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Optimization of Power System Problem with Renewable Energy Sources Using Enhanced Differential Evolution Algorithm

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Abstract- Electricity demand in most homes is supplied using conventional electric power resources such as coal, and other fossil fuels. With the passage of time, these resources are depleting and producing a large amount of greenhouse gases which is harmful for the ozone layer and eventually leading to global warming. In order to reduce these emissions and provide clean energy, renewable energy resources come into action. After all, due to the increasing costs as well as the harmful emissions, renewable resources offer the best means of replacing them. Solar and wind are the most commonly used renewable resources and are also easily available. Solar and wind energy resources are important sources for providing renewable and clean energy. In general, depending on any one resource as such is not recommended as each has its own drawbacks and thus forming a hybrid renewable energy system helps in integrating various energy sources to form a single system. In this paper, a sizing optimization that involves optimizing the number of solar panels, battery units and the number of micro turbines is done using optimization algorithms. A small region in Palestine was selected for carrying out the experimentation. The Objective function minimizes the cost of energy (COE) and also satisfies the energy demand for the whole year round. Enhanced Differential Evolution Algorithm is being implemented to meet the requirements. Results obtained from enhanced DE is compared with other optimization algorithms to prove its effectiveness.

Keywords: *Solar Energy, Wind energy, Optimization algorithms, Hybrid systems, Differential Evolution*.

1. Introduction

Conventional Economic Load Dispatch (CELD) is one of the most important tools in power system which systematically determines the optimal number of generation facilities with lowest economy-[1]. The main objective of CELD problem is to maintain stability, reliability and security in the power systems by meeting the electricity demand and by satisfying different inequality and equality constraints. These non-linear constraints of CELD problem have motivated the different researchers in solving this problem using different Evolutionary Algorithms (EAs).

The objective of CELD problem is met using the Conventional Energy Sources (CES) like natural gas, coal or oil and due to its continuous usage atmospheric gets emitted which leads to increased global warming[3]. Also the continuous usage of CES leads to more problems which has forced the researchers to limit the usage of CES. One of the way by which the usage of CES can be reduced is by using renewable energy sources (RES) in additional to the CES.

Though RES have its own advantages, the major disadvantages of these RES is that it purely depends on weather and climatic conditions [4]. Moreover, the variability of wind power and solar power creates severe impact on the reserve which creates more challenges in satisfying equality constraint and to maintain stability and reliability in the power system operation. The one possible solution to overcome these problems is integrating one or more RES with CES and a storage system in suitable hybrid architecture. The so formed system is called Hybrid Renewable Energy Systems (HRES) which can be operated in either standalone or grid connected mode. An optimally designed HRES that combines different RES along with a CES and a storage device as backup is the viable and attractive solution. In specific, the HRES first capitalizes the power obtained from RES and if the demand is not met, to ensure the power system reliability, power from backup generator or storage device is used.

In [2], in a remote area, the design, implementation and operation of a HRES is discussed. Pranav M.S et al, have studied about the basic different types of hybrid renewable energy systems that can be harnessed in India [5-12]. A small brief summary about the various types of hybrid system are being discussed. The paper concludes by saying that with hybrid renewable energy systems, it is possible to achieve better results, at lower cost and hence save resources by implementing the enhanced algorithm.

Ismail, et al. [13] provided an iterative approach to analyze the hybrid system consisting of PV and Micro turbines as a backup source. Here the modeling of the PV system was being formulated using the basic equations while at the same time including the effects of the series and the shunt resistors in the equivalent circuit. The effect of the ideality factor was included in the final equivalent equation for the diode circuits in the PV array system.

Ismail, et al. [14] used genetic algorithm to optimize the various sizes of the components in the hybrid system consisting of PV panels, battery units and micro turbines as a backup source for diesel generators. The main objective was to minimize the COE function while at the same time meet the energy demand. Many cases were considered such as using diesel generators instead of the micro turbines, and the different types of mounting structures for the PV panels. All data required for the simulation process are included in the end section as well. The PV Mounting structure is also being optimized. The PV tilt angle and the azimuth angles are optimized before handedly. The obtained results are then compared with the results obtained from other stochastic algorithms.

Differential Evolution (DE) algorithm which is first proposed by Storn and Price (1997) is mostly widely used in solving power system problems. Based on the generation of current population, the DE algorithm differs from other EAs [15-20]. The performance (searching accuracy and convergence speed) of DE algorithm is sensitive to population size , mutation and crossover rate which like other EAs are kept fixed throughout the DE algorithm. However, there is no suitable method or technique for setting these parameters for a particular problem. In [22], a enhanced DE algorithm is proposed to solve the power system problem which is used in this paper to solve HRES problem.

The parameters of the HRES system which is to be determined by implementing modified DE algorithm is shown in Figure 1.

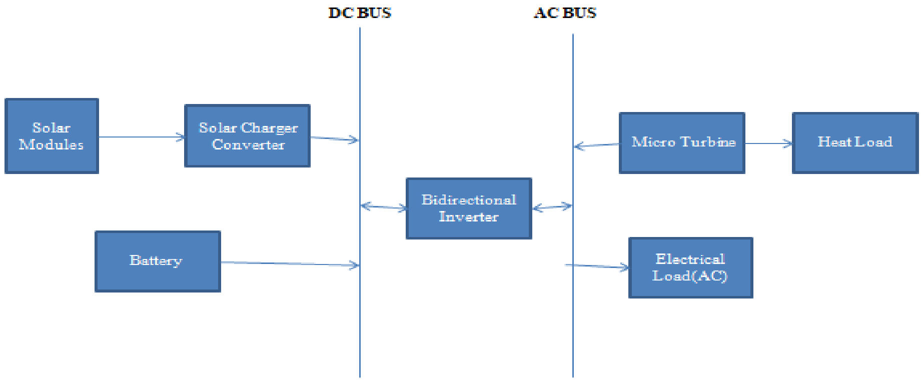

Fig 1: Hybrid System

2. System Components

2.1. PV Panels

The PV panels generate power based on the solar radiation from the sun and the angle with which it is inclined to the sun's radiation at each hour during the day. The angle is optimized to such a value that the efficiency of the PV panels is at a maximum value. There are two main types of mounting structures for the PV panels i.e., fixing on the roof or ground and single axis tracker.

2.2. Micro turbine

Here, we have considered the micro-turbine as a back-up source for our hybrid system. In order to ensure that the micro-turbine supplies the electrical load during emergencies or in case when the renewable resources aren't able to supply the load, the rating of the micro-turbine is generally fixed at the peak demand of the system. The design for the hybrid system leads us to have two different types of micro turbines and their ratings along with the capital and maintenance costs are summarized in the Table. The fuel for the micro-turbine is calculated using a second order equation:

$$FF_{MT} = 0.0007(P_{MT-OUT})^2 + 0.29(P_{MT-OUT}) + 1.684 \quad (1)$$

where PMT-out stands for the rated power of the micro turbine in kW and FFMT is the natural gas fuel consumption in (m3/Liter).

2.3. Solar charger converter

It is used to regulate the power flow from the solar panels to the electrical load in a smooth manner. It thus ensures that both the solar panel as well battery banks is well protected. The solar banks are protected in such a way that there isn't any reversal of power flowing through it. It also safeguards the battery against deep discharges and excessive overcharging. Since the converter forms a special part of the hybrid system, its efficiency affects the overall efficiency of the system.

2.4. Bidirectional converter

It helps in interconnecting both the AC and the DC buses respectively. It works as an inverter to supply AC loads, and as a rectifier while charging the battery using the output obtained from micro turbine. Its rating is selected to suit both battery bank and load. The bidirectional inverter plays a major role in determining the rating of the solar PV panels as well as the battery banks. Both of their ratings are inversely proportional to the efficiency of the bidirectional converter, and hence their rating increases as the efficiency of the converter decreases.

2.5. Economic Modelling

To minimize the cost, all the major and minor costs have to be included in the analysis. The major costs include the capital cost for the micro turbine, the battery bank, the solar panel and the bidirectional converter. The minor costs include the maintenance cost, and the emission costs cause due to the micro turbine, operation costs as well as the replacement costs. Life cycle costing analysis has been used in this paper for economic modeling. For comparison purposes, the cost of production of one unit of energy (COE) is to be considered. The COE includes the total life cycle cost of the system (25 years). Since each part of the hybrid system has varying lifetimes as specified by the manufacturer, each lifetime is included and calculated individually and then combined as a whole.

Another important governing factor while calculation of the COE is the satisfaction of the total energy demand for the whole year. The unit for COE is ($/kWh) and is given by

$$COE = \frac{TAC}{TALE} \quad (2)$$

where TAC is the total annual cost in $/year and TALE is the total annual load energy in kW h/year.

Here, TAC is calculated by dividing total life cycle cost (TLCC) in $, over cumulative present worth factor (CPWF), as follows:

$$TAC = \frac{TLCC}{CPWF} \quad (3)$$

The (CPWF) is calculated as follows:

$$CPWF = \frac{1-X^n}{1-X} \quad (4)$$

where n is the project lifetime. The variable X can be calculated as follows:

$$X = \frac{1+i}{1+d} \quad (5)$$

where ‘i’ is the inflation rate and ‘d’ is the depletion rate (both in percentages).

3. System Inputs

Remote small communities in Palestinian, Ramallah region are taken for account. These areas are sparsely populated and hence maximum utilization of the resources is possible. Though the wind energy cannot be harnessed to the extent at which solar energy is being harnessed due to the latitude and longitude positions (31.8N and 35.23E), they have decided to use hybrid resources consisting of solar and micro turbine. The hourly and yearly solar profile is recorded and the average solar profile is taken into consideration. The tilt angles of the solar panels have been optimized accordingly in order to obtain maximum efficiency.

They have two seasonal climates. One is the summer (May to October) and the other is the winter (November to April). The average load profile for the same is 368 kWh and 332kWh respectively. Measurements of the total load for both these categories for a whole weak and an hourly average values have been obtained.

For the optimization purposes, four types of PV panels, two types of mounting fixtures, two types of micro turbines and four types of battery units are considered from various manufacturers and their ratings, capital cost, maintenance cost and other operational costs are briefly given in [13]. Other important data includes the capital cost of the bidirectional converter, solar charger converter. The amount of greenhouse gases emitted from the micro turbine and their respective costs are also summarized in [13].

4. Implementation of Enhanced Differential Algorithm

Differential evolution Algorithm was first formulated by Storn and Price in 1995. Since its origin, the DE algorithm has become one of the most prominent, competitive, fast and versatile algorithms in solving numerous real world problems existing in various science and technological problems such as the economic dispatch, short-term scheduling, and power system planning. It easily helps in determining the global optimum solution for functions which require a continuous search space, or when the objective functions are nonlinear, non convex, multi-modal or non-differentiable functions.

The various steps involved in the DE are the same as that of other optimization algorithms which are: initialization, mutation, crossover, and selection. Although the DE algorithm has brought about significant breakthroughs, in order to reduce the computational time, the conventional differential algorithm is replaced by the enhanced differential evolution algorithm which is proposed by [21]. In the enhanced differential evolution algorithm, trial and error method of determining the control value parameters for a particular problem is replaced by an automatic tuning method. A brief description about the various processes involved in Modified DE in [21]. A flowchart to explain the process of Modified DE is given in Figure 2.

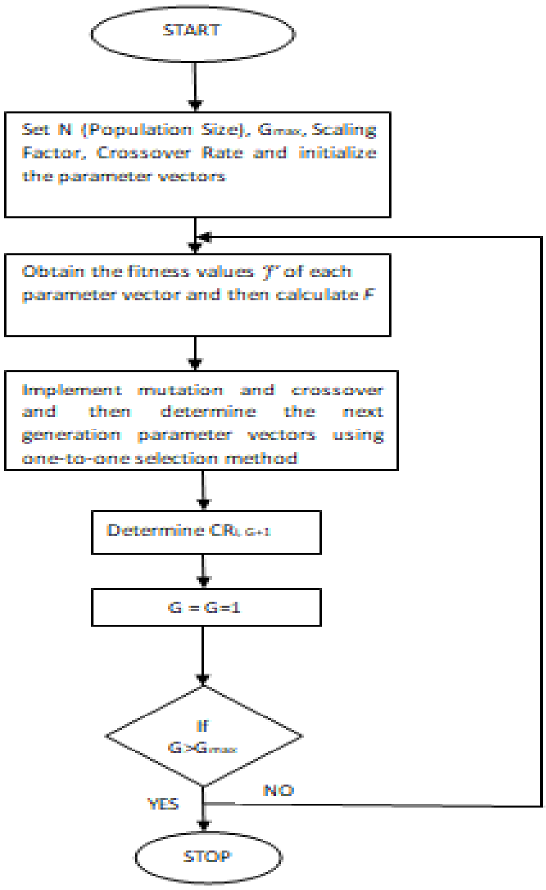

Fig 2: Flowchart of the Enhanced Differential Evolution Algorithm

3. Results and Discussions

The Optimization Algorithms are being implemented to minimize the objective functions and the best results are being summarized in Tables 1, 2, 3 and 4.

Table: 1 Results of simulation of different cases using Genetic Algorithm

Case	PV Type	Battery Type	Micro Turbine Type	PV Fixture Type	Micro Turbine Nos.	PV Panel Nos.	Battery Units Nos.	COE	Running Hours
1	4	4	1	1	1	61	20	0.5666	3200

2	4	4	1	1	1	64	17	0.5679	3200
3	1	1	1	1	1	60	5	0.5682	3221
4	2	2	1	1	1	64	11	0.5730	2752.8
5	3	3	1	1	1	78	9	0.5734	3200
6	2	2	1	1	1	56	6	0.5737	3200
7	2	2	1	1	1	63	14	0.5746	2536.9
8	2	2	1	1	1	56	6	0.5747	3200
9	3	3	1	1	1	57	8	0.5753	3200
10	1	1	1	1	1	62	4	0.5775	3200
11	1	1	1	1	1	65	4	0.5807	3200
12	3	3	1	1	1	66	23	0.5816	2078.3
13	4	4	1	1	1	82	11	0.5872	3200
14	3	3	1	1	1	90	5	0.5920	3200
15	4	4	1	1	1	95	25	0.6002	2435.9
16	1	1	1	1	1	200	1	0.6148	3200

Table 2: Results of simulation of different cases using PSO Algorithm

Case	PV Type	Battery Type	Micro Turbine Type	PV Fixture Type	Micro Turbine Nos.	PV Panel Nos.	Battery Units Nos.	COE	Running Hours
1	2	4	1	1	1	56	17	0.566	3200
2	1	3	1	1	1	56	10	0.56667	3200
3	1	4	1	1	1	56	5	0.56757	3200
4	1	1	1	1	1	56	5	0.56757	3200
5	2	2	1	1	1	56	8	0.5686	3027.3
6	2	1	1	1	1	56	5	0.569	3123.5
7	1	2	1	1	1	52	12	0.57044	2666.1
8	4	4	1	1	1	56	15	0.57122	3200
9	3	4	1	1	1	55	16	0.57141	3200
10	2	3	1	1	1	56	15	0.57215	2720.1
11	4	3	1	1	1	56	8	0.57266	3200
12	4	1	1	1	1	56	4	0.57298	3200
13	3	2	1	1	1	55	6	0.57339	3200
14	3	3	1	1	1	52	15	0.57967	2663.9
15	4	2	1	1	1	56	11	0.58106	2574.8
16	3	1	1	1	1	56	7	0.58197	2719

Table 3: Results of simulation of different cases using Enhanced Differential Evolution Algorithm

Case	PV Type	Battery Type	Micro Turbine Type	PV Fixture Type	Micro Turbine Nos.	PV Panel Nos.	Battery Units Nos.	COE	Running Hours
1	2	4	1	1	1	55	19	0.56561	3130.2
2	1	4	1	1	1	55	19	0.5657	3192.3
3	2	2	1	1	1	55	7	0.56739	3147.9
4	1	3	1	1	1	56	11	0.56767	3117.1
5	2	3	1	1	1	57	9	0.56799	3200
6	1	2	1	1	1	57	8	0.56828	3097.1
7	2	1	1	1	1	55	5	0.56899	3130
8	1	1	1	1	1	62	5	0.5701	3171.2
9	4	2	1	1	1	55	7	0.57394	3058.8
10	4	4	1	1	1	55	15	0.57435	3182.4
11	3	4	1	1	1	55	16	0.57538	3166.4
12	4	1	1	1	1	55	4	0.57552	3187.4
13	3	2	1	1	1	56	6	0.5759	3170.5
14	4	3	1	1	1	55	9	0.57635	3100.5
15	3	3	1	1	1	55	9	0.5768	3129.4
16	3	1	1	1	1	55	5	0.57768	3055.7

The modified differential evolution algorithm is applied to the HRES system problem in a small rural region in Palestine using MATLAB. To analyze the betterment of the DE Algorithm, it is compared with other optimization algorithms such as Particle Swarm Optimization Algorithm and the Genetic Algorithm.

The parameters used in each of the optimization algorithms are selected in such a way that the COE function is minimized to a great extent. The best optimized results are then obtained for the crossover rate and the mutation rate.

Table 4: Best Optimized results from various Optimization Algorithms

Algorithm	PV Type	Battery Type	Micro Turbine Type	PV Fixture Type	No. of Micro Turbines	No. of PV Panels	No. of Battery Units	COE	Running Hours
GA	1	4	1	1	1	61	20	0.5666	3200
PSO	2	4	1	1	1	56	17	0.566	3200
Enhanced DE	1	4	1	1	1	55	19	0.5656	3130.2

Table 4 summarizes the comparison of the three optimization algorithms implemented in this paper.

The convergence characteristics for each of Modified DE, PSO, and GA and are shown in the figure 3. The abscissa for the convergence plot gives the COE and its perpendicular axis gives the number of iterations for which it took to reach the global minimum in each of the situations.

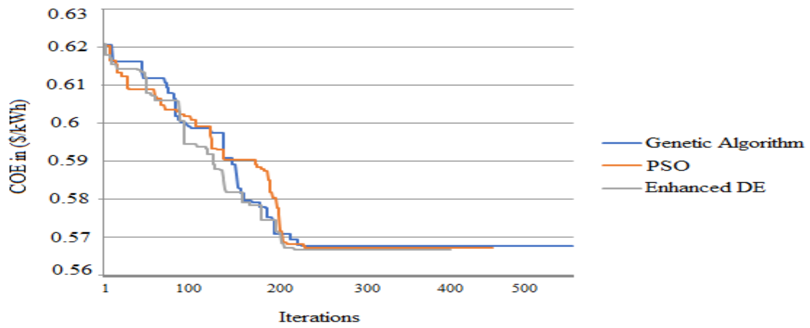

Fig 3: Convergence Characteristics of chosen HRES

A careful observation from the graph reveals that the modified DE is quite faster in the optimization which thus reduces the computational burden and eventually leads to minimal computer resource utilization. The optimal solution using various optimization algorithms is summarized in Table 4.

Although the difference in the COE function obtained from the modified DE as compared to PSO (as it holds results better than GA) is a meager value of 0.003, it still produces a very large difference as the unit of COE is $ per kilowatt hour ($/kW h) and hence this accounts for a profit of more than $330,000 for a year. These figures indicate that the small difference in the best solution of the Modified DE produces a very large value. The average values obtained from the best solutions obtained from the Modified DE is also far better when compared with other optimization algorithms such as GA and PSO.

5. Conclusion

In this paper, an attempt has been made to implement the enhanced DE optimization algorithm for HRES problem. The developed methodology was tested and the obtained results were compared with those obtained from GA as well as with PSO. Results reveal that the enhanced DE evolutionary algorithm outperforms the Genetic Algorithm as well as the particle swarm optimization algorithm. A hybrid system consisting of PV Type 1, Battery Type 4, PV Fixture Type 1, Micro turbine Type 1, and having 55 number of PV Panels and 19 Battery units, with the micro turbine running for 3192.3 hours produces the most reliable and economical solution for the considered case study area. The developed model takes into account the lifetime of each of the system components ranging from the PV Panels to the bidirectional converter and also includes the cost for the greenhouse gas emissions.

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