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ENVIRONMENTAL/ECONOMIC SCHEDULING OF A MICROGRID WITH RENEWABLE ENENGY RESOURCES USING PARTICLE SWARM OPTIMIZATION TECHNIQUE

A THESIS SUBMITTED TO THE FACULTY OF ENGINEERING AND TECHNOLOGY JADAVPUR UNIVERSITY IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF ENGINEERING IN POWER ENGINEERING

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Jadavpur University
Department of Power Engineering
Certificate of Recommendation

We hereby recommend the thesis, entitled, ***"ENVIRONMENTAL/ECONOMIC SCHEDULING OF A MICROGRID WITH RENEWABLE ENERGY RESOURCES USING PARTICLE SWARM OPTIMIZATION TECHNIQUE"*** *prepared under the guidance of Prof.(Dr.) Kamal K Mandal and Mr. Bhimsen Tudu,Department Of Power Engineering, Jadavpur University, 2nd campus, Kolkata -700098, by Soumyadip Roy, be accepted in partial fulfillment of the requirements for the award of the Degree of "Master of Engineering" in Power Engineering Department at Jadavpur University.*

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The foregoing thesis is hereby approved as a creditable study of an engineering subject carried out and presented in a manner satisfactory to warrant its acceptance as a prerequisite to the Degree for which it has been submitted. It is understood that by this approval the undersigned does not necessarily endorse or approve any statement made, opinion expressed or conclusion drawn therein but approved the thesis only for the purpose for which it is submitted

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Declaration of Originality and Compliance of Academics Ethics

*I hereby declare that this thesis entitled, "**Environmental/Economic Scheduling of A Microgrid with Renewable Energy Resources using Particle Swarm Optimization Technique**", contains literature survey and original research work by the undersigned candidate, as a part of my Degree of Master of Engineering in Power Engineering Studies.*

All the information in this document has been obtained as presented in accordance with academic rules and ethical conduct.

I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.

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Abstract

The demand of electric power consumption is increasing day by day where as the alternating energy resources i.e. fossil fuel reserves are exhausting and it has harmful environmental effects. Introduction of Hybrid energy and Microgrid can solve this kind of problem. The concept of microgrid is very much significant where transmission of electric power is not feasible or not profitable. An efficient scheduling of microgrid can meet load demand without shedding any load and the optimization is required to make it profitable and eco-friendly.

In this regard this thesis work implements a 24 hours based environmental/economic scheduling of distributed generating units with renewable energy sources in a microgrid connected with main grid .This thesis work proposes a framework for optimal scheduling of microgrid which minimize the cost of generating units as well as emission. **Particle Swarm Optimization** technique has been employed to solve this problem. Weighting factor is used for optimization in multi-objective framework where both cost and emission are minimized simultaneously.

In this thesis work, a comparative study of employing different types of Particle Swarm Optimization has been made where Hierarchical Particle Swarm Optimization (HPSO) performs better incorporating different constraints. The results of proposed Particle Swarm Optimization method are compared and verified with results of others method which is recently employed. Finally, the comparison study indicates that proposed method gives superior solution than previous method in case of operating cost and emission.

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1 Introduction

Electrical Energy is a basic necessity for the economic development of a country. Many functions which are necessary to live in present days will be stopped in absence of Energy. It is practically impossible to evaluate the actual role of Energy that has played to build up the present day civilization. Some factors like living standard etc. are fully or partially dependent on Energy.

Energy exists in different form in nature but the most important form is the Electrical Energy. The consumption of Electrical Energy across the whole world is increasing day by day. But Electrical Energy in bulk is generated only in centralized areas because of availability of raw materials. These are called Generating station. After generating the power, it has to be transmitted over a long distance which is called Transmission System. Then energy is distributed over the consumers called Distribution system. Several technical and non technical problems are arised in this total process which have to take in account and minimized by the introduction of Distributed Generation. In this research work different sources of energy are used to develop a Distributed Generating System and cost is optimized with optimal scheduling using Particle Swarm Optimization (PSO) technique.

1.1 An Overview of Power System

The basic components of Electrical power systems are Generating system, Transmission system and Distributed system. First of all generating system consists of different kinds and different size of generators as per requirement. The voltage level of these generators are generally from 11 to 25 KV. But at the time of Transmission this voltage level is increased up to 765 KV but generally 132 KV to decrease the line loss which is directly proportional to the current. As the power is constant when voltage level is stepped up, the current level is decreased. After transmitting the power the voltage level is again stepped down to the level of Distribution voltage. In a distribution system all loads are connected in a particular area to the transmission lines. Power is transmitted through transmission lines from generating station to distributed system.

Individual power systems are connected to the regional grids for economical and technological advantages where as regional grids can operate technically independently but these are interconnected and form a national grid. But the Distributed Generation (DG) by Independent Power Producers(IPP) can generate electric power by whatever means and is allowed to access to the power grid for selling power to the consumers.

A Microgrid is a localized grouping of electricity generation, energy storage, and loads that normally operate connected to a traditional centralized grid (Maingrid).The microgrid can then function autonomously. Generation and loads in a microgrid are usually interconnected at low voltage and it can operate in DC, AC or the combination of both. According to the recent developments in renewable energy systems, storage systems, and the nature of newly emerging loads, there are so many for comparing the efficiency and performance of AC and DC microgrids.

1.2 Different kinds of sources of Electrical Energy

Sources of energy can be classified into two main groups: Conventional and Non Conventional.

1.2.1. Conventional Source of Energy

Conventional energy such as thermal power, hydro electric power are used from many years ago and becomes abundant at present. Generally these kinds of energy sources are non renewable except hydro electric power. These sources of energy generally cause pollution from their emission.

1.2.2. Non-Conventional Source of Energy

Non-Conventional energy such as Solar energy, Geothermal energy, Wind energy, Tidal energy etc. are used from recent few years and becomes popular at present. Generally these kinds of energy sources are renewable. These sources do not cause pollution and they are cheaper in running cost than Conventional Energy.

1.3 Renewable Energy in India

Renewable energy sources are appearing as best alternatives of conventional energy sources in India. India' annual solar installation will grow over four times by 2017. Solar capacity of 10.86 will be added by 2016-17. The target of Indian government is to generate 175 GW by renewable energy sources at the end of 2022.

Table1.1: Installed Grid Interactive Power Capacity in India as of 2016[1]

Source	Total installed capacity(MW)
Wind Power	26,769.05
Solar Power	6,762.85
Biomass Power	4,831.33
Small Hydro Power	4,273.90
Waste to power	115.08
Total	42,752.21

1.4 Hybrid Energy

Hybrid renewable energy systems are becoming popular as stand-alone power systems for providing electricity in remote areas due to advances in renewable energy technologies and subsequent rise in prices of petroleum products. A hybrid energy system, or hybrid power, usually consists of two or more renewable energy sources used together to provide increased system efficiency as well as greater balance in energy supply. Its features are given in below.

- Hybrid energy systems are fuel flexible, efficient, reliable, economic.
- Generally, hybrid energy has an ability to conserve energy compared individual technology.
- Redundant technology and energy storage improves reliability of hybrid energy.

1.5 Importance of this research work

There are several disadvantages of conventional power system such as polluted emission by fossil fuel based power plant, decreasing amount of fossil fuel, transmission loss etc where as load demand is increasing day by day. From here concept of Microgrid comes.

A microgrid system generally consists of distributed generating units with Renewable Energy sources (RES), energy storage systems and controllable or uncontrollable loads. There is also a provision where micogrid can connect with maingrid. As per load demand, microgrid can export power to main grid or import power from maingrid, maintaining the frequency and voltage level. The advantage is that it gives more reliability, as well as cost of generation can be optimized in present energy market. Microgid system is more significant where pricing of utility grid is changing from hour to hour. By a perfect scheduling of microgrid components, it is possible to optimize both cost and emission simultaneously where the objectives are of conflicting nature. The combined economic emission load dispatch problem is a complex combinatorial optimization problem and several optimization techniques have been applied in several research works to solve these kinds of problems. Particle Swarm Optimization technique is applied to solve this problem. A test microgrid model consists of micro turbne, fuel cell, PV cell, Wind turbine and Battery connecting with main grid is used as attest model in this research work.

In this research work, in first step, only economic side is considered that means cost is optimized where emission is neglected and evaluate both cost and emission by using Particle Swarm Optimization.

In second step, only emission is minimized where cost is neglected and evaluate both cost and emission.

In third step both cost and emission are optimized simultaneously with same weighting factor and evaluate both cost and emission.

In forth step, a comparison study using different PSO has been made.

In fifth step, a modified 24 hours basis study has been proposed where both cost and emission are minimized fairly.

1.6 Outline of Thesis report

This Thesis report contains eight chapters.

In *chapter 2*, the concept of microgrid and distributed generation is discussed. This chapter also gives information about key features, different types of microgrids and different modes of operation and control.

In *chapter 3,* previous and recent research works about economic dispatch problem and combined economic and environmental dispatch problem have been discussed. Soft computing techniques used by different researchers for this problem are highlighted in this chapter.

In *chapter 4,* different types of soft computing technique such as Genetic Algorithm, Differential Evolution algorithm, Particle Swarm Optimization, Cuckoo Search method, Ant Colony Optimization, Firefly Algorithm are discussed briefly.

In *chapter 5*, concept, basic algorithm and flow chart of Particle Swarm Optimization are discussed and different types of PSO such as Canonical Particle Swarm Optimization, Time Varying Inertia Weight Particle Swarm Optimization, Stochastic Inertia Weight Particle Swarm Optimization, Time Varying Coefficient Particle Swarm Optimization and Fully Informed Particle Swarm Optimization are highlighted in this chapter.

In *chapter 6*, problem formulation and solution technique are focused.

In *chapter 7*, results obtained from calculations are discussed, compared and verified with previous method. Results from different PSO methods are analyzed in this chapter.

In *chapter 8*, the conclusion of the work and the future scope of microgrid has been given.

2 An Overview of Microgrid with Distribution Generation

Wide utilization of Renewable power resources and decentralization of power generation are two main trends of present development of electric power system. The power generation capacities of these generators are small basically from kilowatts to few megawatts and these are known as distribute generator. These are automatically operated or remote control based operated. In today's environment, balancing between power generation and consumption is a very much significant issue because of higher consumption rate. All power consumed in any area should be generated in that area. The concept of microgrid is very much useful here.

2.1 Basic Concept of Microgrid

Microgrids are generally integration of Renewable Energy Sources (RES), Energy Storage System(ESS) and loads in same grid[2]**.** In other language microgrids are the tiny power system which consist of various components such as Distributed Generating units, storage devices, Point of common coupling(PCC) and controlled and uncontrolled loads operating together in a coordinated manner. There are also protective devices integrated with controlled power electronics devices in purpose of active and reactive power flow control and voltage and frequency regulation[3].

2.2 Key Features of Microgrid[4]

I. Microgrid can operate in two modes, island mode and grid connected mode.
II. As per requirements, microgrids are capable to connect or disconnect to the main utility grid.
III. It should be able to meet peak load demand.
IV. The distributed energy sources and energy storage device which are incorporated in microgrid should be able to control and operate by a master operator.

2.3 Classification of Microgrid

Microgrid can be classified into two categories based on their operation field, AC microgrid system and DC microgrid system.

2.3.1 AC Microgrid System

Normally an AC microgrid system is connected with a Medium Voltage system at Point of common coupling. A typical model is shown in figure where two AC systems are formed incorporating with DGs, ESSs and loads. In this system, in normal operating condition load demands are met by distributed generating units, ESS and sometimes by utility grid. When power demand is more than generation, then power is imported from utility grid and when power demand is less than power generation the surplus power is exported to utility grid.

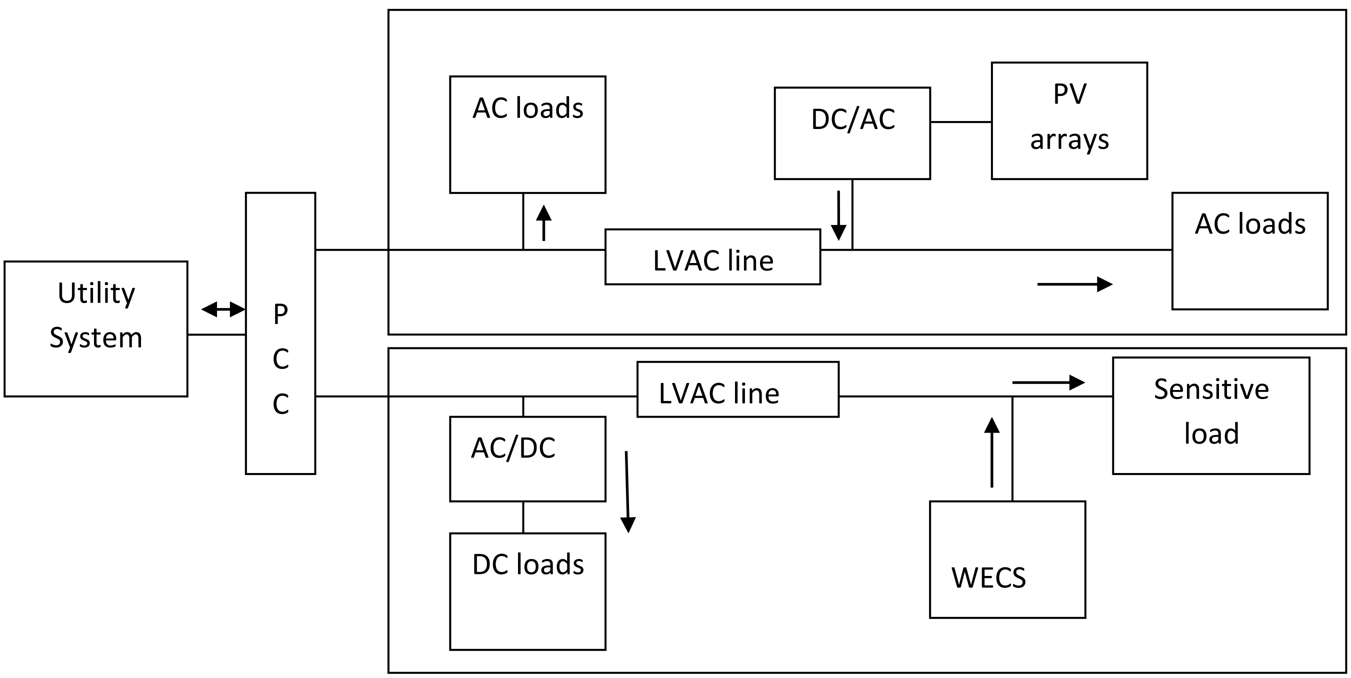


Figure2.1: AC microgrid structure with the DG units and mixed types of loads.

These two AC systems connected to low voltage AC lines are called AC microgrid. Microgrids can operate individually and met the load demand. AC/DC or DC/AC converters are required both loads and distributed generating units may be in form either AC or DC. Power electronics devices are used in micogrids to control the power flow. Economic operation of a microgrid can be optimized by Smart Energy Management System (SEMS) strategy which uses DG units power output forecasting and ESS management [3].

2.3.2 DC Microgrid system

In traditional electric power system High Voltage AC (HVAC) is used in transmission lines and lower voltage AC is used in distribution lines. But there are several applications of DC power system such as industrial power distribution system, telecommunication infrastructure, point to point transmission over long distance etc. Power electronics devices which are used in microgrid to control power flow required DC power for their operation. If AC microgrids are used in such application, power conversation is mandatory where rectifiers are very much inefficient. In another case where DC based DGs are used first DC has to be converted into AC to connect with the AC grid and AC/DC conversion is required before use in DC based application [3]. A DC microgrid with DG units and mixed types of loads is shown in figure3.2

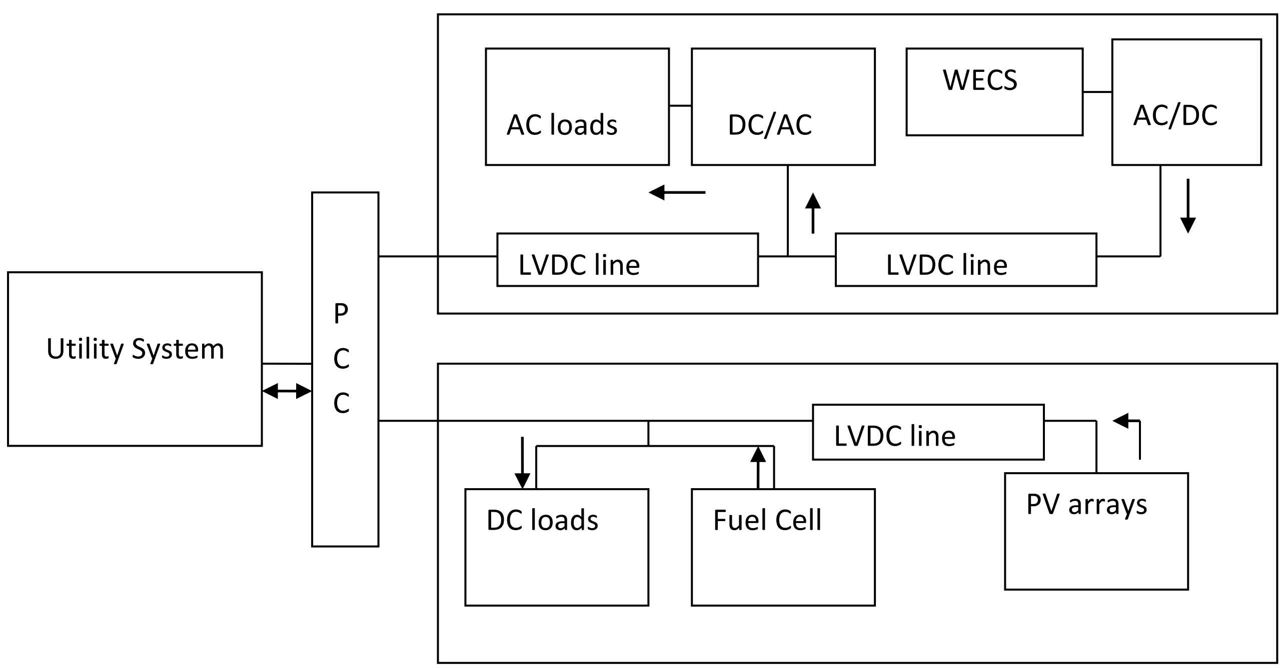


Figure2.2: Model of a DC microgrid system with the DG units and mixed types of loads

As same as AC microgrid, utility grid is connected with the DC microgrid via a PCC. DGs, ESS and loads are connected with LVDC lines.

2.4 Different modes of connection of Microgrid

Actually, there are two modes of operation of both AC and DC microgrid. One is grid connected mode and another one is islanding mode.

2.4.1 Grid connected Mode

Grid connected mode means microgrid is connected with utility grid via point of common coupling(PCC). In grid connected mode, in case of AC microgrid, active and reactive power of DG units are controlled and ensuring synchronized operation, exchange of power with utility grid is maintained by Microgrid Central Controller(MGCC). In case of DC microgrid, the power flow and load end voltage profile of the DG units are controlled independently by MGCC in response to any disturbance and load changes.[3]

2.4.2 Islanding Mode

Islanding mode means microgrid is not connected with utility grid and operates separately. In islandind mode, in case of AC microgrid, the function of MGCC is to control active and reactive power of DGs for maintaining stability. It is duty of MGCC of AC microgrid that to switch to grid connected mode when utility grid supply is restored with maintaining the voltage and frequency stability. In case of DC microgrid, it is duty of MGCC to control power flow and load end voltage profile independently in any load variation and disturbance condition. MGCC automatically reconnects microgrid to the utility grid when utility grid is restored.[3]

2.5 Microgrid control and Power management

Proper control strategies are required for the power converters which are interconnected to the various components of microgrid. The vital points of control strategy [2] are

1. Energy should be imported from utility grid and exported to utility grid.
2. System voltage and frequency must be maintained within predefined limits.
3. Active and reactive power must be controlled.
4. Supply of DG should be coordinated and load sharing should be optimal.
5. For an optimal transmission of power microgrid should be synchronized with the the power network.

6. Cost should be optimized (minimized) and energy efficiency should be improved depending on market situation, power demand etc.

In grid connected microgrid system, signals from the main grid are used by the inverter as a reference to obtain the signal with correct frequency and voltage in purpose to improve the power factor etc. But in island mode operation where signal from main grid is not available reference voltage is generated by DG units individually and internally in both AC and DC microgrids. In this case DG units are operated as a controlled voltage sources and maintained load sharing [3].

2.6 Conclusion

Energy crisis becomes a major problem in recent power sector. Amount of fossil fuel is decreasing day by day where as power demand is increasing. In such a problem, power generated from renewable energy sources is highly demanded but the problem is that it can not be possible to generate a large amount of power from that kind of sources. Thus the concept of microgrid comes and it has a great future trends. Microgrid can meet the power demand efficiently in an optimized way. Many research works are continuing to schedule the power flow of microgrids in an optimized way. Another advantage of using microgrid is the pollution less generation of distributed generators. Transmission loss can be successfully minimized by using microgrid. In microgrid concept, different types of generating units operate together and it is presented as a single generating units.

3 Recent works on Hybrid Energy and Environmental-Economic Dispatch

There are so many research works based on modeling and operation of hybrid energy because the concept of hybrid energy is becoming popular in remote areas where transmission of conventional electrical energy is not feasible or costing is very high. Source of fossil fuels are decreasing day by day and use of renewable energy sources has great advantage of free of pollution and also minimum running cost. That's why optimization of hybrid energy models to increase performance and efficiency are gaining popularity by researchers. Optimization is required for sizing, combinations, operation strategy or scheduling of these sources.

In today's environment, it is also a major issue that pollutants produced by fossil-fueled electric power plants are increasing and it becomes a matter of concern. The environmental protection requirement can not be met by the conventional economic power dispatch when only economic side (minimization of cost) is considered.

But now a days, it is possible to develop hybrid energy system model, environmental-economic dispatch model in power system by using few analytical methods and meta-heuristic methods like particle swarm optimization, genetic algorithm, evolutionary algorithm etc. Meta-heuristic methods are very much efficient than analytical methods in real application generally where equations are non-linear. Meta-heuristic is an iterative generation process which can solve most of the complex combinatorial optimization problems very easily by the use of computer programming. But analytical methods are not iterative process and it takes less time to obtain result. There is no convergence problem in analytical method.

The multi-objective optimization technique has been implemented in many research works to size, model, schedule or combination of hybrid system to increase performance and efficiency or to minimize cost and emission simultaneously. There are so many research works where performance of micro-grid or hybrid renewable energy system has been analyzed after applying multi-objective optimization.

Seeling-Hochmuth[5] proposed a method where optimal operation strategy and sizing of hybrid PV system have been achieved by using cost/benefit function for the optimization of hybrid system formulated by Marrison and Seeling-Hochmuth.

The sizing optimization that means optimize capacity sizes of hybrid solar-wind power generation system employing a battery bank has been presented by Yang et al.[6]The optimization sizing has been developed in this paper based on Loss of power supply probability (LPSP) concept and Levelised Cost of Energy (LCE) concept.

Ekren et al.[7] have optimized size of autonomous PV/wind hybrid energy system using Response Survey Methodology (RSM) and break-even analysis has been done to decide optimal distance. Finally, the result has shown that more than 4817 m, hybrid energy system installed at GSM based station is more economical than electricity network.

A methodology has been developed by Muselli et al.[8] for optimized size of hybrid PV system incorporating with diesel or gasoline based electrical generator and its management for cost minimization.

Three hybrid systems i.e, PV/Battery system, PV/Fuel cell system and PV/Battery/Fuel cell system have been developed and analyzed by Li et al.[9] in a multi-objective framework where both cost and efficiency of the system have been minimized and verified that PV/Battery/fuel cell has given minimum cost and higher efficiency.

An optimization of system performance and cost of a stand-alone solar powered, battery-hydrogen hybrid energy storage system through 'state of charge' and 'intelligent' control strategy has been developed by Vosen et al.[10] where supply and demand has become matched daily and seasonally.

A Hybrid Renewable Energy Source based model's components, design and their evaluation have been described by Deshmukh et al.[11] in their research work.

A simulation based optimization procedure, OptQuest, integrating various heuristic methods has been applied on a PV/Wind hybrid system with battery storage by Ekren et al.[12] to minimize the hybrid energy system cost with varying the size where as Ekren et al.[13] have also applied Simulated Annealing algorithm to optimize the cost of a PV/wind integrated hybrid energy system with battery storage with varying size.

In research work of Protogeropoulos et al.[14], the main objective was to determine the optimal size of the components of a stand-alone system incorporating wind and PV and also battery storage with given weather forecasting and load demand data.

An optimized model for community based hybrid energy system with battery and diesel generator back up has been proposed by Ashok[15] and found the optimal combination with battery back up. The proposal was able to supply electricity in 24 hours.

Nazir[16] has designed a model of hybrid energy system employing micro-hydro-photovoltaic (MHP)system using HOMER and MATLAB software and has shown that minimum energy cost and minimized emission has been achieved by largest capacity of MHP.

Norouzia et al.[17] employed a new technique which is based on lexicographic optimization and ε-constraint method to solve the combined economic emission scheduling problem of a hydrothermal system. For hydrothermal scheduling, there are two objective functions which are minimized, one is cost function and another one is emission function. For this multi-objective optimization technique Pareto sets have been derived and fuzzy logic has been used to determine the most prefer solution. There are four cascade hydro units and three thermal units in presented model. The relation between water discharge rate and power generated through these hydro units is non-linear. This optimization method also has been applied on IEEE 18 bus test system. This technique has given better result than other approach.

Another application of optimal lexicographic optimization as well as hybrid augmented-weighted ε-constraint technique is discussed in below. Norouzi et al.[18] have proposed for short term security-constrained unit commitment for hydrothermal generation units. In this paper optimal lexicographic optimization as well as hybrid augmented-weighted ε-constraint technique has developed Pareto solution and Fuzzy decision maker has been utilized to determine the most preferable solution among the Pareto solution. Both cost and emission have been minimized of a modified IEEE 118-bus system comprising 54 thermal units and 8 hydro units by using this optimization technique. A comparison between result of proposed method and others method have been analyzed in this paper.

Ahmadi et al.[19] have proposed a hydrothermal self scheduling (HTSS) problem in a day ahead. The HTSS problem has been solved in multi-objective optimization framework that is maximize the GENCO profit and minimize the emission of this HTSS. For this problem Pareto optimal solutions have been formulated by using the lexicographic optimization and hybrid augmented-weighted ε-constraint technique. Fuzzy decision maker is used to determine most preferable solution and achieve the more profit and minimum emission. Finally the proposed method is applied on IEEE 118-bus system.

Rezvani et al.[20] have proposed a 24 hours based strategic scheduling of a microgrid consisting of micro turbine, fuel cell, PV cell, wind turbine and battery by employing lexicographic optimization and hybrid augmented-weighted epsilon-constraint method to generate Pareto optimal solution in multi-objective framework. Microgrid is also connected with utility grid. Fuzzy decision maker have been employed to obtain best solution from pareto sets. A competitive study of 24 hours based power output, cost and net emission of proposed method with others method is done and verified better performance.

Normal Boundary Intersection (NBI) is a popular methodology for a general nonlinear multi-criteria optimization problem. It can handle more than two objective function and it is successful in producing Pareto sets. Rezvani et al.[21]also applied NBI for the same microgrid model, Pareto sets have been generated by using Normal Boundary Intersection(NBI) and Fuzzy logic has been employed for decision making process. Finally, result of proposed method has been compared with other methods and verified that solution of proposed method is better for operation cost, emission and execution time. In both research works transmission loss has been ignored.

Vahidinasab et al.[22] have used normal boundary intersection(NBI) to develop an optimal bidding strategies for participants of oligopolistic energy market .A bi-level optimization have been used to develop optimal bidding strategy mathematically. After applying NBI technique, Pareto optimal sets have been generated and Fuzzy decision maker has been used to determine most prefer solution. The development algorithm also has been applied to IEEE 30 bus system.

Vahidinasab et al.[23] have proposed Multi-objective mathematical programming approach where the aim of the paper is to joint economic and emission dispatch in energy markets. A standard IEEE 30 bus system including six generators has been used as a test system in this problem. Proposed method has taken less time than strength Pareto evolutionary algorithm (SPEA).

Another important soft computing technique is Artificial Neural Network which is successfully used in optimization. Chaouachi et al. [24] have proposed an intelligent energy managing micro-grid model using artificial intelligence techniques jointly with linear-programming-based multi-objective optimization. Operational cost and emission of micro-grid both have been minimized in multi objective optimization environment taking in account pre-operational variables and load demand (LD). 24 hours ahead PV generation and 1 hour ahead wind power generation have been developed by an Artificial Neural Network (ANN). Battery has been scheduled in this paper by a fuzzy logic expert.

Meta-heuristic methods such as Particle Swarm Optimization, Modified Bacterial Foraging Optimization Firefly algorithm etc are very much useful tools in optimization.

Multi-objective chaotic particle swarm optimization technique have been applied by Cai, et al.[25] in two test system where objectives are both cost and emission minimization in two test power systems. Ultimately, cost and pollutant emission obtained from MOCPSO have been reduced to a significant value in two test system. In this paper, authors have shown that MOCPSO is more effective and feasible in cost and emission optimization than conventional MOPSO method.

There are also some modified PSO techniques applied for optimization problem. Another research work of Moghaddam et al. [26] is about minimization of both total cost and emission of micro-grid in multi-objective optimization environment. This micro-grid constitutes of various RES (Renewable Energy Sources) accompanied by back up Micro-turbine/Fuel Cell/Battery to make up or store the surplus energy. In this paper an expert multi-objective Adaptive Modified Particle Swarm Optimization has been used and Fuzzy Self Adaptive (FSA) structure has been utilized to improve the optimization process. The performance of proposed algorithm has been compared with PSO and Genetic Algorithm. An enhanced PSO technique has been used to solve dynamic economic emission dispatch (DEED) problem where total electrical energy cost and emission over a 24 hours time span has been minimized simultaneously. A self-adaptive probabilistic mutation strategy has been used by Aghaei et al.[27] to escape from local minima which has improved the quality of solutions attained by PSO. Finally it has applied to four test system. Multi-objective particle swarm optimization techniques have been used for EED problems and successfully generated a set of well distributed Pareto optimal solutions by Abido.[28] in his research work.

Wang et al.[29] have presented a multi-objective generation dispatch. In this study, a typical IEEE 118-bus test system with 14-generators is used to investigate the effectiveness of the proposed Fuzzified Multi-Objective Particle Swarm Optimization (FMOPSO) approach. Weighted Aggregation method in PSO and Multi-objective Optimization Evolutionary Algorithm have been used for same network for comparative study. Finally it has been shown that FMOPSO has given superior characteristics than Weighted Aggregation method and Multi-objective Optimization Evolutionary Algorithm Wang et al.[30] have implemented both deterministic and stochastic method and also improved PSO technique to obtain environmental-economic dispatch. a comparative study has been made between the proposed PSO approach and other approaches including weighted aggregation and evolutionary optimization.

Amer et al.[31]has given proposed optimization of generation of power from a hybrid renewable energy system. Particle Swarm Optimization has been used to reduce the levelized cost of energy.

Multi-objective chaotic ant swarm optimization(MOCASO) has been successfully implemented and verified by Cai et al.[32] for EED problem in three test system considering power balance constraints and generating limit constraints. Wang and Singh[33] have also used muli-objective PSO in their research work to present a reserve-constrained multi-area environmental/economic dispatch.

Apostopoulos et al.[34] have proposed, applied and tested firefly algorithm in two different test system for various load demands consisting of six generators to optimize both cost and emission and compared the result with PSO technique. This technique has given better power loss, generating cost and emission than PSO technique.

In recent environment it is necessary to produce efficient and reliable power with maintaining profitability of power systems operations and taking into account the environmental concern about emission of fossil-fuel based plants. Evolutionary algorithm have been implemented successfully for both cost and emission minimization. Wu [35] have shown superiority of multi-objective differential evolution algorithm for EED problem which has been tested in IEEE30 and IEEE 118 bus where as Niched Pareto genetic algorithm has been used by Abido[36] to find the optimized solution of environmental/economic load dispatch problem. These kinds of solution technique have no restriction of optimized objectives. Both cost and emission of IEEE 30 bus system have been minimized simultaneously by a non-dominated sorting genetic algorithm based approach which was proposed by Abido[37]. A diversity-preserving mechanism has been developed to find widely different Pareto optimal solutions.

A multi objective design of PV-wind-diesel-hydrogen-battery system has been presented by Dufo-Lopez et al.[38] where total cost throughout the useful life of the installation, emission and unmet load were the minimized objectives and both multi-objective evolutionary algorithm(MOEA) and genetic algorithm(GA) have been used.

Dufo-Lopez et al.[39] have developed Hybrid Optimization by Genetic Algorithm(HOGA) program to optimize size and operation control of a PV Diesel system by using C++ and compare with stand alone PV system, where solar irradiation are load demand are same.

Using genetic algorithm technique, Dufo-Lopez et al.[40] have designed PV diesel system to obtain most effectiveness.

Basu[41] has used non-dominated sorting genetic algorithm-II for dynamic economic emission dispatch problem to optimize conflicting objectives cost and emission. In this research work, a 24 hours based result as per load demand has been shown where ten unit test system with non-smooth fuel cost and emission has been used.

Motevasel et al. [42] have proposed an IEMS (intelligent energy management system) where cost and emission both have been optimized(minimized) efficiently of a CHP based micro-grid using MBFO(Modified Bacterial Foraging Optimization) algorithm. The entire micro-grid consists of various DERs, CHP systems, ESS and loads. A smart energy storage system consists of electrical and thermal storage has been introduced for optimal operation of micro-grid. Fuzzy decision maker has been used to simulate the trade-off between conflicting objectives cost and emission in multi objective optimization. The paper has shown that the optimized result of proposed IEMS has fulfilled load demand smartly with minimum cost and emission.

Mondal et al.[43] has employed gravitational search algorithm to solve the problem of economic emission load dispatch, where both thermal generator and wind turbine have been considered. IEEE 30 bus system consisting of six conventional thermal generators is the test system in this research work where two wind turbines have been into two weak load bus in the system.

Niknam et al.[44]have proposed a stochastic model for environmental economic dispatch of a micro-grid where both cost and emission are minimized**.** A scenario-based stochastic programming have been used to model forecasted load demand, available output power of wind and PV units and market pricing. To solve the proposed problem, a two-stage stochastic scenario based method has been implemented in this paper. At the first stage, all the discrete control variables have been made for all generation units before the uncertainty of input random variables are realized. The load demands, the market prices, and powers output of PV and WT units are the uncertain variables. These uncertainties have been realized using a scenario-based technique. In the next stage, continuous dispatch variables (wait-and-see) are generated. The performance of the presented algorithm has been improved by a novel self adaptive probabilistic modification strategy. In a repository, a set of non dominated solution has been stored and fuzzy-based clustering technique has been used to control the size of repository. Finally, the niching mechanism has been used to store the best expected compromise solution stored in the repository.

Analytical methods are not very much effective but these are used in muli-objective optimization. Palanichamy et al.[45] have proposed an analytical strategy based on mathematical modeling to minimize cost and emission simultaneously by a single equivalent objective function and this technique has been applied to dissimilar realistic system at different load conditions. Bayon et al. [46]have presented the exact analytical solution for EED problem and obtained Pareto optimal solutions taking into account the units capacity constraints. Finally, propsed method has been validated by using a standard test system. This method has provided global solution unlike heuristic methods.

LaGrangian Relaxation method has been implemented by El-Keib et al.[47] to solve environmentally constrained economic dispatch (ECED) problem. This paper has used the test system consisting of 101 units where 73 are coal-fired based,19 are oil based,6 are nuclear based and 3 units are combination of coal and oil. This test system has used an hourly load and corresponding unit commitment and transmission losses have considered here.

Combined economic and emission load dispatch(CEELD) has been also solved by a technique based on progressive articulation of preference information. Yalcinoz et al.[48] used a suitable non-linear optimization algorithm named NIMBUS algorithm which is based on standard multi objective programming. Finally the proposed method has been compared with the genetic algorithm and a neural network approach.

Hafez et al. [49] have planned and designed renewable energy based supply system for micro-grids. Optimal design, planning, sizing and operation of a renewable energy based micro-grid have been focused and the ultimate goal is to minimize the cost and emission simultaneously. A diesel only, a fully renewable based, an external grid connected micro-grid and a diesel renewable mixed have been designed to compare their performance. HOMER, the software for hybrid renewable energy system has been used in this purpose.

In real world problem different practical constraints such as ramp rate limits, muli-fuel option, operating zones, transmission losses etc make problem complex and it is very much challenging. Jeddi et al. have applied Modified Harmony Search Algorithm(MHSA) to solve both economic load dispatch problem and combined economic and emission load dispatch problem considering these practical constraints. A comparison study also has shown in this paper.[50]

Piperagkas et al.[51] have presented an extended stochastic multi-objective model for economic dispatch(ED) incorporating optimization process heat and power from CHP units and expected wind power. A multi-objective Particle Swarm Optimization technique has been used in this paper to solve the ED problem. In this paper inequality constraints are stochastic restrictions for CO_2, SO_2 and NO_x emission. Simulation has been performed on IEEE 30 bus network with 2 congestion units and actual wind data.

Asumait et al.[52]have described in their paper a novel hybrid approach based on combination of Genetic Algorithm(GA), Pattern Search(PS) and Sequential Quadratic Programming optimization(SQP) to study power system Economic Dispatch(ED) problem where valve point effect has taken in account. 3 test cases have been studied in this paper.

Chaotic Quantum Genetic Algorithm has been applied by Liao[53] to solve economic dispatch problem including wind farm where as an improved version of PSO has been applied by Coelho and Lee[54] to solve a economic dispatch problem where ramp rate limits and prohibited operating zones has been taken into account.

4 Soft Computing Techniques

Sometimes some real world problem cannot be modelled or too difficult to model mathematically. To design such a model, soft computing is the fusion of methodologies which enables solution to real world problems. The aim of soft computing is to enable the tolerance for imprecision, uncertainty, approximate reasoning and partial truth in order to achieve robustness and low cost solution. The guiding principle of soft computing technique is to compute an acceptable solution at low cost, by seeking for an approximate solution to an imprecisely or precisely formulated problem.

There are some difference between soft computing and hard computing. Unlike hard computing it has tolerance of approximation, imprecision and uncertainty. The human mind is the role model of soft computing technique and it is a part of artificial intelligence. Basically, the difficult problems which are very hard to answer, soft computing is a optimization technique to find that kinds of solutions.

Soft computing methods take a few of computational time than traditional hard computing methods .Soft computing was a formal area of study in Computer Science in the early 1990s.Fuzzy Logic, Neural Computing(NC),Evolutionary Computation(EC),Machine Learning(ML) are the principal constituents of soft computing.

Possibility is used in case of lack of enough information to solve a problem but soft computing technique is used in case lack of enough information about the problem itself. This is the main difference between possibility and soft computing. Now a days Soft computing techniques are the best alternatives for the traditional hard computing methods.

From the observation it is noticed that inductive reasoning plays a larger role in soft computing than in hard computing. Acquisition of information from inaccurate and uncertain data is the important features of soft computing.

4.1 Optimization

The optimization is the process for finding maximum or minimum output value with adjusting the input value for a given function. With this mechanism one can find the optimal value of a function or process by varying the inputs.

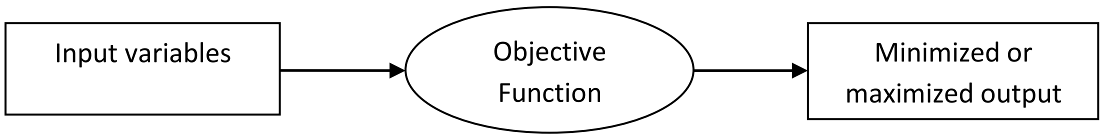


Figure 4.1: Optimization Process

This mechanism can be used in everywhere such as physics, chemistry, engineering etc to maximize efficiency and to measure optimal output. Optimization means either minimization or maximization the output of objective function and one is opposite to another.

Generally when a new idea or concept is formulated in the mind of an engineer or a scientist then optimization technique is used to improve and find the maximum efficiency. The perfect tool for the optimization is the computer where some input data are fed for a given objective function. After optimizing, computer gives the solution.

Exact methods generated solution in hand but it is not applicable for real life problems because large computation time is taken for their complex nature. Use of heuristic and meta-heuristics methods are fruitful application for these kinds of large problems. As computation time is significant, large and real life complex problems have been solved successfully by meta-heuristic methods by different researchers. Different methods are classified and discussed in below.

4.2 Components of Soft Computing

Soft computing is a group of methodologies where object is to exploit the tolerance for uncertainty to achieve low solution cost and robustness. Fuzzy logic, neural computation, probabilistic reasoning are the principal of soft computing. There are many application of soft computing where role model is the human mind.

Components of soft computing include:

- Neural Networks(NN)
- Support Vector Machines.(SVM)
- Fuzzy Logic(FL)
- Evolutionary Computation(EC) includes
    - Evolutionary Algorithms.
        - Genetic Algorithms.
        - Differential Evolution
    - Meta-heuristic and Swarm intelligence
        - Ant Colony Optimization
        - Particle Swarm Optimization
        - Firefly Algorithm
        - Cuckoo Search

Evolutionary computation are discussed in below.

4.2.1 Evolutionary Computation

Evolutionary Computation can be defined as subfield of artificial intelligence and the algorithms which are about evolutionary computation are called evolutionary algorithm. Iterative progress like growth of development in a population are used in evolutionary algorithm. After that, selecting the population in a guided random, parallel processing is used to achieve the desired end. Such kind of processes are similar to the biological mechanism of evolution. Growth in population is developed by iterative progression.

The evolution is simulated on a computer in evolutionary computation. The result of such simulation is a series of optimization algorithm. According to the iteration that optimization is recalled which improves the solution until the optimized solution is found. Evolutionary computation includes genetic algorithms, evolution strategies and genetic programming.

4.2.1.1 Genetic Algorithm

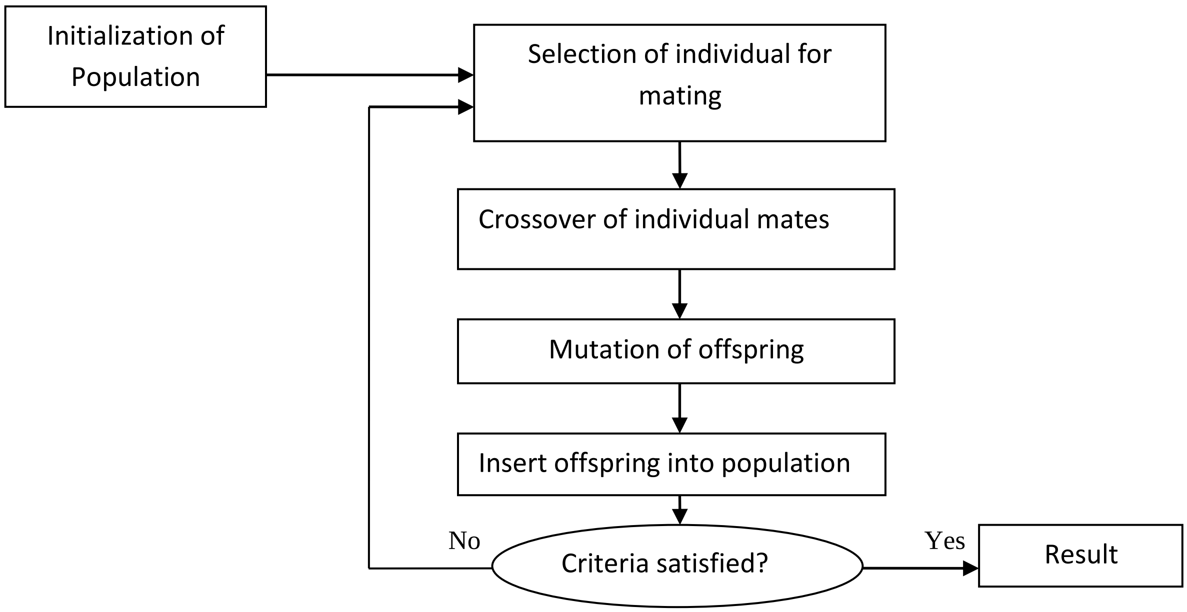
Genetic Algorithm was first proposed by John Holland[55]. It is a heuristic solution-search or soft computing approach which principals were inspired by natural genetics to solve the problem. Basically genetic algorithms are inspired by Darwin's theory about evolution. Each GA operates on a population of artificial chromosomes. Each chromosome represents a solution to a problem and has a fitness which is a real number to measure the performance of a solution to the particular problem.

GA starts with randomly generated population of chromosome and proceeds to produce a successor population on the basis of selection and recombination in the next generation. Child chromosome is produced by recombination of genetic material of parent chromosomes. In this way population is succeed until the number of iteration is completed. In this way GA generated a best solution to a given problem. A large number of engineering and scientific problem such as machine learning, automatic programming, optimization, adaptive control etc have been successfully solved by GA.GA has a great measure of success in optimization and search problem because of its ability to exploit the information accumulated from initially unknown search space. The large and complex problems which have poorly understood search space are specially solved by GA where classic tools are inappropriate, inefficient or time consuming.

Mechanism of GA

The fundamental stages of GA are given in below.

I. Initial population is generated randomly.
II. The chromosomes which give the best fitness values are selected.
III. Selected chromosomes are recombined using crossover and mutation operators.
IV. Offspring is inserted into the population.
V. If iteration is completed, return the chromosome(s) with the best fitness Otherwise, go to second step.



Genetic Algorithm has been used designing of hybrid energy system [56] and also size and operation control of PV-diesel system.[57]

4.2.1.2 Differential Evolution

Differential Evolution was first developed by Storm and Price in the year 1996[58].Generally real parameter and real valued functions are optimized by DE technique. Optimization of a function can be done by DE method and the quality of candidate solutions are improved on the basis of the specified measure of the quality. Multi-dimensional real valued functions are generally solved by DE. There may be no assumption or very few assumptions at the starting time of the program in case of DE but it covers a larger search space of the candidate solution.

The population or candidates of DE are known as agents. The function of these agents is to move in entire search space and improve the position. The improved agent then becomes a part of population and when there is no improvement population is discarded. This process is repeated until get a optimized solution.

Differential algorithm has been applied for environment and economic dispatch of IEEE 30 and IEEE118 bus system [59].

4.2.2 Meta-heuristic and Swarm intelligence

Different types of Meta-heuristic and Swarm intelligence are discussed in below.

4.2.2.1 Ant Colony Optimization (ACO)

The ant colony optimization was first proposed by Marco Dorigo and Colleages in 1992[60] based on the behavior of ants searching for food. At first the ant starts random search for food. When an ant finds a source of food, after leaving pheromones it comes back to the colony .The reason of leaving pheromones is to marks the path which has food. Ants also use pheromones to communicate information among individuals. The other ants come across the pheromones and follow the path. Then they also leave their pheromones to identify the path when they bring the food back.

Every time they bring food in shorter path because they drop pheromones. In meantime some ants are involved in random moving for closer food sources. Once the food source is depleted, the pheromones slowly decay with time and the route is no longer populated.

This optimization is very much useful in several difficult discrete combinational optimization problem like Travelling Salesman problem, Sequential ordering etc. As the ant colony works on very dynamic system .it works very well in graphs with changing topologies. In recent years ACO has been implemented successfully for continuous optimization problem.

It becomes possible to prove that some versions of algorithm are convergent. In 2000,it was convergent for the first time.

Solution construction, Pheromone update, Local search and Re-initialization are the four stages of ACO algorithm. Some of most popular algorithms of ACO are given in below.

1. Elitist Ant System
2. Max-min ant system
3. Ant colony system
4. Rank-based ant system
5. Continious orthogonal ant colony
6. Recursive ant colony optimization

Ant colony optimization has been successfully applied by Cai et al.[61] for EED problem in three test system.

4.2.2.2 Particle Swarm Optimization

Particle Swarm Optimization was proposed by Kennedy and Eberhart[70] in 1995. This technique is inspired by fish schooling and bird flocking. In PSO variables of the objective function are called particle. And swarms are the population where each population is prepared by objective function. The implementation of PSO is very easy and PSO results in faster convergence rate than other optimization technique. The details of PSO are discussed in next chapter.

Amer et al.[62] has used PSO technique to optimize power generation of a hybrid system. PSO has been successfully applied in another problem of microgrid for cost and emission minimization.[63]

4.2.2.3 Firefly Algorithm

Firefly algorithm was first developed by Xin-She Yang [64] in late 2007 and 2008 at Cambridge University. This algorithm is inspired by flashing pattern and behavior of fireflies. There are three rules which are maintained in FA.

I. Unisex fireflies attract one to another regardless of their sex.
II. The attractiveness and brightness both are inversely proportional to the distance between them. Less brighter firefly always moves towards the brighter one. In absence of brighter firefly than a particular firefly, it will move randomly.
III. The landscape of the objective function determines the brightness of a firefly.

Now the variation of attractiveness β with the distance r is given by,

$$\beta = \beta_0 e^{-\gamma r^2} \ldots\ldots.(4.1)$$

Where β_0 is the attractiveness at $r=0$

The movement of less attractive firefly *i* to the more attractive firefly *j* is determined by

$$x_i^{t+1} = x_i^t + \beta_0 e^{-\gamma r^2}.\left(x_j^t - x_i^t\right) + \alpha_t.\varepsilon_i^t \qquad \text{....(4.2)}$$

Here the second term is due to the attraction. Third term is randomization with α_t being the randomization parameter and ε_i^t is a vector of random number.

Discrete version of firefly algorithm has been developed for discrete problem and combinational optimization. Travelling salesman problem etc can be solved by these kind of algorithm. This FA optimization technique has been used efficiently in optimization problem.

Firefly algorithm has been applied to different test system to minimize both cost and emission [65].

4.2.2.4 Cuckoo Search

Cuckoo search (CS) is an evolutionary optimization algorithm which is inspired by Yang and Deb (2009) [66].The theory of this optimization is based on a bird species named cuckoo. They are very much popular because of their reproduction strategy. They lay their eggs in the nest of other host birds.

This is known as obligate brood parasitism. Every solution is represented by each egg in a nest and new solutions are represented by cuckoo's eggs. When host birds discovers that eggs are not of them, sometimes those eggs are thrown away by them or it abandon its nest and build up a new nest elsewhere.

Generally, cuckoo eggs hatch earlier than the host eggs. Sometimes cuckoo gets the opportunity of more feeding and early grow up than the host birds. When host bird can not recognize the cuckoo's eggs, cuckoo grows up and become mature.

There may be two forms of cuckoo in modeling, either egg or mature cuckoo. A society or group will be formed by mature cuckoos. Environmental features and the immigration of societies or groups of cuckoos hopefully lead them to converge and find the best environment for breeding and reproduction. The objective of the cuckoo search algorithm is to find the global maximum of objective functions through the best environment for breeding and reproduction.

Cuckoo Search Methodology

There are three important rules upon which cuckoo search methodology is based on.

I. Each cuckoo can lay one egg at a time and dumps its egg in a randomly chosen nest.

II. The next generation is carried over by the best nest with high quality eggs.

III. The number of available host's nest is fixed and host bird discovers the egg of a cuckoo with a probability which lies between 0 and 1.

Generating Initial Cuckoo Habitat

It is required to form a problem variables array to solve an optimization problem. This array is called habitat. There are some formulas [67] to generate a cuckoo habitat.

1. Habitat = [x_1, x_2, . . . xN_{var}]→In a N_{var} – dimensional optimization problem, a habitat is an array of 1 ×N_{var} representing current living position of the cuckoo.

2. Profit = f_p(habitat) = f_p (x_1, x_2,. . . xN_{var}) → The profit of a habitat is obtained by the evaluation of profit function $f_p$at a habitat of (x_1, x_2,. . .xN_{var}).

3. Profit = −Cost (habitat) = $-f_c$ (x_1, $x_{2,}$. . .$x_{N_{var}}$) → This algorithm is to maximize a profit function.

ELR is the egg lying radius of a real cuckoo. It is also known as maximum distance from their habitat.ELR is proportional to the total number of eggs or number of current eggs and also variable limits. Variable limits are defined by var_{hi} and var_{low}.

ELR=α × Number of current cuckoo's eggs/Total number of eggs ×($var_{hi}-var_{low}$)

Where, f_p is the profit function and f_c is the cost

var_{hi} and var_{low} are upper limit of variables and lower limit of variables respectively.

α is the step size and *x* is the habitat.

ω is a parameter that constrains the deviation from the goal habitat.

λ is a random number

Cuckoo's Style for Egg Laying

Eggs are laid by each cuckoo randomly in the nest of host's nest maintaining the ELR. After that some of eggs which are not familiar to the host's eggs are thrown away from the nest. *p*% of all eggs(with less profit value) which is generally 10% will be killed. Then the remaining eggs hath and are fed by host bird. But only one egg grows in a nest. There may be two cases. In first case if cuckoo egg hatches earlier and chick comes out, it throws the host bird's eggs and in second case when cuckoo egg hatches later, cuckoo's chick eats most of food because of their own habit. As a result host bird's own chick die from hunger and cuckoo chick remains in the nest.

Immigration of Cuckoos

In the next stage immigration of cuckoos, the matures immigrate to new and better habitats where they found more similarities to the eggs of host birds and more availability of food for their chicks. Thus a new group will be formed in a different area. The group with the best profit is the goal point of the cuckoos to immigrate.

But the problem is that there is a problem to recognize a cuckoo belongs to which group. This problem is solved by using k means clustering method in grouping of cuckoos. In clustering method, cuckoos are grouped in a cluster and then find the best group and select the goal habitat. Then mean value is calculated for each group. The goal group is determined by the maximum value of the mean profit values and for immigrant cuckoos the best group habitat is the new destination habitat. The fly of each cuckoo is limited by only λ % of the entire distance toward the goal habitat and it has deviation of φ radians. For each cuckoo, λ and ϕ are defined[67] as follows:

$$\lambda \sim U(0,1) \qquad \dots (4.3)$$

$$\varphi \sim U(-\omega, \omega) \qquad \dots (4.4)$$

The value of λ lies between 0 and 1 and parameter that constraints the deviation from the goal habitat is ω .The value of ω set to π/6 (rad) for good convergence of cuckoo population to global maximum profit. When all cuckoos immigration towards the goal point is completed and new habitats are specified, eggs are given by each mature cuckoo. After that an ELR is calculated for each cuckoo and its time to restart the new egg lying process

Eliminating Cuckoos in worst Habitats

In society of cuckoos there is a limitation of maximum number of live cuckoos because of inability to find proper nest, food limitation etc. N_{max} number of cuckoos only can survive that have better profit values.

Convergence

In final stage, the entire cuckoo population move to one best habitat with maximum similarities of eggs with eggs of host bird maximum availability of food. The loss of eggs is least in best habitat and maximum profit will be come from this habitat.

Application of Lévy flights in CS [67] is very much significant for generating new solutions,

$$x_{t+1} = x_t + sE_t \qquad \text{.....(4.5)}$$

Here E_t is taken from standard normal distribution with zero mean and unity standard deviation for random walks or taken from Lévy distribution for Lévy flights. s is the step size which determines the movement of random walker for a fixed number of iteration.

5 Particle Swarm Optimization(PSO)

Particle Swarm Optimization (PSO) is an evolutionary computation technique which can easily optimize non linear optimization problems .It was developed by Kennedy and Eberhart in 1995.Simple concept like bird flocking or fish schooling are the basic concepts upon which PSO is based on.PSO is similar to a genetic algorithm(GA)in that the system is initialized with a population of random solution. In PSO each solution is assigned a randomized velocity, and the potential solutions, called particles, are then flow through the problem space.

The number of variables generally which consists the objective function are called Particles in this technique and the set of particles which are taken in this technique is called Swarm. Particle Swarm Optimization is a very simple concept and it is implemented in a few lines of computer code. Only primitive mathematical operators are required in PSO and it is computationally inexpensive in terms of both memory requirements and speed.

5.1. Basic Concept of PSO

PSO is an iterative search technique in which particle moves around the wide area of search space according to objective function (OF).Movement of each particle is based on its own experience as well as others experiences. The concept of PSO technique is based on food searching techniques of birds and fishes in a wide area. There is only one piece of food in searching area. All the birds or fishes do not know the exact location of food. In that condition, they travel in search space according to the own experience and neighbour's experience. That means in each iteration, there is a comparison between distance of present location and target to the previous one and as well as the best position of neighbour which is closest to the target. Accordingly modifying their own speed they find the food. This is the basic concept of PSO."Particles" are the technical term of birds or fishes and "Particle Population" is the technical term of flock. All the particles have own fitness or objective value which is calculated from Objective Function(OF).For the optimization of Objective Function particles positions are updated by velocity vectors and it depends on personal influence and social influence. In PSO at first particle positions are initialized randomly according to problem constraints. This is called initial population or initial swarm. After that random velocities are generated for each particle.

According to the Objective Function, objective value is evaluated. In the initial condition, position corresponds to the optimum value is called "P_{best}" as well as "G_{best}"(for initial condition).Then particles velocities and positions are updated according to personal influence and social influence. The expression of updated velocity is given below. [68,69]

$$V_i^{k+1} = V_i^k + c_1.rand_1 .\left(P_{best_i}^k - X_i^k\right) + c_2.rand_2.(G_{best}^k - X_i^k) \quad \ldots(5.1)$$

Where

V_i^k	Velocity of individual i at iteration k;
c_1	Cognitive Parameter;
c_2	Social Parameter;
$rand_1$ *and* $rand_2$	Random numbers between 0 and 1;
X_i^k	Position of individual i at iteration k;
$P_{best_i}^k$	Best position of individual i until iteration k;
G_{best}^k	Best position of the group until iteration k.

Here $c_1.rand_1 .\left(P_{best_i}^k - X_i^k\right))$ term is for personal influence and $c_2.rand_2.(G_{best}^k - X_i^k)$ is for social influence. [68]

Each individual moves from the current position to the next one by the modified velocity using the following equation:

$$X_i^{k+1} = X_i^k + V_i^{k+1} \quad \ldots ..(5.2)$$

Particle's velocities on each dimension are limited to a maximum velocity V_{max}. V_{max} is a important parameter which determines the resolution with region between the present position and the target position are searched. Particles may cross the good solution when V_{max} is too high and when V_{max} is too low particles only explore the locally good regions.[69]

The acceleration constant c_1 & c_2 in equation represent the weighting of acceleration which pul each particle towards P_{best} and G_{best}position. Low values of c_1 & c_2 allow particles to move far from the target regions before being back and high value of c_1 & c_2 allow particles abrupt movement toward or past target region.

From early experience with Particle Swarm Optimization technique the value of acceleration constant c_1& c_2 set to 2.0 for almost all application.

5.2. Basic Algorithm

1. Begin
2. Initialize a swarm of particles while satisfying constraints.
3. Employing objective function to evaluate each particle position.
4. Satisfying the constraints, velocity and position updates

   Update particles velocities according to

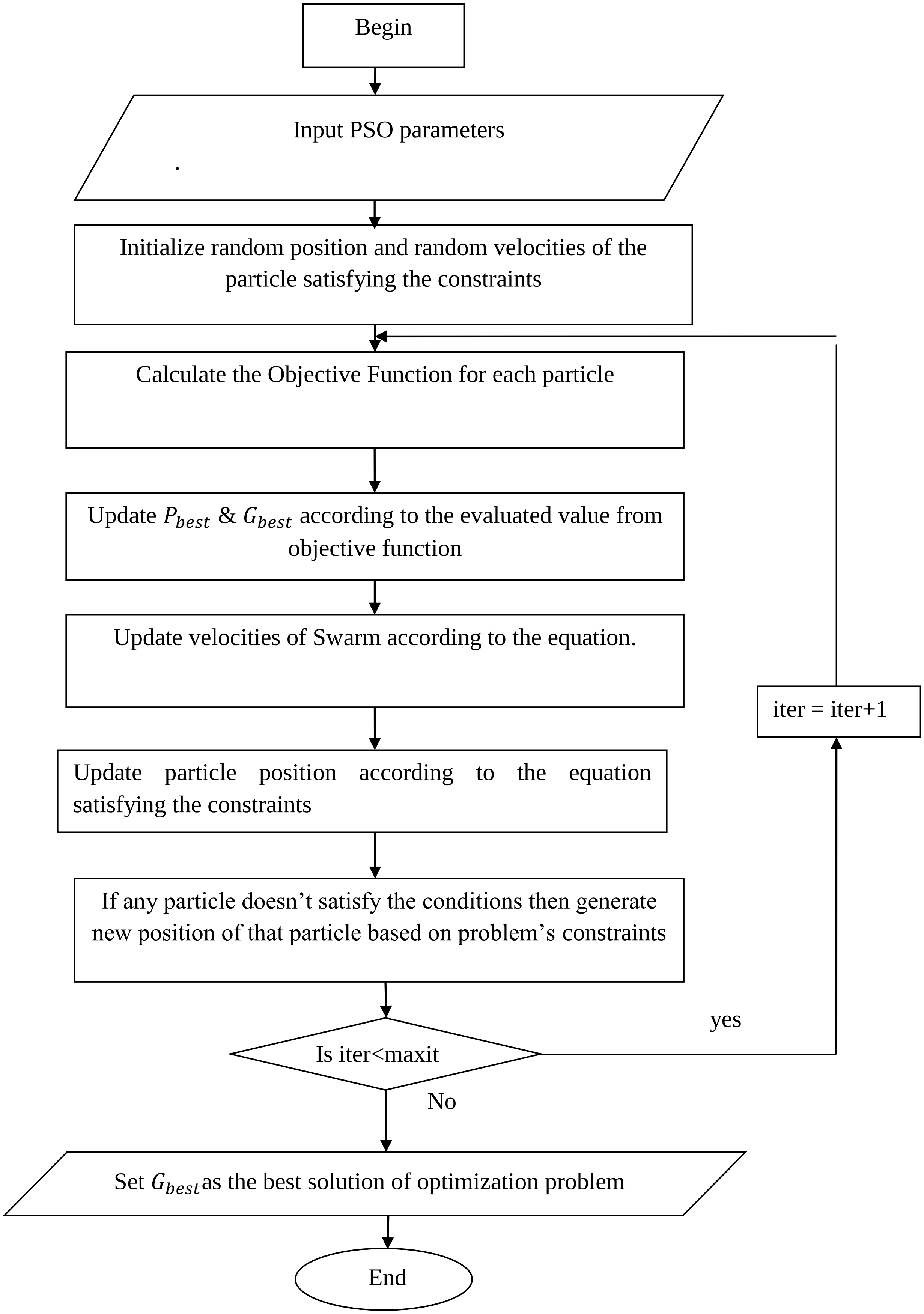
   $$V_i^{k+1} = V_i^k + c_1.rand_1 .\left(P_{best_i}^k - X_i^k\right) + c_2.rand_2.(G_{best}^k - X_i^k)$$

   Update particles position

   $$X_i^{k+1} = X_i^k + V_i^{k+1}$$

5. Update P_{best} andG_{best}.
6. Go to step 2 until satisfying stopping criteria.
7. End

5.3. PSO Flow Chart



5.4 Different types of PSO

There are different kinds of optimization problem which have been solved by PSO.As basic PSO can not be used efficiently in all problems because of stochastic nature, many variants of original algorithm is proposed. These are discussed in below.

5.4.1 Canonical Particle Swarm Optimization

As Particle Swarm Optimization technique is originated from social system, a thorough mathematical foundation for the methodology or algorithm was not developed but there are some attempts since now to build this foundation.

Use of Constriction factor to insure convergence of the particle swarm algorithm was done first by Clerc (1999).[69]The Constriction factor K is multiplied with the previous general equation .The use of constriction factor in equation and structure of constriction factor are given in below.

$$V_i^{k+1} = K[V_i^k + c_1.rand_1 .\left(P_{best_i}^k - X_i^k\right) + c_2.rand_2.(G_{best}^k - X_i^k)] \quad ..(5.3)$$

K =Constriction Factor, and $K = \frac{2}{|2-\varphi-\sqrt{(\varphi^2-4\emptyset)}|}$, where $\varphi = c_1 + c_2$, $\varphi > 4$

The value of φ is set to 4.1 when Clerc's constriction factor is used and the value of K will be 0.729.That means the previous velocity is being multiplied by 0.729..

5.4.2 Time Varying Inertia Weight Particle Swarm Optimization

This technique was first proposed by Yuhui Shi and Russell Eberhart [70]. The global exploration ability of a particle swarm is dependent on the maximum velocity V_{max}. Larger V_{max} facilitates global exploration and smaller V_{max} facilitates local exploitation. For better controlling of exploration and exploitation the concept of inertia weight was developed. In 1998 the inertia weight was included first time in literature in Particle Swarm Optimization to eliminate the function of V_{max}.

The use of inertia weight improved the performance in a number of applications. Generally, the value of inertia weight w is varied linearly in a range 0.4 to 0.9.As inertia weight is varied from one iteration to another iteration, it is called time varying inertia weight. If the value of inertia weight increases then it is called Inc-IW and If the value of inertia weight decreases then it is called Dec-IW.[71]

for Dec-IW, $$W_{it} = W_{max} + \frac{W_{max}-W_{min}}{it_{max}} . it \quad ..(5.4)$$

for Inc –IW , $$W_{it} = W_{min} + \frac{W_{max}-W_{min}}{it_{max}} . it \quad ..(5.5)$$

Where,

$W_{it} \Rightarrow$ Inertia weight varies with respect to iteration number

$W_{max} \Rightarrow$ Maximum value of inertia weight i.e. 0.9

$W_{min} \Rightarrow$ Minimum value of inertia weight i.e. 0.4

$it_{max} \Rightarrow$ Maximum number of iteration

$it \Rightarrow$ Iteration number

A balance between global and local exploration and exploitation can be achieved by suitable choice of inertia weight and optimal result can be found within fewer iteration.[69,72] Now the modified equation of velocity and position with inertia weight will be given below.

$$V_i^{k+1} = W_{it}.V_i^k + c_1.rand_1 .\left(P_{best_i}^k - X_i^k\right) + c_2.rand_2.(G_{best}^k - X_i^k) \quad ....(5.6)$$

$$X^{k+1}{}_i = X_i^k + V_i^{k+1}$$

After experienced with inertia weight, it can be concluded that V_{max} could not always be eliminated.

5.4.3 Stochastic Inertia Weight Particle Swarm Optimization

This technique was first introduced by Russell Eberhart and Yuhui Shi.[70] In this the value of inertia weight is randomly selected in a range 0.5 to 1. And the value of acceleration coefficient c_1 & c_2 are set to 1.494.

5.4.4 Time-Varying Acceleration Coefficients Particle Swarm Optimization

In this PSO technique particles are basically changed with cognitive parameter and social parameter respectively. Here the proper optimization is carried out by varying c_1 & c_2 and get the optimal solution efficiently. The value of c_1 varies from 2.5 to 0.5 and value c_2 of varies from 0.5 to 2.5.[68] Mathematically the variation can be represented as

$$c_1 = c_{1i} + \frac{c_{1f} - c_{1i}}{it_{max}}.it \quad \ldots(5.7)$$

$$c_2 = c_{2i} + \frac{c_{2f} - c_{2i}}{it_{max}}.it \quad \ldots(5.8)$$

These values are should be taken as follows. $c_{1i} = 2.5$, $c_{1f} = 0.5$, $c_{2i} = 0.5$, $c_{2f} = 2.5$

5.4.5 Fully Informed Particle Swarm Optimization Technique

This technique was first introduced by Mendes et al.[73] In this version information from all neighbours are collected and used to compose the equation. Here φ which is summation of cognitive parameter and social parameter is decomposed into $\varphi_{k.}=\varphi/|N|$, $k\epsilon N$, where N is the neighbor of the particle. The velocity equation will be

$$V_i^{t+1} = X\left[V_i^{t+1} + \sum_{k\epsilon N} \varphi_{k.}\, w(k).U_k.\left(p_k - X_i^k\right)\right] \quad \ldots(5.9)$$

Where $w(k)$ is the weighting function and particle's position of individual i at iteration k is denoted by X_i^k

5.4.6 Hierarchical Particle Swarm Optimization

This is a improved version of Particle Swarm Optimization where velocity update is not dependent on previous velocity [74]. Accordingly velocity is updated with equation

$$V_i^{k+1} = c_1.rand_1 .\left(P_{best_i}^k - X_i^k\right) + c_2.rand_2.(G_{best}^k - X_i^k) \quad \ldots(5.10)$$

6 Problem Formulation and Solution Technique

6.1 Introduction

The problem is formulated in purpose to schedule of 24 hours power generation of a low voltage microgrid with Renewable Energy Sources (RES) consisting of micro-turbine, fuel cell, photovoltaic cell, wind turbine, battery and which is connected with utility grid. The objectives of the problem are to minimize both cost and emission simultaneously and improved version of Particle Swarm Optimization Technique has been used for environmental economic scheduling of this microgrid model.

Table6.1: Nomenclature

Indices		$P_{max}(*,t)$	Maximum power output at hour t
b	Battery	$P_{min}(*,t)$	Minimum power output at hour t
f	Fuel cell	$PF_{max}(*,t)$	Maximum forecasted power output at hour t
g	grid	$PF_{min}(*,t)$	Minimum forecasted power output at hour t
m	micro turbine	*Load(t)*	Load at hour t
p	photo-voltaic	*SUC**	Start-up cost
t	time	*SDC**	Shut-down cost
w	wind turbine	***Variables***	
Units		F_1	The primary objective function(cost minimization)
BA	Battery	F_1	The secondary objective function(emissi -on minimization)
FC	Fuel cell	*P(*,t)*	Power generation at hour t
MT	Micro turbine	*V(*,t)*	Binary variable which is equal to 1 if unit is online at hour t
PV	Photo voltaic		
WT	Wind turbine		
Constants			
B(,t)*	Bid at hour t		
$E_i(*,t)$	Emission coefficient of ith emission (CO_2,SO_2 and NO_X) of unit at hour		

6.2 Objective Functions

There are two objective functions in multi-objective framework in reference [20].There are two objective function in multi-objective function.

1. Cost Minimization [F_1]
2. Emission Minimization [F_2]

6.2.1 Cost Minimization

1. The main objective function is the Cost Minimization [F_1][20] and given in below.

$$F_1 = \sum_{t\in T}\Big\{\sum_{m\epsilon MT} P(m,t) * B(m,t) + SUC_m * V(m,t) * [1 - V(m,t-1)] + SDC_m * V(m,t-1) * [1 - V(m,t)] + \sum_{f\epsilon FC} P(f,t) * B(f,t) + SUC_f * V(f,t) * [1 - V(f,t-1)] + SDC_f * V(f,t-1) * [1 - V(f,t)] + \sum_{p\epsilon PV} P(p,t) * B(p,t) + SUC_p * V(p,t) * [1 - V(p,t-1)] + SDC_p * V(p,t-1) * [1 - V(p,t)] + \sum_{w\epsilon WT} P(w,t) * B(w,t) + SUC_w * V(w,t) * [1 - V(w,t-1)] + SDC_w * V(w,t-1) * [1 - V(w,t)] + \sum_{b\epsilon BA} P(b,t) * B(b,t) + SUC_b * V(b,t) * [1 - V(b,t-1)] + SDC_b * V(b,t-1) * [1 - V(b,t)] + P(g,t) * B(g,t)\Big\} \qquad \ldots(6.1)$$

This objective function is the primary objective function and F_1 is the operating cost of microgrid in unit €ct and it includes bid cost, start up cost and shut down cost of different components of microgrid. Electrical energy pricing due to power exchange between microgrid and utility grid has been also included in cost function and it is denoted by $B(g,t)$. $P(m,t)$ stands for generating power of micro-turbine at hour t, $B(m,t)$ is the bid cost of micro turbine at hour t. SUC_m and SDC_m are the start-up and shut down cost of micro turbine and $V(m,t)$ is the binary variable of online status of micro turbine at hour t (1 for online). These are same for others component of microgrid. $P(g,t)$ denotes the active power which is imported or exported from the others grid.

6.2.2 Emission Minimization

The secondary objective function i.e. Emission Minimization [F_2] in reference [20] is given in below.

$$F_2 = \sum_{t\in T} \sum_{i\in ET} \left\{ \begin{matrix} \sum_{m\in MT} P(m,t) * E_i(m,t) + \\ \sum_{f\in FC} P(f,t) * E_i(f,t) + \\ \sum_{b\in BA} P(b,t) * E_i(b,t) + P(g,t) * E_i(g,t) \end{matrix} \right\} \quad \text{…(6.2)}$$

Here ET is comprised of three important pollutants i.e. CO_2, SO_2 and NO_X. F_2 is the emission in kg/MWh which are generated by micro turbine, fuel cell and battery respectively. $E_i(m,t)$ denotes the ith emission type (CO_2, SO_2 and NO_X) of the micro turbine at hour t. Remaining are same as this.

6.2.3 Combined Objective Function

The combined objective function is F and it is given in below.

$$F = W_1 * F_1 + W_2 * F_2 \quad \text{..(6.3)}$$

Where W_1 is the weighting factor for cost function and W_2 is the weighting factor for emission function. F is the combined objective function.

6.3 Constraints

Different constraints of this problem are discussed in below.

6.3.1 Power Balance

Power balance is the most significant constraints in scheduling base problem of microgrid because the hours based load demands have to meet by the generated power of microgrid components. The constraint equation is indicated in reference [20].

$$\sum_{m\in MT} P(m,t) + \sum_{f\in FC} P(f,t) + \sum_{p\in pv} P(p,t) + \sum_{w\in WT} P(w,t) + \sum_{b\in BA} P(b,t) + P(g,t) = Load(t) \quad \text{….(6.3)}$$

The transmission losses are neglected in this problem.

6.3.2 Power generation capacity

The generated power for each component of microgrid should be within limit of their generation capacity for each period of scheduling at their online period. The constraints equations are according to the reference[20]

$$P_{min}(m,t) * V(m,t) \leq P(m,t) \leq P_{max}(m,t) * V(m,t)$$
$$P_{min}(f,t) * V(f,t) \leq P(f,t) \leq P_{max}(f,t) * V(f,t)$$
$$PF_{min}(p,t) * V(p,t) \leq P(p,t) \leq PF_{max}(p,t) * V(p,t)$$
$$PF_{min}(w,t) * V(w,t) \leq P(w,t) \leq PF_{max}(w,t) * V(w,t)$$
$$P_{min}(b,t) * V(b,t) \leq P(b,t) \leq P_{max}(b,t) * V(b,t)$$
$$P_{min}(g,t) \leq P(g,t) \leq P_{max}(g,t) \qquad \ldots \ (6.4)$$

6.4 A typical microgrid model for problem

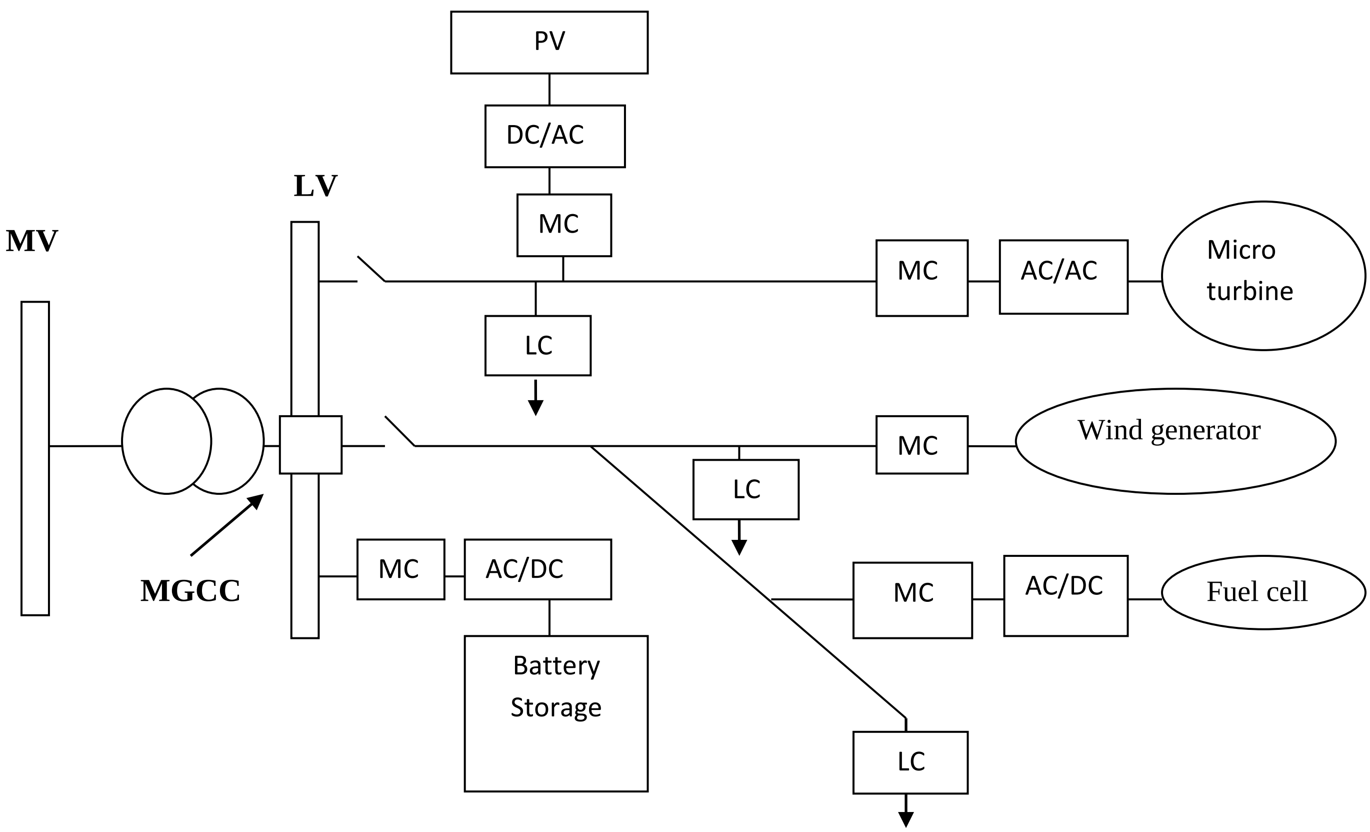


Fig 6.1: A typical low voltage microgrid model

In model, a typical low voltage (LV) microgrid is connected with medium voltage (MV) utility grid through a Microgrid Central Controller (MGCC) which takes the decision of import or export of power between microgrid and utility grid. Micro-controllers (MC) are connected to each component for their autonomous operation and AC/DC or DC/AC converters are used according to their power generation type. In this problem, all Distributed Generation (DG) sources are operated in unity power factor without generating or absorbing reactive power. Each DG sources have their own maximum and minimum power output limit, start up and shut down cost, bidding cost and also emission coefficient. The capacity of the battery is 1 MWh and charge and discharge efficiency is equal to one[20]. The suitable ON/OFF states also depends on the output of the DGs. A strategy of import or export the power to or from utility grid is involved in this problem because electrical energy price varies from hour to hour. The costing is calculated by multiplying amount of imported or exported power with electrical energy prices. It is not requires to determine the nominal capacity of the units because placement of DGs have not been considered here.

According to the model, the objective is to find the best 24 hours based unit commitment where cost and emission are minimum. Particle Swarm Optimization technique and adaptive weighted sum method have been employed for multi-objective optimization purpose.

6.5 Research Work production and its analysis

Research work is produced here by several stages.

1. Considering only the cost function, optimized cost and corresponding emission have been evaluated by using Hierarchical PSO.
2. Considering only the emission function, optimized emission and corresponding cost have been evaluated by using Hierarchical PSO and the obtained pay off table compared and verified with reference. [20]
3. Considering both objective function, cost and emission have been minimized simultaneously by using Hierarchical PSO and compared with reference paper [20] and also verified.

4. In economic scheduling and environmental scheduling framework, cost and emission have been minimized differently by using different version of PSO and compared their results. Different PSO analyzed in this thesis work are given below.

- Canonical PSO
- Basic PSO
- Time Varying Inertia Weight PSO
- Time Varying Acceleration Coefficient PSO
- Stochastic Inertia Weight PSO

5. Finally the problem is modified with some changing in data and analyzed by using Hierarchical PSO. Economic, Environmental and Economic-Environmental scheduling have been analyzed.

6.6 Solution Technique by Particle Swarm Optimization

1. Begin

Start the program

2. Initialization of variables

Read the various data i.e. maximum and minimum generation limit of DG units of microgrid, 24 hours power demand, population size, maximum number of iteration, number of particles, cognitive parameter, social parameter, weighting factor etc.

3. Initialization of swarm and velocities

Generate random population of generation of DG units within limit of maximum and minimum power generation by equations,

$$X = X_{min} + (X_{max} - X_{min}) * rand(popsize, 1) \quad ..(6.5)$$

$$X = X_{min} + (X_{max} - X_{min}) * rand(popsize, 1) * randi([0,1]popsize, 1) \quad ....(6.6)$$

Where, X_{max} and X_{min} are the maximum and the minimum power generation limits of the DG units. Equation no. 6.6 has been used for micro turbine and fuel cell and eq. no. 6.5 has been used for other DG units.

Initialize the random velocities (V) of all the particles.

$$vel = rand(popsize,npar)$$

where $npar$ is the no of particles.

Calculate the amount of power exchange between utility grid and microgrid within permissible limit according to the total power generation of DG units and power demand.

UT=PD-(MT+FC+PV+WT+BT)

UT is the amount power exchange of utility grid and PD is power demand where MT, FC, PV,WT and BT denotes the amount of power generated by that units.

4. Evaluation of objective function

Evaluate the objective function of all the particles considering the generated output power limit according to the eq. no. (6.3)

$$F = W_1 * F_1 + W_2 * F_2$$

5. Find the best particle in initial population

According to the evaluation of objective function of all particles, find the global minima or local minima (initially both are same) and also find the best position of the particle corresponding to the optimum value which is called global best and also find the personal best. Initially, personal best position is the initial population.

6. Start iteration

Set, *iter=1* at the starting time of iteration.

7. Update Particle's velocity and position

Update particle's velocity according to the equation

$$V_i^{k+1} = V_i^k + c_1.rand_1 .\left(P_{best_i}^k - X_i^k\right) + c_2.rand_2.(G_{best}^k - X_i^k) \qquad ..(6.8)$$

And then update particle's position according to the equation

$$X_i^{k+1} = X_i^k + V_i^{k+1} \qquad .(6.9)$$

8. Checking and re-initializing (if necessary) of particles

Check the particles according to the limiting condition i.e. maximum and minimum power generation limit of DG units and if new position of particles are out of limit then particles has to be regenerated maintaining their limiting condition. At first maximum and minimum limits are checked by

$$condition1 = particle <= maximum\ size$$

$$condition2 = particle >= minimum\ size$$

condition1 and *condition2* are the condition checking parameter.
then re-initialize the particles which are out of maximum and minimum limit

*particle=particle.*condition1+not(condition1).*((maximumsize-minimumsize).*rand(popsize,no. of particles) + minimum size)*

9. Evaluation of new particle's objective function value

Evaluate the objective function value of new particles according to the eq. no. (6.3)

10. Update personal best and global best

The new objective values and old objective values are compared and if current position is better than previous best position, then update it. The particle's position corresponding to the optimum objective value is set as global best value. Also update the personal best.
New and old objective values are compared by

$$better\ objective\ value\ =\ objective\ value < local\ objective\ value$$

where better objective value is the condition checking parameter

Formation of local objective value is set by following equation,

*local objective value = objective value.*better objective value + local objective value.*not(better objective value);*

particles are reformed by

local particle = particle.(better objective value *ones(1, no. of particles)+1)) + local particle.*not(better objective value *ones(1, no. of particles)+1))*

Best objective value is evaluated by

[globalobjective value indx] = min(localobjective value)

Global best particle is evaluated by

global particle = local particle (indx,:)

11. Increment the iteration counter

The iteration counter is incremented by 1, means *iter =iter+1*

12. Convergence condition check

If maximum iteration is reached proceed to the next step otherwise go to step 7

13. Display result, evaluation time count and plot the graph

Display the optimized cost and emission and corresponding 24 hours power output of DG units and display the time taken for evaluation and plot the graph between values of objective function versus iteration number.

14. End

Finish the program.

7 Result & Discussion

In this chapter results obtained from various cases have been discussed in below. After that a comparative study has been shown whether, the comparison is between proposed method and previous method for same microgrid model.

The upper and lower bound of power out, bidding cost (€ct/kwh), start up and shut down cost ((€ct/kwh) and emission coefficient (kg/Mwh) of different DG units of microgrid has given in below in reference.[20]

Table7.1: DG unit's data

Type	P_{Min} (kW)	P_{Max} (kW)	Bid (€ct/kWh)	SUC/SDC (€ct)	CO_2 (kg/KWh)	SO_2 (kg/MWh)	NO_x (kg/KWh)
MT	6.000	30.00	0.4570	0.9600	720.0	0.003600	0.1000
FC	3.000	30.00	0.2940	1.650	460.0	0.003000	0.007500
PV	0.000	25.00	2.5840	0.000	0.000	0.000	0.000
WT	0.000	15.00	1.0730	0.000	0.000	0.000	0.000
Bat	-30.00	30.00	0.3800	0.000	10.00	0.0002000	0.001000
Utility	-30.00	30.00	Table7.2	0.000	0.000	0.000	0.000

The capacity of battery is 1 MWh and the charge and discharge efficiency of the battery are equal to one. All DG sources are operated at unity power factor without absorbing or generating reactive power.

The maximum power outputs derived from WT and PV can be estimated by employing an expert prediction model but it is the beyond of this thesis work and a table of forecasted output of WT and PV, 24 hours basis load and electrical energy price is given in below in reference.[20]

Table 7.2: Forecasted output of WT and PV, load and market price

Hour	Forecasting PV output(KW)	Forecasting WT output(KW)	Load(KW)	Electrical Energy price €ct/kWh
1	0.000	1.785	52.00	0.2300
2	0.000	1.785	50.00	0.1900
3	0.000	1.785	50.00	0.1400
4	0.000	1.785	51.00	0.1200
5	0.000	1.785	56.00	0.1200
6	0.000	0.9140	63.00	0.2000
7	0.000	1.785	70.00	0.2300
8	0.1940	1.308	75.00	0.3800
9	3.754	1.785	76.00	2.500
10	7.528	3.085	80.00	4.000
11	10.44	8.772	78.00	4.000
12	11.96	10.413	74.00	4.000
13	23.89	3.923	72.00	1.500
14	21.05	2.377	72.00	4.000
15	7.865	1.785	76.00	2.000
16	4.221	1.302	80.00	1.950
17	0.5390	1.785	85.00	0.6000
18	0.000	1.785	88.00	0.4100
19	0.000	1.302	90.00	0.3500
20	0.000	1.785	87.00	0.4300
21	0.000	1.302	78.00	1.170
22	0.000	1.302	71.00	0.5400
23	0.000	0.9140	65.00	0.3000
24	0.000	0.6120	56.00	0.2600

7.1 Case Study using Hierarchical PSO

There are different case studies which are discussed in this thesis work.

Case 1: Economic Scheduling

In case 1, only cost function is considered that means weighing factor for cost function (W_1) is set to 1 and weighting factor for emission (W_2) is 0. In case 1, when only cost is the objective function, the total cost becomes 144.3476 €ct while the corresponding emission is 593.6692 kg. The 24 hours based power outputs of DG units are given in table 7.3.

Table 7.3: Results obtained for Economic Scheduling

(population no.=50, no. of iteration=1000, $c_1 = c_2 = 2$, $W_1 = 1, W_2 = 0$)

Hour	MT(KW)	FC(KW)	PV(KW)	WT(KW)	Battery(KW)	Utility(KW)
1	0.0000	29.9199	0.0000	0.0082	-7.9257	29.9975
2	0.0000	29.7770	0.0000	0.0000	-9.7760	29.9990
3	0.0000	29.6020	0.0000	0.0005	-9.5973	29.9948
4	0.0000	29.8611	0.0000	0.0041	-8.8638	29.9986
5	0.0000	29.5939	0.0000	0.0000	-3.5933	29.9995
6	0.0000	29.9898	0.0000	0.0015	3.0231	29.9856
7	0.0000	29.7172	0.0000	0.0000	10.2872	29.9956
8	0.0000	29.9999	0.0006	0.0004	24.9839	20.0152
9	29.9850	29.9610	1.3490	1.7840	29.9817	-17.0607
10	29.9879	29.9494	7.5168	3.0784	29.9852	-20.5176
11	29.9493	29.9812	9.3482	8.5994	29.9669	-29.8450
12	29.7935	29.9966	3.5122	10.3590	29.9567	-29.6180
13	29.8854	29.9389	0.0057	2.6681	29.9424	-20.4405
14	29.8790	30.0000	10.4507	1.5807	29.9389	-29.8493
15	29.9859	29.9625	0.1109	1.6055	29.9989	-15.6638
16	29.9988	29.9920	0.3420	1.1047	29.9934	-11.4309
17	29.9857	29.7731	0.0040	0.0085	29.9901	-4.7615
18	6.0035	29.9905	0.0000	0.0039	29.8874	22.1146
19	6.0257	29.8159	0.0000	0.0016	24.2602	29.8966
20	6.2964	29.9388	0.0000	0.0012	29.9705	20.7931
21	29.9641	29.9995	0.0000	1.1491	29.9929	-13.1056
22	29.9735	29.9998	0.0000	0.0023	29.9832	-18.9587
23	6.2351	29.7154	0.0000	0.0000	-0.9103	29.9598
24	6.0056	29.7749	0.0000	0.0010	-9.7543	29.9728
Total Cost (€ct) 144.3476				Total Emission(Kg) 593.6692		

From result, it is observed that from 1 to 8th hours micro turbine remains offline situation where power is imported from main grid. In middle hours micro grid has exported power to utility grid. Negative sign indicates battery is charging mode in that hours.

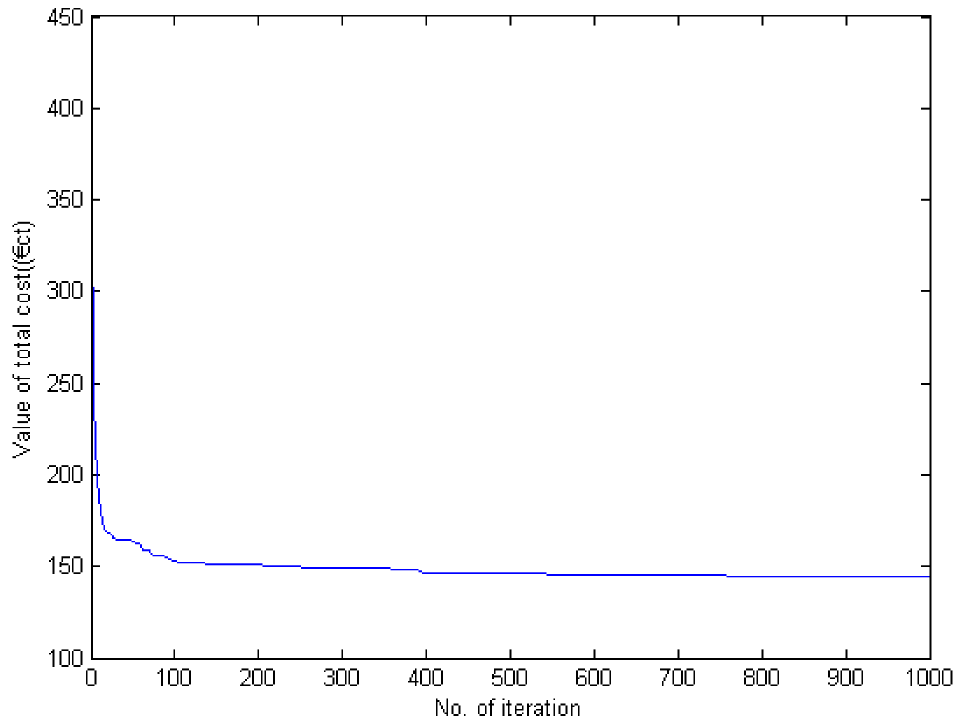


Fig7.1: Variation of total cost with iteration for economic scheduling

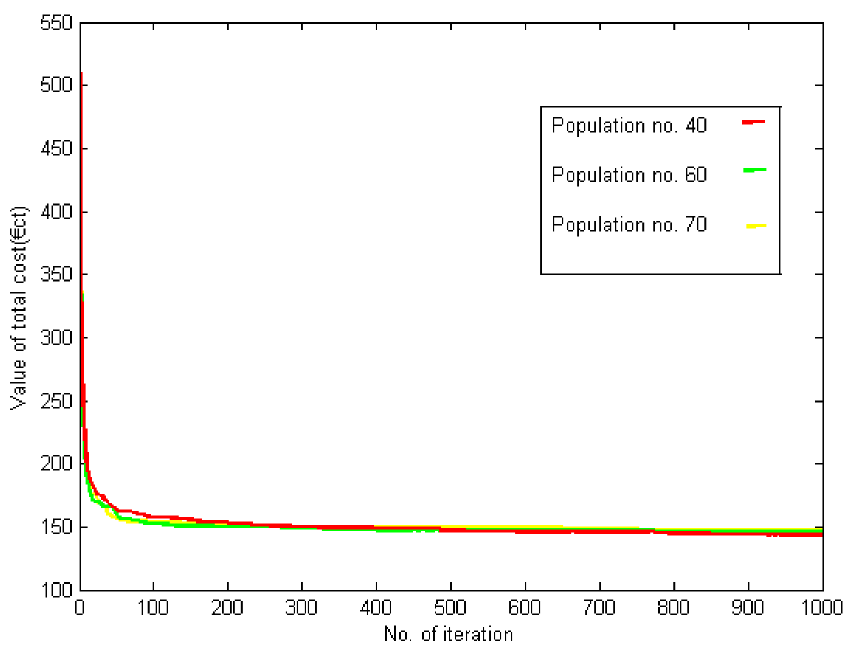


Fig 7.2: Variation of total cost with iteration number for different population size for economic scheduling

Case 2: Environmental Scheduling

In case 2, the weighting factor for cost (W_1) is set to 0 and weighting factor for emission (W_2) becomes 1. In case 2, only the secondary objective function is considered that means only emission is optimized and it is shown that total emission is reduced to 98.8776 from 593.6692 which is discussed in previous case. The corresponding cost is 1486.3000 €ct. The power output of DG units are shown in table 7.4

Table 7.4: Results obtained for Environmental Scheduling

(population no.=50, no. of iteration=1000,$c_1 = c_2 = 2, W_1 = 0, W_2 = 1$)

Hour	MT(KW)	FC(KW)	PV(KW)	WT(KW)	Battery(KW)	Utility(KW)
1	0.0000	0.0000	0.0000	1.7804	20.2204	29.9992
2	0.0000	0.0000	0.0000	1.7842	18.2159	29.9999
3	0.0000	0.0000	0.0000	1.7846	18.2196	29.9959
4	0.0000	0.0000	0.0000	1.7849	19.2184	29.9967
5	0.0000	0.0000	0.0000	1.7829	24.2173	29.9998
6	0.0000	3.0011	0.0000	0.8100	29.3646	29.8243
7	0.0000	8.3090	0.0000	1.7836	29.9195	29.9879
8	0.0000	13.6723	0.1004	1.2962	29.9940	29.9370
9	0.0000	10.6840	3.7178	1.6709	29.9534	29.9740
10	0.0000	9.8485	7.3770	3.0814	29.7171	29.9760
11	0.0000	0.0000	10.4203	8.7666	28.9221	29.8910
12	0.0000	0.0000	11.8473	10.3492	21.8037	29.9999
13	0.0000	0.0000	23.8230	3.9027	14.3231	29.9511
14	0.0000	0.0000	21.0304	2.3082	18.6675	29.9939
15	0.0000	6.8672	7.7022	1.7518	29.7292	29.9494
16	0.0000	15.0501	4.1369	0.8617	29.9909	29.9604
17	0.0000	22.8394	0.5227	1.7420	29.8969	29.9990
18	0.0000	26.2869	0.0000	1.7350	29.9970	29.9811
19	0.0000	28.7962	0.0000	1.2278	29.9761	29.9999
20	0.0000	25.2662	0.0000	1.7489	29.9927	29.9922
21	0.0000	16.7644	0.0000	1.2675	29.9937	29.9944
22	0.0000	9.7291	0.0000	1.3011	29.9720	29.9978
23	0.0000	4.1867	0.0000	0.8767	29.9592	29.9775
24	0.0000	0.0000	0.0000	0.6110	25.3890	30.0000
Total Cost (€ct) 1486.3000				Total Emission(Kg) 98.8776		

When the emission minimization is only the objective function MT is in offline mode for all time because of its high emission coefficient and maximum amount of power within limit is imported from utility grid for its zero emission co-efficient.

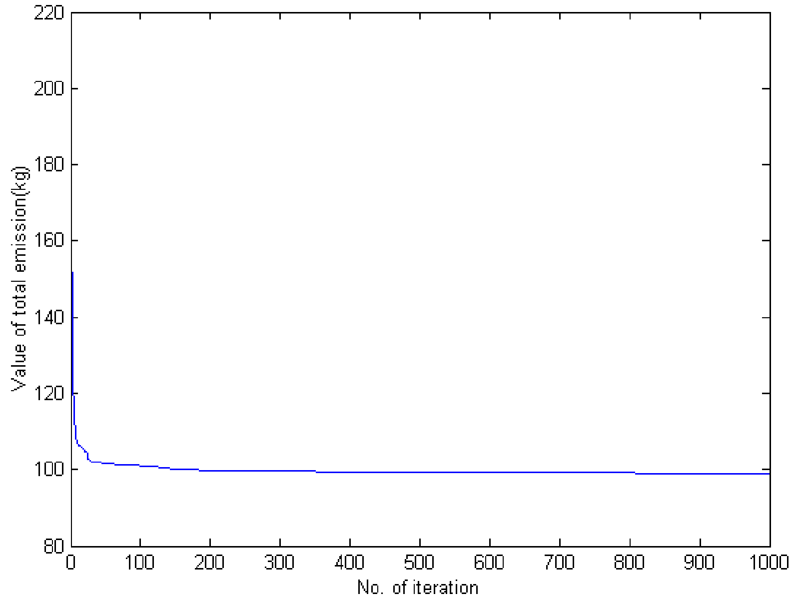


Fig7.3: Variation of total emission with iteration number for environmental scheduling

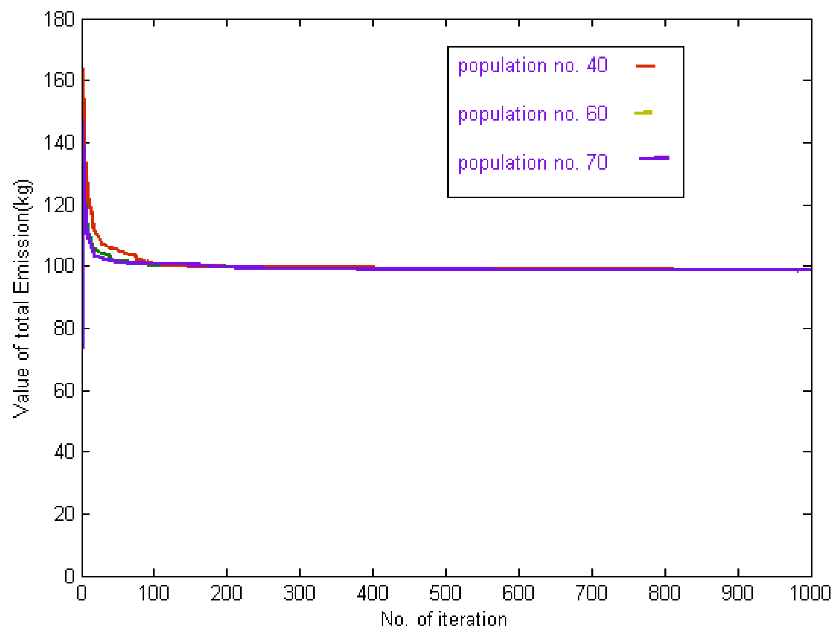


Fig 7.4: Variation of total emission with iteration number for different population size for environmental scheduling

A pay off table is created, where first row represent value of total cost and total emission when only cost function is considered and second row represent value of total cost total emission when only emission function is considered.

So, the pay off table is represented as follows.

$$\emptyset_{proposed} = \begin{pmatrix} 144.3476 & 593.6692 \\ 1486.30 & 98.8776 \end{pmatrix}$$

It can be observed from pay off table that when only cost function is minimized the cost will be 144.3476 €ct and corresponding emission is 593.6692 Kg. But when only emission function is considered cost is increased from 144.3476 €ct to 1486.30 €ct and emission is decreased from 593.6692 Kg to 98.8776 Kg.

Where the pay off table which was obtained in reference [20]

$$\emptyset_{previous} = \begin{pmatrix} 177.550 & 552.672 \\ 1269.49 & 108.105 \end{pmatrix}$$

That means when cost function was minimized, the cost was 177.550 €ct and corresponding emission was 552.672 kg and when emission function was minimized, the emission was reduced to 108.105 kg and corresponding cost was 1269.49 €ct.

So, the proposed method gives better cost than previous one where a small variation in emission value in cost minimization. In case of emission minimization, proposed method also gives better emission than previous one where the corresponding cost of proposed method is 216.81 €ct higher than previous method.

Case 3: Economic-Environmental Scheduling

This is a fair optimization where both cost and emission is optimized with equal preference that means weighting factor for both cost and emission are 1.0. The 24 hours based power output and cost and emission of proposed method and previous method using lexicographic optimization and hybrid augmented-weighted epsilon-constraint method in reference [20] are shown in table.

Table7.5: A comparison study for Economic-Environmental Scheduling

(population no.=50, no. of iteration=1000, $c_1 = c_2 = 2$, $W_1 = 1, W_2 = 1$)

	Previous method[20]						Proposed Method					
Hr	MT (KW)	FC (KW)	PV (KW)	WT (KW)	Battery (KW)	Utility (KW)	MT (KW)	FC (KW)	PV (KW)	WT (KW)	Battery (KW)	Utility (KW)
1	0.000	0.000	0.000	0.000	22.00	30.00	0.0000	0.0000	0.0000	0.0000	22.0000	30.0000
2	0.000	0.000	0.000	0.000	20.00	30.00	0.0000	0.0000	0.0000	0.0000	20.0005	29.9995
3	0.000	0.000	0.000	0.000	20.00	30.00	0.0000	0.0000	0.0000	0.0000	20.0000	30.0000
4	0.000	0.000	0.000	0.000	21.00	30.00	0.0000	0.0000	0.0000	0.0001	21.0000	30.0000
5	0.000	0.000	0.000	0.000	26.00	30.00	0.0000	0.0000	0.0000	0.0001	25.9999	30.0000
6	0.000	3.000	0.000	0.000	30.00	30.00	0.0000	3.1717	0.0000	0.0086	29.8280	29.9918
7	0.000	8.215	0.000	1.786	30.00	30.00	0.0000	10.0186	0.0000	0.0070	29.9744	30.0000
8	0.000	13.70	0.000	1.302	30.00	30.00	0.0000	15.0730	0.0001	0.0000	29.9510	29.9759
9	0.000	14.21	0.000	1.786	30.00	30.00	29.9897	29.9942	2.9216	1.7804	29.9907	-18.6766
10	30.00	30.00	7.528	3.085	30.00	-20.61	29.9982	29.8457	7.5249	3.0850	29.9633	-20.4171
11	28.79	30.00	10.44	8.772	30.00	-30.00	29.7021	29.9111	9.6989	8.6897	29.9811	-29.9829
12	21.62	30.00	11.96	10.41	30.00	-30.00	29.9484	29.9942	3.5408	10.4106	29.9741	-29.8681
13	0.000	8.077	0.000	3.923	30.00	30.00	29.9916	29.9923	0.0130	3.8178	29.8122	-21.6269
14	24.66	30.00	14.96	2.377	30.00	30.00	29.4503	29.9707	10.7646	1.9454	29.8599	-29.9908
15	0.000	30.00	0.000	1.786	30.00	14.21	29.9906	29.9988	0.3567	1.7263	29.9632	-16.0357
16	0.000	30.00	0.000	1.302	30.00	18.70	29.9963	29.9911	0.1778	1.2999	29.9995	-11.4647
17	0.000	23.21	0.000	1.786	30.00	30.00	0.0000	24.9939	0.0010	0.0204	29.9895	29.9953
18	0.000	26.21	0.000	1.786	30.00	30.00	0.0000	27.9874	0.0000	0.0215	29.9939	29.9971
19	0.000	28.70	0.000	1.302	30.00	30.00	0.0000	29.8967	0.0000	0.1251	29.9905	29.9878
20	0.000	25.21	0.000	1.786	30.00	30.00	0.0000	27.0362	0.0000	0.0015	29.9901	29.9723
21	0.000	16.70	0.000	1.302	30.00	30.00	0.0000	30.0000	0.0000	1.0235	29.9992	16.9774
22	0.000	9.698	0.000	1.302	30.00	30.00	0.0000	11.0000	0.0000	0.0109	29.9936	29.9955
23	0.000	4.086	0.000	0.914	30.00	30.00	0.0000	4.9595	0.0000	0.0537	29.9882	29.9986
24	0.000	0.000	0.000	0.000	26.00	30.00	0.0000	3.0134	0.0000	0.0051	22.9814	30.0000
Total Cost (€ct) 466.4			Total Emission(Kg) 248.5				Total Cost (€ct) 200.5727			Total Emission(Kg) 375.2209		

The result shows that cost of generation of proposed method is 265.8273 €ct lower than the previous method according to reference. [20]But the emission of proposed method is 126.7209 kg more than previous one.

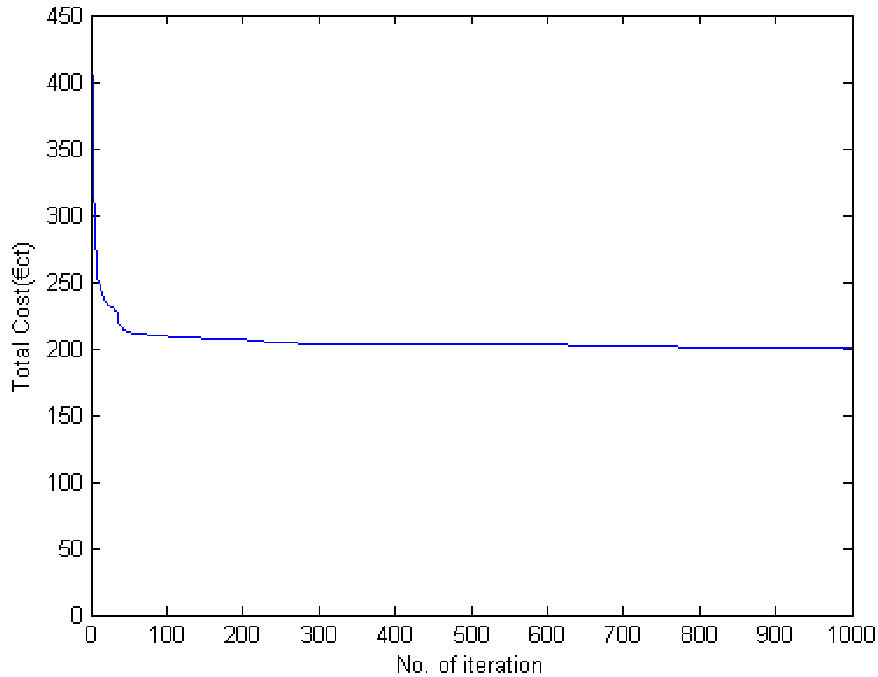


Fig 7.5: Variation of total cost with no. of iteration for economic-environmental scheduling

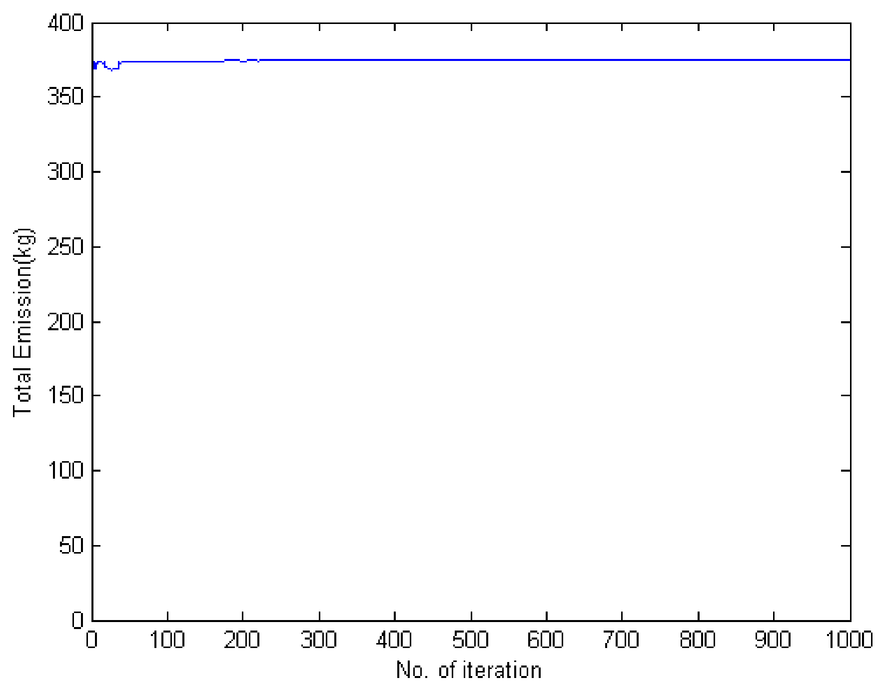


Fig 7.6: Variation of total emission with no. of iteration for economic-environmental scheduling

Table 7.6: Variation of total cost and total emission in different types of scheduling using Hierarchical PSO

Type of Scheduling	Total Cost(€ct)	Total Emission(kg)
Economic based Scheduling	144.3476	593.6692
Environmental based Scheduling	1486.3000	98.8776
Combined Economic & Environmental based scheduling	200.5727	375.2209

From above table it can be concluded that total cost is highest for environmental based scheduling and lowest for economic based scheduling where as total emission is highest for economic based scheduling and lowest for environmental scheduling. Combined economic & environmental scheduling gives the moderate value of total cost and total emission.

7.2 24 hours based scheduling of DG units for economic scheduling using different version of PSO

There are different versions of improved PSO and these are employed here to obtain different optimized value of cost and corresponding emission and have been compared here when considering cost function for optimization.

I.Canonical PSO

(population no.=50, no. of iteration=1000,$c_1 = c_2 = 2.05$,K=0.729, $W_1 = 1, W_2 = 0$)

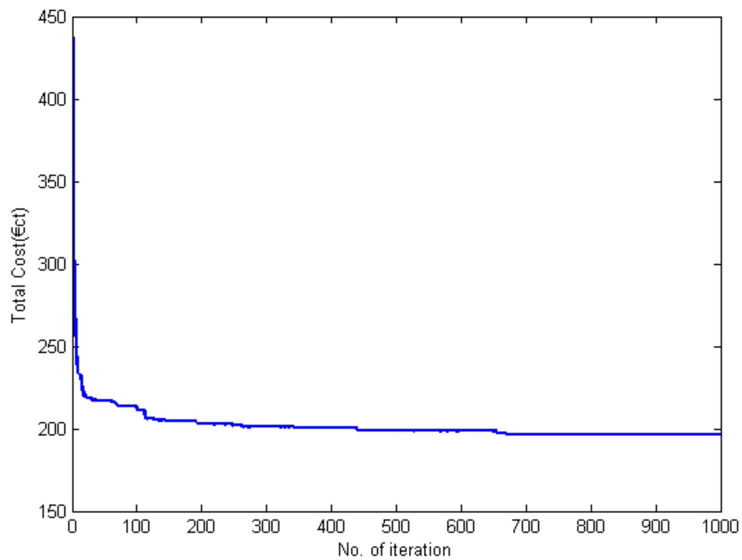


Fig 7.7: Variation of total cost with iteration using canonical PSO

II. Basic PSO

(population no.=50, no. of iteration=1000,$c_1 = c_2 = 2.0$, $W_1 = 1, W_2 = 0$)

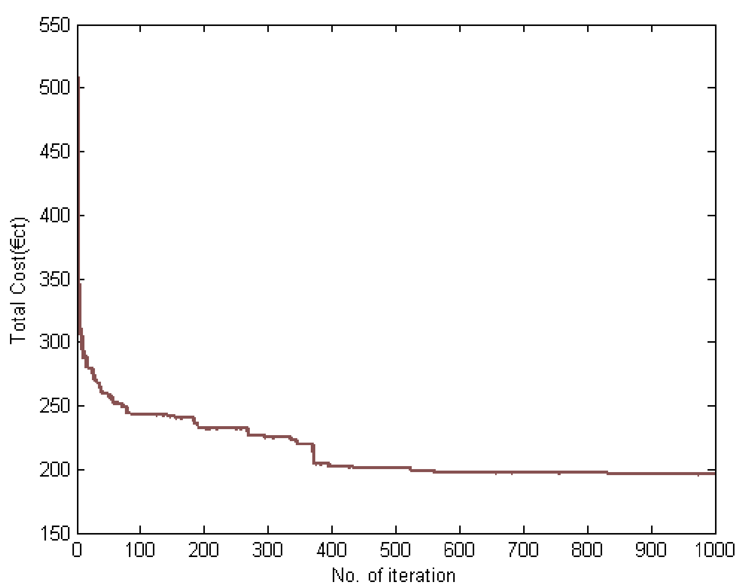


Fig 7.8: Variation of total cost with iteration using Basic PSO

III. Time-Varying Inertia Weight PSO(Dec-IW)

(population no.=50, no. of iteration=1000,$c_1 = c_2 = 2.0$,$W_{max} = 0.9, W_{min} = 0.4, W_1 = 1, W_2 = 0$)

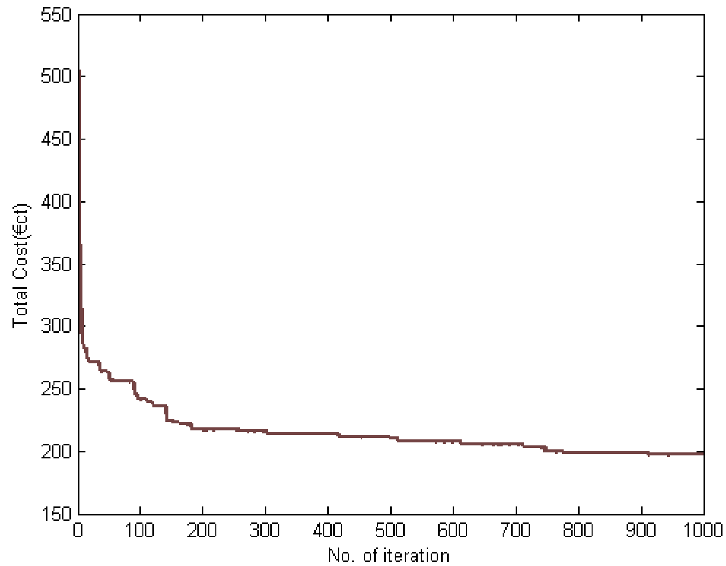


Fig 7.9: Variation of total cost with iteration using Time varying IW-PSO

IV. Time Varying Acceleration Coefficient PSO

(population no.=50, no. of iteration=1000,$c_{1i} = 2.5, c_{1f} = 0.5, c_{2i} = 0.5, c_{2f} = 2.5, W_1 = 1, W_2 = 0$)

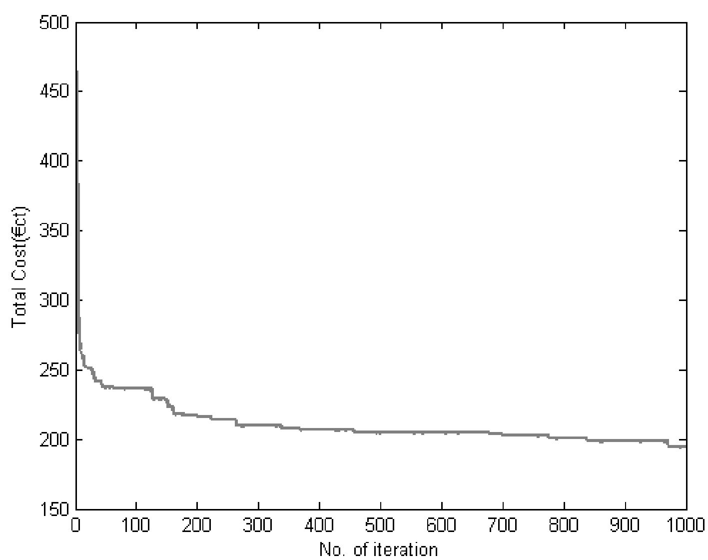


Fig 7.10: Variation of total cost with iteration using Time varying Acceleration Coefficient PSO

V. Stochastic Inertia Weight PSO

(population no.=50, no. of iteration=1000, $c_1 = c_2 = 1.494, W_1 = 1, W_2 = 0$)

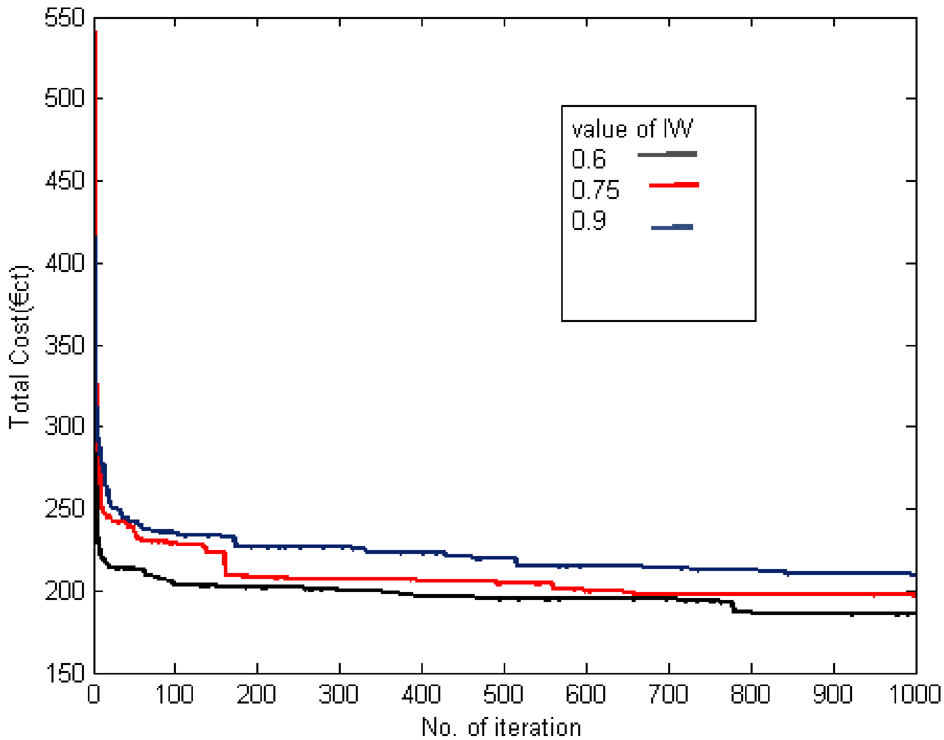


Fig 7.11: Variation of total cost with iteration using Stochastic IW- PSO for different IW value

From the curve it is concluded that the best value of total cost is obtained for Inertia weight 0.6. The values of total cost are 185.5099, 197.3422 and 209.6287 for IW value 0.6, 0.75 and 0.9 respectively. The best value is given to the comparison table.

Table 7.7: A comparison study of using different PSO for economic scheduling

Different types of PSO	Value of optimized cost(€ct)	Value of corresponding emission(kg)	Time taken(sec)
H-PSO	144.3476	593.6692	13.7424
Canonical PSO	196.3200	475.8423	16.6324
Basic PSO	195.7920	483.7707	16.4314
TV-IW PSO (Dec-IW)	197.1271	540.7645	16.099
TV-AC PSO	194.3950	491.4773	16.0213
Stochastic IW PSO (IW-0.6)	185.5099	524.1118	15.765

From the table and characteristics curve it can be concluded that, H-PSO gives the best result among all the PSOs. The total cost may not be converged up to 1000 iteration for TV-AC PSO. From the it also be observed that TV-IW PSO has given the highest value of total cost. Stochastic IW PSO has given best optimized value for choosing low value of IW.

7.3 24 hours based scheduling of DG units for Environmental Scheduling using different version of PSO

There are different versions of improved PSO and these are employed here to obtain different optimized value of emission and corresponding cost and have been compared here when considering emission function for optimization.

I. Canonical PSO

(population no.=50, no. of iteration=1000,$c_1 = c_2 = 2.05$,K=0.729, $W_1 = 0, W_2 = 1$)

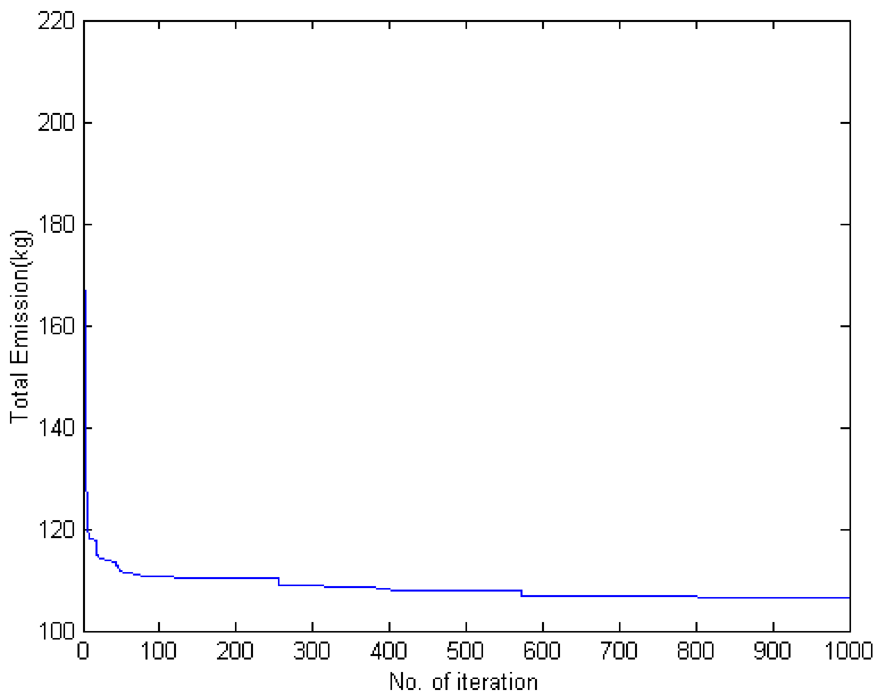


Fig 7.12: Variation of total emission with iteration using canonical PSO

II. Basic PSO

(population no.=50, no. of iteration=1000,$c_1 = c_2 = 2.0$, $W_1 = 0, W_2 = 1$)

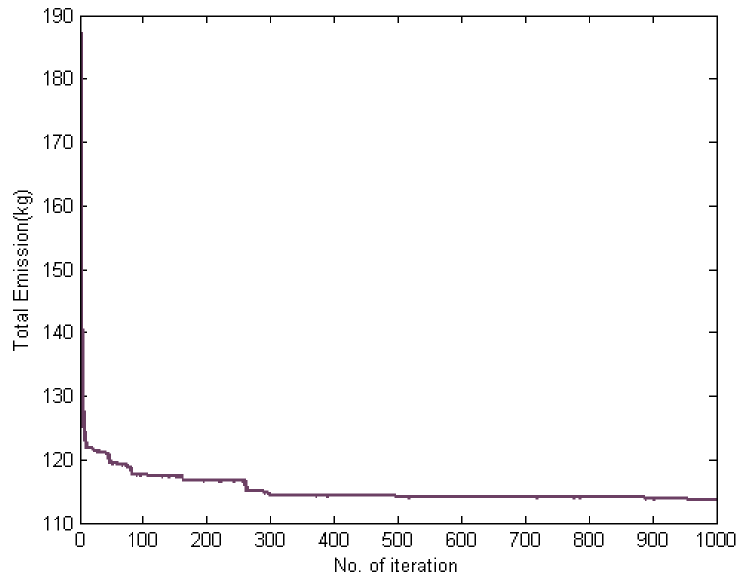


Fig 7.13: Variation of total emission with iteration using basic PSO

III. Time Varying Inertia Weight PSO(Dec-IW)

(population no.=50, no. of iteration=1000,$c_1 = c_2 = 2.0$,$W_{max} = 0.9, W_{min} = 0.4, W_1 = 0, W_2 = 1$)

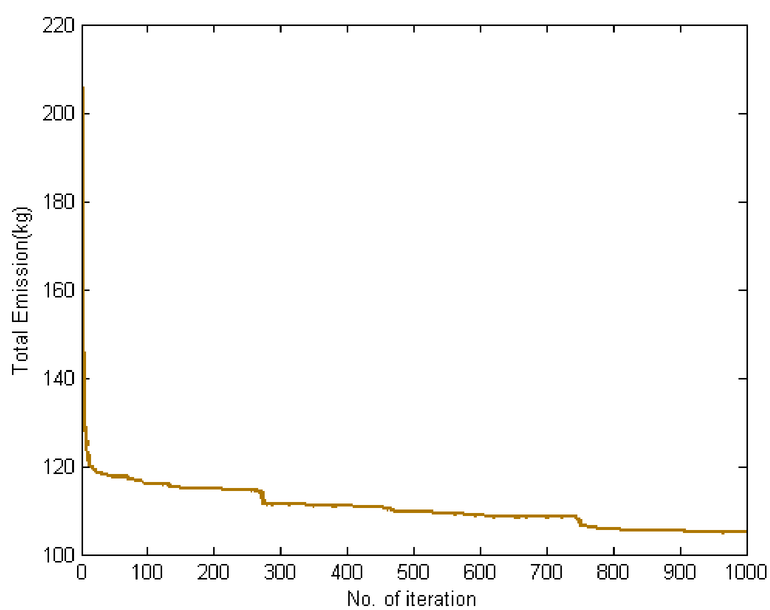


Fig 7.14: Variation of total emission with iteration using Time Varying Inertia Weight PSO

IV. Time varying acceleration coefficient PSO

(population no.=50, no. of iteration=1000, $c_{1i} = 2.5, c_{1f} = 0.5, c_{2i} = 0.5, c_{2f} = 2.5, W_1 = 0, W_2 = 1$)

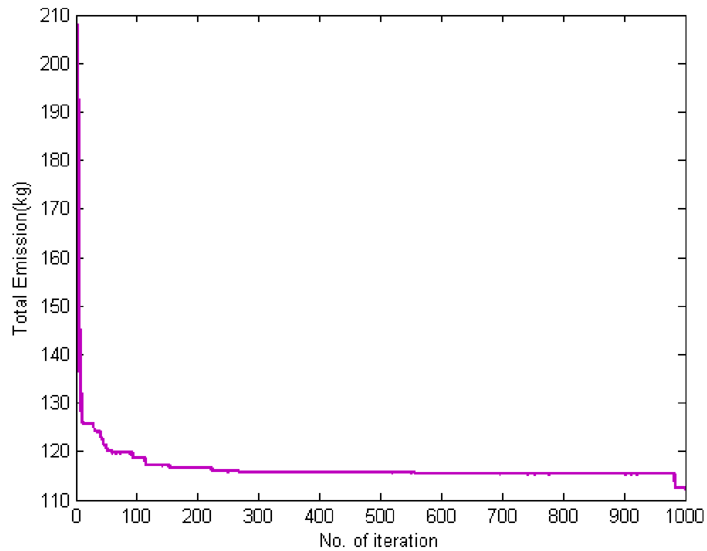


Fig 7.15: Variation of total emission with iteration using Time Varying acceleration coefficient PSO

V.Stochastic Inertia Weight PSO

(population no.=50, no. of iteration=1000, $c_1 = c_2 = 1.494, W_1 = 0, W_2 = 1$)

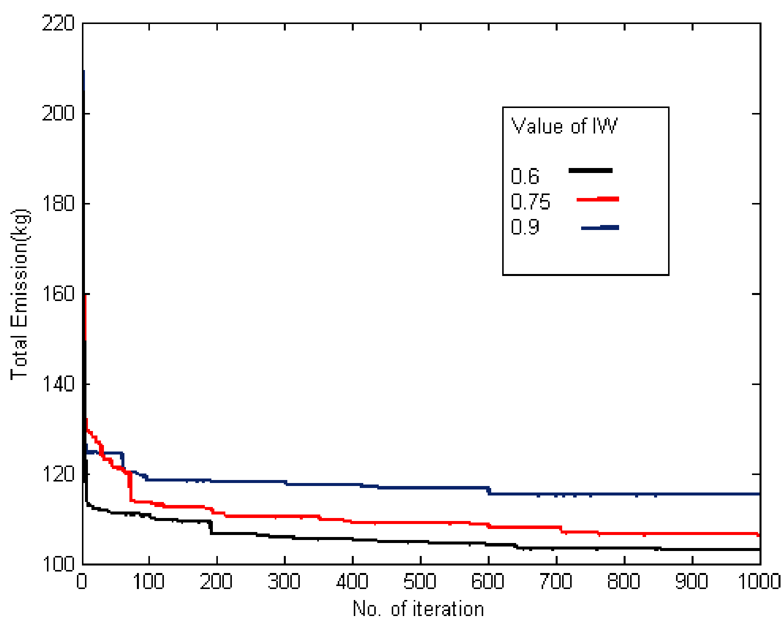


Fig 7.16: Variation of total emission with iteration using Stochastic IW- PSO for different IW value

The value of optimized total emission is decreasing with the decreasing value Inertia Weight. The values of total emission are 103.1321, 106.3118 and 115.1085 for IW 0.6, 0.75 and 0.9 respectively. The best value is given to the comparison table.

Table 7.8: A comparison study of using different PSO for environmental scheduling

Different types of PSO	Value of corresponding cost(€ct)	Value of optimized emission(kg)	Time taken(sec)
H-PSO	1486.3000	98.8776	16.4331
Canonical PSO	1015.6	106.5012	18.1419
Basic PSO	1061.9	113.6697	18.0164
TV-IW PSO (Dec-IW)	1158.8	105.0002	17.84
TV-AC PSO	1074.7	112.3211	18.1841
Stochastic IW PSO (IW=0.6)	1180.0	103.1321	18.0137

The optimized value of emission also has been given by H-PSO where basic PSO has given worst value. From curves it can be concluded that in case of TV-AC PSO and basic PSO value of emission are not converging in 1000 iteration

7.4 A different case study for modification of problem using Hierarchical PSO

The problem is modified where there are two differences from previous one.

1. Utility grid is not emission coefficient for the power plant feeding into the grid is equal to the emission coefficient of micro turbine.
2. Limitation for power exchange between utility grid and micro grid is 100.0 kw instead of 30.0 kw.

Result and graphical figure is given in below.

Case 1: Economic Scheduling for modified problem

Result and graphical representation have given below.

Table 7.9: Result of Economic Scheduling for modified problem

(population no.=50, no. of iteration=1000,$c_1 = c_2 = 2$, $W_1 = 1, W_2 = 0$)

Hour	MT(KW)	FC(KW)	PV(KW)	WT(KW)	Battery(KW)	Utility(KW)
1	0.0000	0.0000	0.0000	0.0003	-29.9995	81.9992
2	0.0000	0.0000	0.0000	0.0005	-30.0000	79.9995
3	0.0000	0.0000	0.0000	0.0000	-29.9968	79.9967
4	0.0000	0.0000	0.0000	0.0005	-29.9999	80.9994
5	0.0000	0.0000	0.0000	0.0009	-29.9998	85.9989
6	0.0000	0.0000	0.0000	0.0002	-30.0000	92.9998
7	0.0000	0.0000	0.0000	0.0001	-29.9941	99.9940
8	0.0000	29.9830	0.001	0.0001	-13.2639	58.2807
9	29.9892	29.9592	0.3082	1.5276	29.9998	-15.7839
10	29.9610	29.9964	7.5169	2.9958	29.9965	-20.4666
11	29.9514	29.9823	10.3709	8.5878	29.9996	-30.8921
12	29.9671	29.9970	11.6093	10.3971	29.9909	-37.9613
13	29.9953	29.9505	0.0019	3.4864	29.8461	-21.2802
14	29.9985	29.8645	21.0453	1.1093	29.9964	-40.0140
15	30.0000	29.9513	0.0114	1.7651	29.9795	-15.7072
16	29.9938	29.9886	0.0963	1.2008	29.9868	-11.2636
17	29.8605	29.9957	0.0277	0.0009	29.8969	-4.7816
18	6.2696	29.9990	0.0000	0.0002	29.5966	22.1346
19	6.0076	29.9420	0.0000	0.0000	-29.8216	83.8720
20	6.0216	29.9941	0.0000	0.0027	29.9582	21.0233
21	29.9998	29.9777	0.0000	1.0106	29.9601	-12.9482
22	29.9139	29.9939	0.0000	0.0009	29.9505	-18.8592
23	0.0000	29.9189	0.0000	0.0008	-30.0000	65.0803
24	0.0000	3.0131	0.0000	0.0008	-29.9913	82.9774
Total Cost (€ct) 46.8393				Total Emission(Kg) 1149.9		

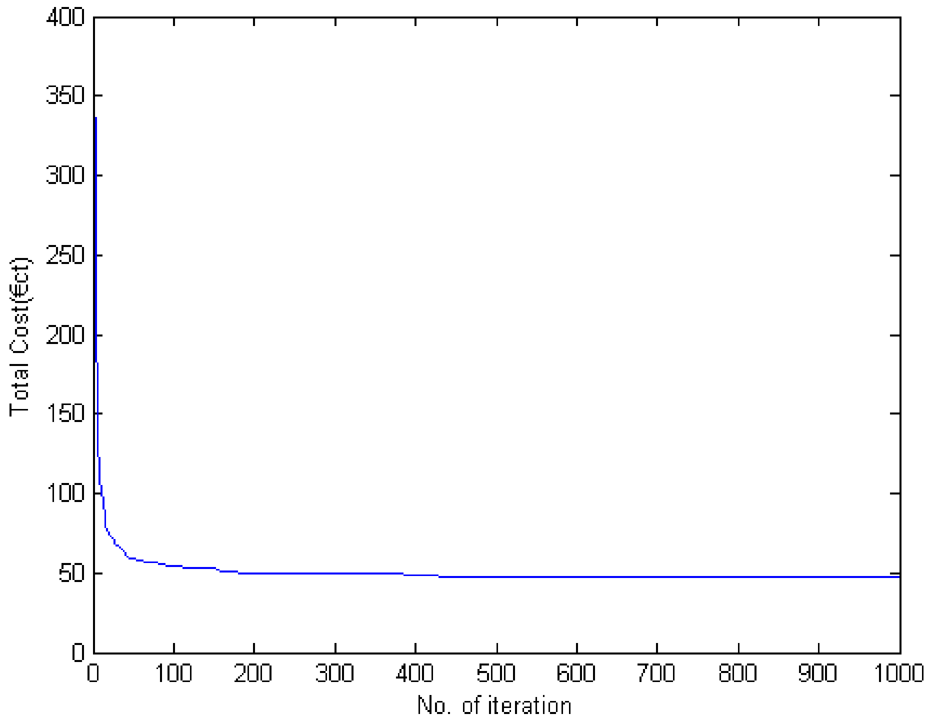


Fig7.17: Variation of total cost with no of iteration economic scheduling

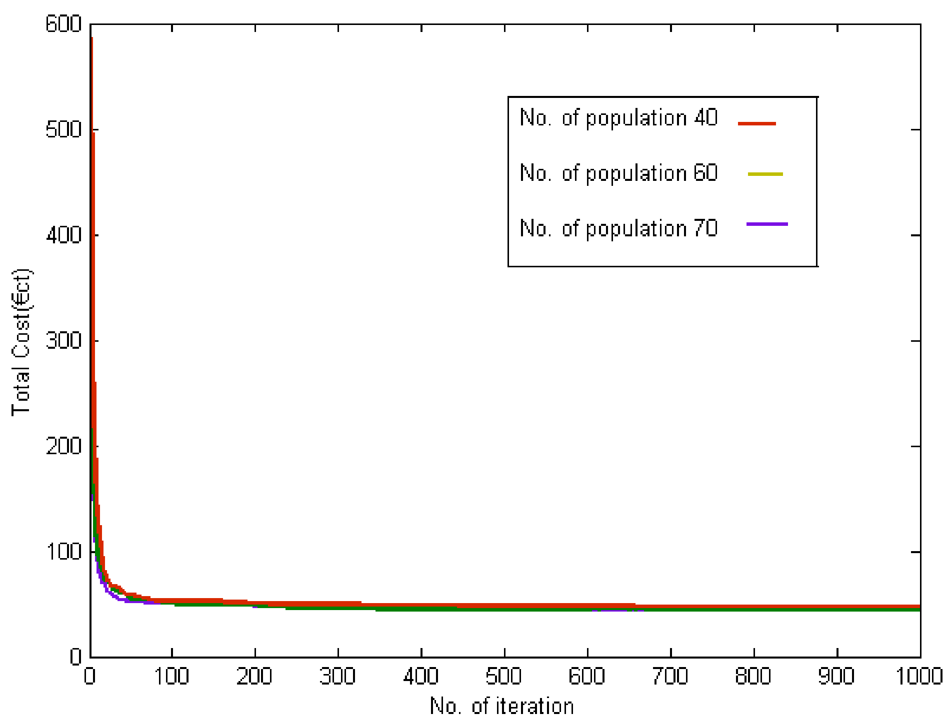


Fig 7.18: Variation of total cost with iteration number for different population size for economic scheduling

In case of economic scheduling, there is a higher utilization of power exchange between utility grid and microgrid because low electric pricing of utility grid. PV is almost unutilized because of its high bidding cost. The total cost comes down to 46.8393 €ct for economic scheduling.

Case 2: Environmental Scheduling for modified problem

Result and graphical representation have given below.

Table 7.10: Result of Environmental Scheduling for modified problem

(population no.=50, no. of iteration=1000, $c_1 = c_2 = 2$, $W_1 = 0, W_2 = 1$)

Hour	MT(KW)	FC(KW)	PV(KW)	WT(KW)	Battery(KW)	Utility(KW)
1	0.0000	20.2165	0.0000	1.7849	29.9987	0.0000
2	0.0000	18.2163	0.0000	1.7850	29.9994	0.0006
3	0.0000	18.2169	0.0000	1.7848	29.9983	0.0000
4	0.0000	19.2183	0.0000	1.7848	29.9971	0.0001
5	0.0000	24.2166	0.0000	1.7843	29.9991	0.0000
6	0.0000	29.9946	0.0000	0.9138	29.9935	2.0981
7	0.0000	29.9985	0.0000	1.7849	29.9926	8.2240
8	0.0000	29.9869	0.1934	1.3070	29.9993	13.5134
9	0.0000	29.9650	3.7340	1.7831	29.9931	10.5247
10	0.0000	29.9655	7.5201	3.0850	29.9796	9.4499
11	0.0000	28.8195	10.4343	8.7652	29.9826	-0.0016
12	0.0000	21.6498	11.9596	10.4116	29.9867	-0.0077
13	0.0000	14.2780	23.8219	3.9151	29.9852	-0.0002
14	0.0000	18.6147	21.0495	2.3494	29.9864	0.0000
15	0.0000	29.9948	7.8611	1.7850	29.9673	6.3919
16	0.0000	29.9957	4.2110	1.2602	29.9955	14.5376
17	0.0000	29.9986	0.5377	1.7786	29.9495	22.7356
18	16.6124	29.9716	0.0000	1.7808	29.9999	9.6352
19	0.0000	29.9861	0.0000	1.2999	29.9993	28.7147
20	0.0000	29.9962	0.0000	1.7850	29.9915	25.2274
21	0.0000	29.9985	0.0000	13008	29.9985	16.7021
22	8.2066	29.9981	0.0000	1.2895	30.0000	1.5057
23	0.0000	29.9973	0.0000	0.9128	30.0000	4.0900
24	0.0000	25.3884	0.0000	0.6120	29.9996	0.0000
Total Cost (€ct) 945.0949				Total Emission(Kg) 439.1016		

For Environmental scheduling total emission can not be minimized as per previous analysis because utility grid is not emission free in this case. As a result of this power exchange has not crossed the limit of 30 kw and micro turbine is almost unutilized.

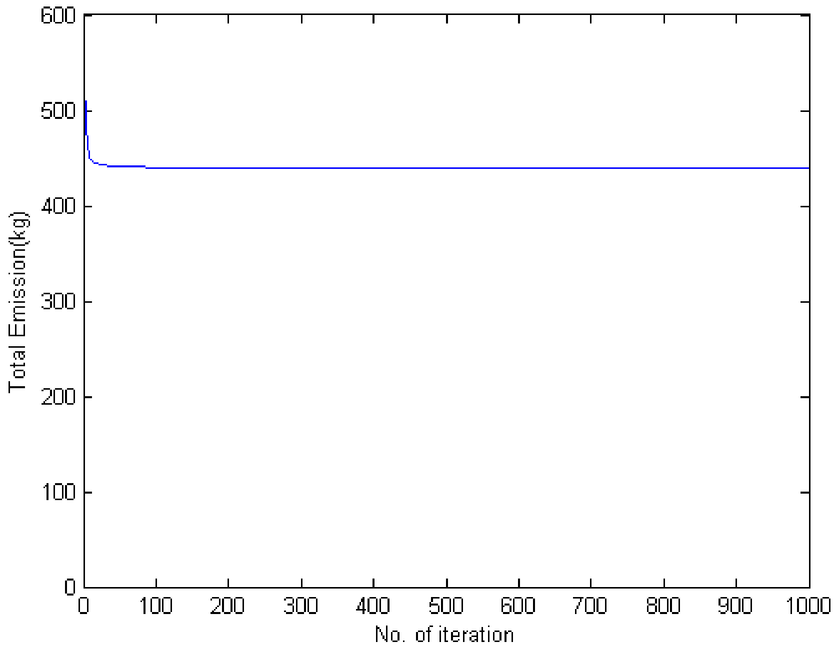


Fig7.19: Variation of total emission with no of iteration for environmental scheduling

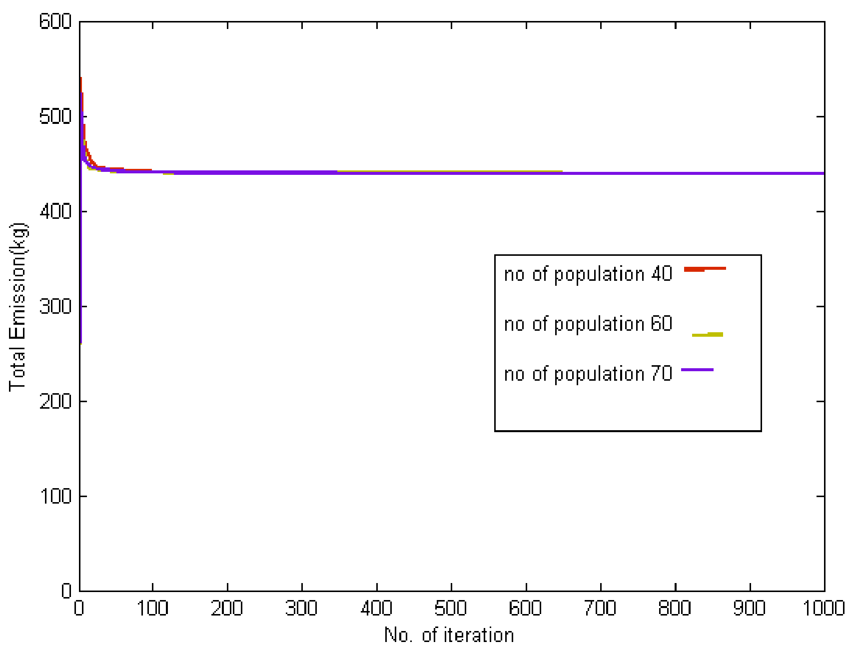


Fig7.20: Variation of total emission with iteration number for different population size for environmental scheduling

Case 3: Economic and Environmental Scheduling for modified problem

Result and graphical representation have given below.

Table 7.11: Result of Economic and Environmental Scheduling for modified problem

(population no.=50, no. of iteration=1000,$c_1 = c_2 = 2$, $W_1 = 1, W_2 = 1$)

Hour	MT(KW)	FC(KW)	PV(KW)	WT(KW)	Battery(KW)	Utility(KW)
1	0.0000	22.0002	0.0000	0.0008	29.9989	0.0000
2	0.0000	19.9989	0.0000	0.0001	29.9998	0.0012
3	0.0000	19.9977	0.0000	0.0000	29.9999	0.0023
4	0.0000	20.9974	0.0000	0.0009	29.9996	0.0020
5	0.0000	26.0027	0.0000	0.0000	29.9973	0.0000
6	0.0000	29.9999	0.0000	0.0015	29.9960	3.0025
7	0.0000	29.9581	0.0000	0.0000	29.9971	10.0178
8	0.0000	29.9993	0.0119	1.0283	29.9980	13.9626
9	29.9862	29.9764	0.8756	1.6705	29.9922	-16.5008
10	29.9897	29.9945	7.3958	2.8272	29.9973	-20.2044
11	29.8404	29.8195	9.9815	8.7710	29.9994	-30.4119
12	29.9195	29.8768	11.9150	10.4126	29.9987	-38.1224
13	29.9913	29.8820	0.0366	3.7625	29.9932	-21.6656
14	29.9586	29.9879	20.9572	2.3546	29.9998	-41.2581
15	29.9834	29.8832	0.0029	1.7730	29.9964	-15.6389
16	29.9788	29.9894	0.0108	1.1153	29.9948	-11.0892
17	24.5198	29.9926	0.0002	0.5115	29.9760	0.0000
18	6.0111	29.9949	0.0000	1.7411	29.9965	20.2564
19	0.0000	29.9998	0.0000	0.0094	29.9991	29.9917
20	0.0000	29.9981	0.0000	1.7779	29.9929	25.2310
21	18.4217	29.9974	0.0000	1.0496	29.9994	-1.4680
22	10.4639	29.9986	0.0000	0.5452	29.9912	0.0011
23	0.0000	29.9969	0.0000	0.6170	29.9996	4.3864
24	0.0000	26.0024	0.0000	0.0000	29.9977	-0.0001
Total Cost (€ct) 179.9724				Total Emission(Kg) 609.7220		

As the limiting value of power exchange between microgrid and utility grid is increased from 30 kw to 100 kw and the hours basis electricity price is low, there is a tendency to exchange more power between them but the more conflicting situation is that emission of microgrid is considered here and both are optimized simultaneously. Finally it shows that cost is lower by

20.6003 unit than previous problem analysis where emission is higher by 234.5011 than previous analysis

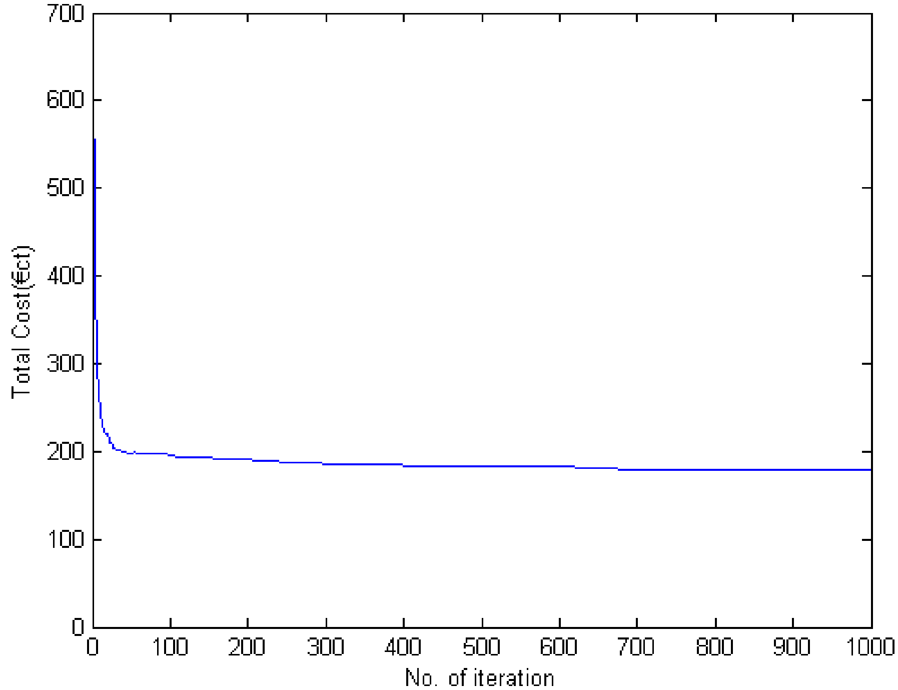


Fig7.21: Variation of total cost with no of iteration for economic-environmental scheduling

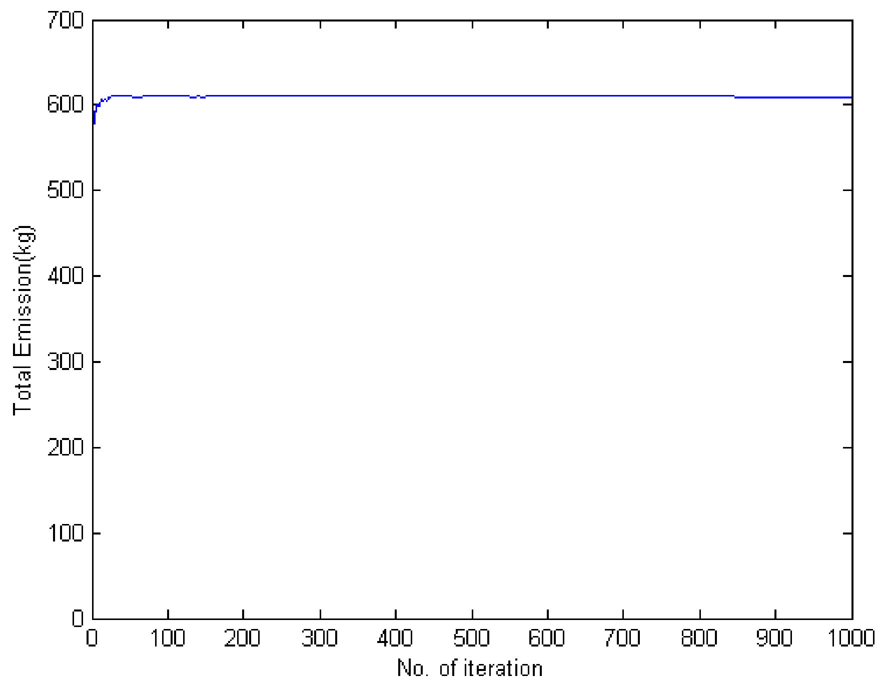


Fig7.22: Variation of total emission with no of iteration for economic-environmental scheduling

Table 7.12: Variation of total cost and total emission in different types of scheduling for modified problem using Hierarchical PSO

Type of Scheduling	Total Cost(€ct)	Total Emission(kg)
Economic based Scheduling	46.8393	1149.9
Environmental based Scheduling	945.0949	439.1016
Combined Economic & Environmental based scheduling	179.9724	609.7220

A MATLAB software of version 7.8.0 (R2013a) is used for implementing all these algorithms. A computer of Windows 8.1 Professional as an operating system, Core I3 @ 1.73 GHz Processor and 4 GB of RAM is used to run these MATLAB Programs.

8 Conclusion and Future Scope of Work

The total thesis work is concluded in this chapter and also future scope of the work is mentioned here.

8.1 Conclusion

The objective of this project is to 24 hours scheduling of DG units of a microgrid including Renewable Energy Sources to minimize both cost and emission. The solution technique Particle Swarm Optimization is used here to optimize cost, emission and both cost and emission simultaneously maintaining constraints and also verified result with technique used for same model. Secondly, a comparison study of employing different improved PSO techniques has been shown for optimizing both cost and emission simultaneously. It is concluded Hierarchical PSO is very much efficient for this problem and result the results obtained are quite satisfactory. The proposed model is efficiently met load demand without compromising any load maintaining the power generation capacity. Another significant point is that, this microgrid model can import or export power from main grid which helps it more profitable and reliable operation.

8.2 Future Scope of Work

. This scheduling is very much significant in remote areas as well as present society where amount of fossil fuel is decreasing and emission of power plant is a matter of concern. This scheduling is more significant where electricity energy price varies from hour to hour for exchanging of power. This scheduling also influences the stable operation of microgrid considering both the profit and pollution matter.

Though there is no variation of pricing of electrical energy from hour to hour in India, it is very much useful in rural areas for reliable operation and also urban areas and meets the load demand successfully. One important condition that microgrid can fulfill that it is capable of plug and play operation.

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