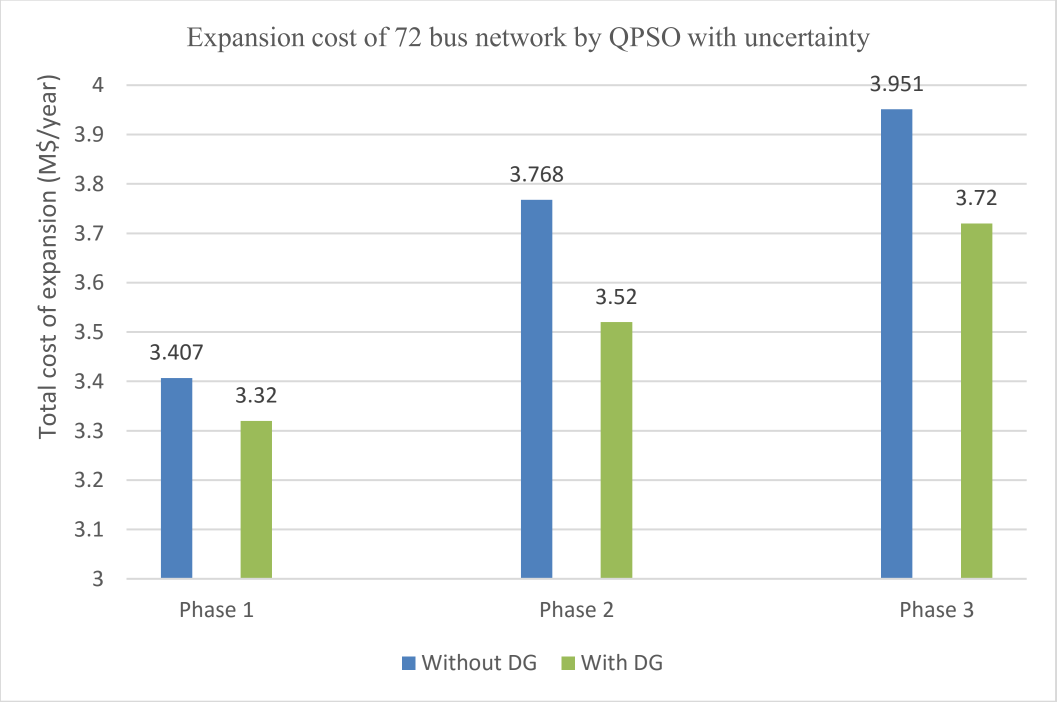

Fig 7.12. Expansion cost of 72 bus network by QPSO with uncertainty

7.2.2.3 Evaluation of the expansion planning Outcomes

In order to exhibit the effectiveness and ability of the QPSO algorithm, the comparison is carried out with other research papers. The comparison shows the superiority of QPSO algorithm over standard PSO, which is displayed in Table 7.19 and Table 7.20 with 20% load increment and 20% load decrement respectively. The effect of uncertainties on planning is clearly compared in Table 7.19 and Table 7.20 over QPSO and PSO algorithm which shows that by considering uncertainties the annual expansion cost and losses are minimized, and the violation of the constraints are also reduced. The effect of uncertainties is tested on 20% load increment and 20% load decrement, in both cases, the recommended expansion planning does not interrupt the line flow and voltage limit constraints while other planning violates these constraints.

TABLE 7.19

COMPARISON OF THE UNCERTAINTY EFFECTS ON THE EXPANSION PLANNING ON LOAD INCREMENT

	20% Increment in Load			
	EC (M$/year)	Losses (pu)	No. of violation in voltage constraints	No. of violation in line flow constraints
Proposed QPSO plan with uncertainties	3.7236	0.0576	0	0
Proposed QPSO plan without uncertainties	3.7956	0.0564	1	1
PSO plan [10] with uncertainties	3.8130	0.0556	0	0
PSO plan [10] without uncertainties	3.8850	0.0546	1	1

TABLE 8.20

	20% Decrement in Load			
	EC (M$/year)	Losses (pu)	No. of violation in voltage constraints	No. of violation in line flow constraints
Proposed QPSO plan with uncertainties	3.7236	0.0304	0	0
Proposed QPSO plan without uncertainties	3.7956	0.0208	0	0
PSO plan with uncertainties	3.8130	0.0218	0	0

PSO plan without uncertainties	3.8850	0.0124	0	0

COMPARISON OF THE UNCERTAINTY EFFECTS ON THE EXPANSION PLANNING ON LOAD DECREMENT

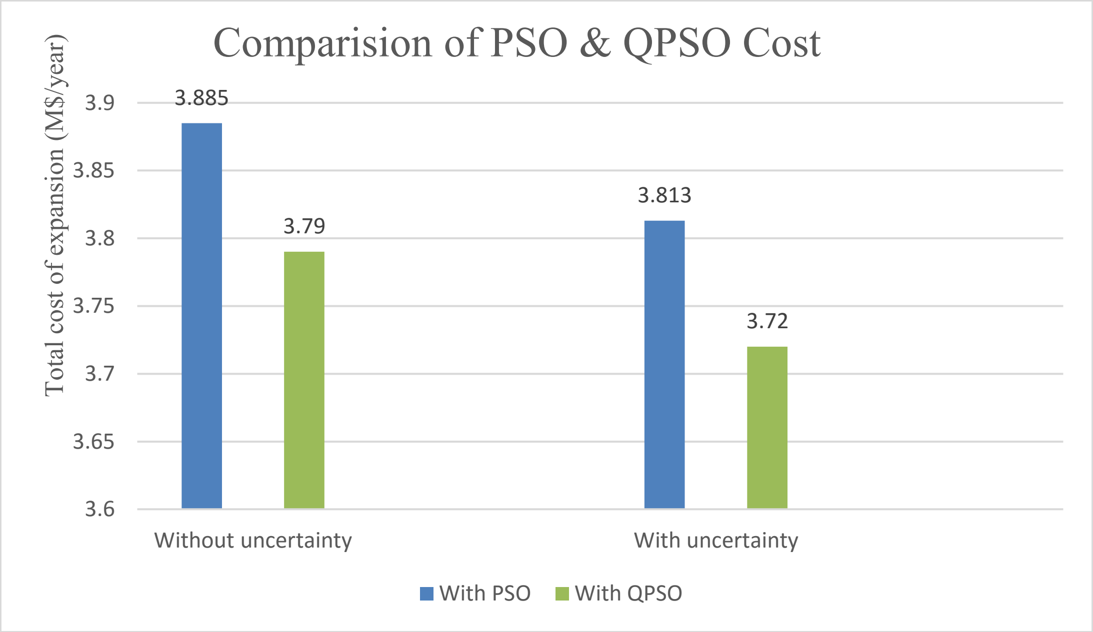

Fig. 7.13 Comparison of expansion cost obtained by PSO and QPSO for 72 bus network

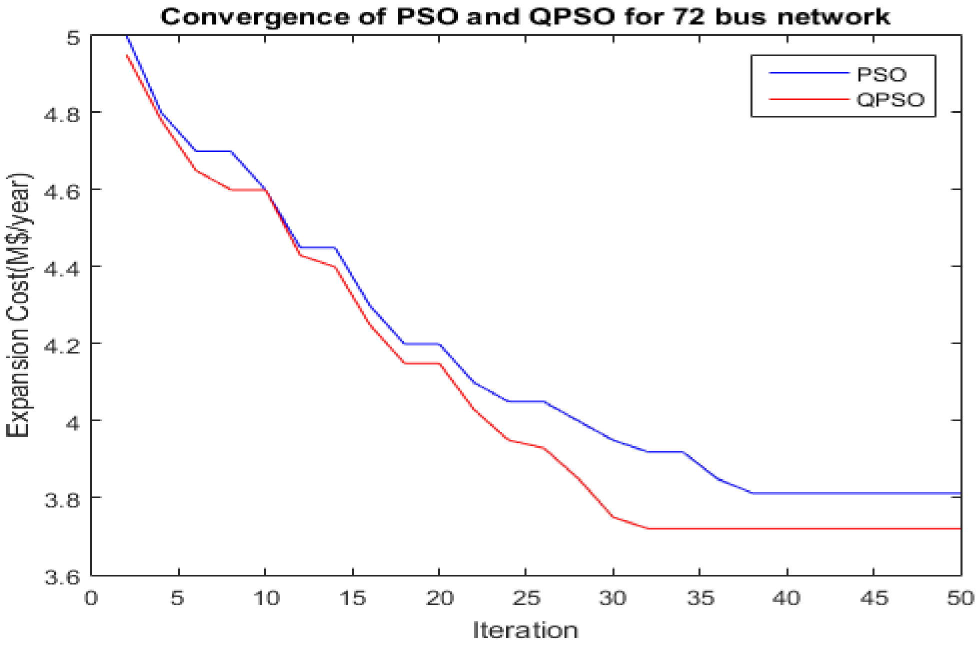

Fig. 7.14 Convergence graph of PSO and QPSO for 72 bus network

The graphical representation of a comparison of expansion planning cost obtained by PSO and QPSO is shown in fig 7.13. Convergence graph of PSO and QPSO is shown in fig 7.14, which shows that QPSO gives the optimal solution in less number of iteration and lower cost of planning than PSO algorithm.

CHAPTER 8

CONCLUSION AND FUTURE SCOPE

Distribution System Expansion Planning (DSEP) answers the services to be mounted and/or reassembled so that the distribution system fulfills the predicted load requirement at the lower cost and satisfy all operational and technical constraints in the particular planning horizon while ensuring the consumer reliability and power quality standards. The emergence of DG technologies as an alternative for energy production has changed the traditional, centralized to a distributed and large scale power generation to small-scale power generation. The important conclusions drawn from this thesis work are summarized below:

This paper proposed a model for distribution system expansion planning in the existence of price and load uncertainties with the integration of DGs is, which minimize the operation and investment cost of substations, feeders, DGs and energy purchasing. This model satisfies the voltage limit, DG capacity, substation capacity, feeder transfer capacity and radial configuration constraints properly. PSO and QPSO algorithm are used as a solution tool to explain this multistage expansion planning. Nine bus and 72 bus distribution system is used for a case study of uncertainties impact and DG integration in expansion planning. The price and load uncertainties are molded as normal PDF and inserted by Monte Carlo simulation. The expansion planning is performed with and without uncertainty, with and without DG integration in such a way that, the impact of uncertainties consideration and DG integration is clearly observed. The result of DG integration demonstrates improvement in voltage Profile and system performance, reduction in expansion planning cost as well as losses.

FUTURE SCOPE

This work can be further extended by applying the proposed algorithm on different test systems and comparison of the proposed method can be done by solving the proposed distribution system expansion planning with different optimization techniques. The proposed expansion planning is further extended by the addition of reliability constraints, DG uncertainties with load and price uncertainties so that an efficient and robust expansion plan should be made which can meet the increasing load demand at a lower cost to the consumer with providing a right amount reliability.

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Load level	Peak loading (%)	Time period in (hour)	Electricity price in ($/MWh)
High	100	1500	70
Medium	70	5000	49
Low	50	2260	35

APPENDIX

TABLE A.1
LOAD LEVEL AND ENERGY COST

TABLE A.2
TECHNICAL/COST PARAMETRES

Planning Parameters	Value

Planning time Horizon of project (year)	30
Interest rate (%)	12.5%
Maintenance cost	3% of total cost of investment
power factor of Load (LPF)	0.85
operation power factor (OPF) of DG	0.9
Acceptable voltage fluctuation (%)	5
Substation Upgradation cost (M$)	0.8
investment Cost of DG (M$/MVA)	0.318
Operation Cost of DG ($/MVAh)	50

TABLE A.3

BUS DATA FOR 9 BUS NETWORK

BUS NO	VOLTAGE	ANGLE	P_G	Q_G	P_D	Q_D
1	1.0400	0	0	0	0	0
2	1.0253	0	1.630	0	0	0
3	1.0253	0	0.850	0	0	0
4	1	0	0	0	0	0
5	1	0	0	0	0.90	0.30
6	1	0	0	0	0	0
7	1	0	0	0	1	0.35
8	1	0	0	0	0	0
9	1	0	0	0	1.25	0.50

TABLE A.4

LINE DATA FOR 9 BUS NETWORK

Sending Bus	**Receiving Bus**	**R(in ohm)**	**X(in ohm)**	B(IN MHO)	NOMINAL TAP RATIO
1	4	0	0.0576	0	1
4	5	0.017	0.0920	0.158	1
5	6	0.039	0.1700	0.358	1
3	6	0	0.0586	0	1
6	7	0.0119	0.1008	0.209	1
7	8	0.0085	0.0720	0.149	1
8	2	0	0.0625	0	1
8	9	0.0320	0.1610	0.306	1
9	4	0.010	0.0850	0.176	1

TABLE A.5

CANDIDATE LOAD DATA FOR 9 BUS NETWORK

Bus No.	Peak demand (MVA) at stage 1	Peak demand (MVA) at stage 2
2	6.1860	6.6508
3	5.4800	6.7900
4	6.1860	6.6508
5	-	3.4822
6	3.7084	3.9870
7	4.4306	5.7454
8	4.9472	5.3190
9	4.1618	4.4746

TABLE A.6

BUS DATA FOR 72 BUS NETWORK

BUS NO	VOLTAGE	ANGLE	PG	QG	P_D	Q_D
1	1.040	0	0	0	0	0
2	1.025	0	1.630	0	0	0
3	1.025	0	0.850	0	0	0
4	1	0	0	0	0	0
5	1	0	0	0	0.90	0.30
6	1	0	0	0	0	0
7	1	0	0	0	1	0.35
8	1	0	0	0	0	0
9	1	0	0	0	1.25	0.50
10	1.040	0	0	0	0	0
11	1.025	0	1.630	0	0	0
12	1.025	0	0.850	0	0	0
13	1	0	0	0	0	0
14	1	0	0	0	0.90	0.30
15	1	0	0	0	0	0
16	1	0	0	0	1	0.35
17	1	0	0	0	0	0
18	1	0	0	0	1.25	0.50
19	1.040	0	0	0	0	0
20	1.025	0	1.630	0	0	0
21	1.025	0	0.850	0	0	0
22	1	0	0	0	0	0
23	1	0	0	0	0.90	0.30
24	1	0	0	0	0	0
25	1	0	0	0	1	0.35
26	1	0	0	0	0	0

27	1	0	0	0	1.25	0.50
28	1.040	0	0	0	0	0
29	1.025	0	1.630	0	0	0
30	1.025	0	0.850	0	0	0
31	1	0	0	0	0	0
32	1	0	0	0	0.90	0.30
33	1	0	0	0	0	0
34	1	0	0	0	1	0.35
35	1	0	0	0	0	0
36	1	0	0	0	1.25	0.50
37	1.040	0	0	0	0	0
38	1.025	0	1.630	0	0	0
39	1.025	0	0.850	0	0	0
40	1	0	0	0	0	0
41	1	0	0	0	0.90	0.30
42	1	0	0	0	0	0
43	1	0	0	0	1	0.35
44	1	0	0	0	0	0
45	1	0	0	0	1.25	0.50
46	1.025	0	1.630	0	0	0
47	1.025	0	0.850	0	0	0
48	1	0	0	0	0	0
49	1	0	0	0	0.90	0.30
50	1.040	0	0	0	0	0
51	1.025	0	1.630	0	0	0
52	1.025	0	0.850	0	0	0
53	1	0	0	0	0	0
54	1	0	0	0	0.90	0.30
55	1	0	0	0	0	0
56	1	0	0	0	1	0.35
57	1	0	0	0	0	0
58	1	0	0	0	1.25	0.50
59	1.040	0	0	0	0	0
60	1.025	0	1.630	0	0	0
61	1.025	0	0.850	0	0	0
62	1	0	0	0	0	0
63	1	0	0	0	0.90	0.30
64	1	0	0	0	0	0
65	1	0	0	0	1	0.35
66	1	0	0	0	0	0
67	1	0	0	0	1.25	0.50
68	1.040	0	0	0	0	0
69	1.025	0	1.630	0	0	0
70	1.025	0	0.850	0	0	0
71	1	0	0	0	0	0
72	1	0	0	0	0.90	0.30
73	1	0	0	0	0	0
74	1	0	0	0	1	0.35
75	1	0	0	0	0	0
76	1	0	0	0	1.25	0.50

77	1.040	0	0	0	0	0

Table A.7

Line data for 72 bus network

Sending Bus	**Receiving Bus**	**R(in ohm)**	**X(in ohm)**	B(in mho)
1	4	0	0.0576	0
14	5	0.017	0.0920	0.158
51	6	0.039	0.1700	0.358
31	6	0	0.0586	0
66	7	0.011	0.1008	0.209
17	8	0.008	0.0720	0.149
11	2	0	0.0625	0
28	73	0.032	0.1610	0.306
19	24	0.010	0.0850	0.176
11	42	0	0.0576	0
54	25	0.017	0.0920	0.158
35	73	0.039	0.1700	0.358
43	67	0	0.0586	0
16	72	0.012	0.1008	0.209
47	16	0.008	0.0720	0.149
68	21	0	0.0625	0
43	73	0.032	0.1610	0.306
29	41	0.010	0.0850	0.176
16	42	0	0.0576	0
43	74	0.017	0.0920	0.158
54	65	0.039	0.1700	0.358
33	60	0	0.0586	0
68	76	0.011	0.1008	0.209
70	22	0.008	0.0720	0.149
8	2	0	0.0625	0
38	49	0.032	0.1610	0.306
9	4	0.010	0.0850	0.176
56	40	0	0.0576	0
4	5	0.017	0.0920	0.158
58	61	0.039	0.1700	0.358
39	56	0	0.0586	0
67	76	0.012	0.1008	0.209
71	33	0.008	0.0720	0.149
57	74	0	0.0625	0
8	9	0.032	0.1610	0.306
23	77	0.010	0.0850	0.176
32	77	0	0.0576	0
48	52	0.017	0.0920	0.158
54	63	0.039	0.1700	0.358
36	61	0	0.0586	0
67	75	0.011	0.1008	0.209
57	74	0.008	0.0720	0.149
9	77	0	0.0625	0

48	74	0.032	0.1610	0.306
77	42	0.010	0.0850	0.176
19	47	0	0.0576	0
43	51	0.017	0.0920	0.158
59	67	0.039	0.1700	0.358
30	29	0	0.0586	0
66	73	0.011	0.1008	0.209
71	55	0.008	0.0720	0.149
8	2	0	0.0625	0
8	9	0.032	0.1610	0.306
9	4	0.010	0.0850	0.176
11	43	0	0.0576	0
4	5	0.017	0.0920	0.158
51	62	0.039	0.1700	0.358
37	64	0	0.0586	0
46	16	0.011	0.1008	0.209
7	8	0.008	0.0720	0.149
8	2	0	0.0625	0
8	9	0.032	0.1610	0.306
66	42	0.010	0.0850	0.176
10	30	0	0.0576	0
40	50	0.017	0.0920	0.158
50	69	0.039	0.1700	0.358
3	6	0	0.0586	0
6	7	0.011	0.1008	0.209
9	77	0.008	0.0720	0.149
8	2	0	0.0625	0
8	9	0.032	0.1610	0.306
23	77	0.010	0.0850	0.176
1	4	0	0.0576	0
4	5	0.017	0.0920	0.158
5	6	0.039	0.1700	0.358
70	76	0	0.0586	0
6	7	0.011	0.1008	0.209

TABLE A.8

NEW LOAD DATA FOR 72 BUS NETWORK

Installation Bus number	Load (kW + j kVAR)	Planning Stage
73	180+100i	1
74	200+1.100000e+02i	2

75	280+150i	3
76	250+130i	4
77	2.300000e+02+120i	5

TABLE A.9

CANDIDATE LINE INFORMATION DATA FOR 72 BUS NETWORK

Line number	Line length(m)	Line number	Line length(m)
28–73	216	23–77	59
35–73	491	32–77	201
43–73	387	70–76	326
43–74	387	68–76	237
48–74	491	67–76	29
57–74	345	67–75	548
9–77	326	64–75	237