Optimization of Distributed Generation Based Hybrid Renewable Energy System for a DC Micro-Grid Using Particle Swarm Optimization

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ABSTRACT

This research work aims to design and optimize a multi-objective function modeled on the variables concerning distributed generators based on photovoltaic, wind and biogas based IC engine hybrid system for community smart DC Micro-grid using particle swarm optimization (PSO). The objectives of the research are to maximize the availability of power and reduction of the cost, which in turn will reduce the size of system with premier achievable availability. The output power of photovoltaic, wind and biogas based IC engine generators would have the highest priority for feeding the direct current bus as per the methodology proposed. It was found that proposed method especially particle swarm optimization had shown the effective cost and availability of photovoltaic, wind and biogas based IC engine generators in terms of accuracy to the practical values and a faster rate of convergence. When compared with other algorithms, particle swarm optimization performs well in reducing the cost of the photovoltaic, wind and biogas based IC engine generators. In addition, it was noted that availability of photovoltaic, wind and biogas based IC engine generators would be easily obtained using PSO algorithm. Future work would pertain to the designing of a similar hybrid Renewable energy system considering Up-time and Ramp rate constraints of biogas based IC engine generators for community smart direct current micro-grid and optimize it using Multi Objective Genetic Algorithm and compare its results with PSO.

Keywords: renewable energy, wind energy, biogas based IC engine and photovoltaic, multi-objective optimization, direct current micro-grid, particle swarm optimization.

INTRODUCTION

Renewable Energy sources like wind, solar, hydro and biogas based IC engine are gaining popularity in micro-grid implementation both for off grid and grid fed systems. Twenty per-cent of dissemination of renewable energy is projected in producing the net global electricity by 2020. By nature renewable energy is distributed and dispersed as well as intermittent. Man requires a regular supply energy in the form of light, heat and power. In emerging nations with large dispersed inhabitants, electricity acts as a promoter of good healthcare, education, population control and agriculture. Moreover, electricity is seen as the best vehicle for carrying energy from source to the land [1].

For sustainable operation of renewable energy based power systems, a combination of distributed power sources and energy storage subsystems is employed [2]. Such a combination is called as *micro-grid*, which is a small-scale grid, developed for providing power particularly for local communities [3]. A Micro-grid is characterized by certain operations and constraints depending on many critical stochastic parameters [4]. It is the aggregation of various distributed generators like conventional generators, renewable energy sources in link with the units of energy storage which combine together as a network for power supply. It performs synchronously in parallel particularly with main grid [5]. Micro-grid is a key enabling technological platform for renewable energy development and energy efficiency improvements [6]. DC micro-grid is an effective and efficient method for combining a high reliability system and the possibility for reducing the losses in a system. It is an effective control and management architecture that makes the implementation of smart grid techniques at distribution level quite easy [7]. The architecture of a micro-grid generally consists of parallel connection of several electronically interfaced distributed generation units and a local load [8]. Technologies of distributed generation involve solar photovoltaic, micro turbines and wind turbines by providing numerous advantages. It could provide higher reliability and security of power and minimal-cost electricity with certain environmental consequences rather than conventional bulk generations of power [9].

Grid operates in a disconnected state or in an islanded mode. Integrating renewable energy into the system of utility grid could be at either the distribution level or transmission level, relying on the generation scale. Large generation of renewable energy like in wind farms is directly interrelated to the system of transmission [10]. Energy storage seems to be a perfect solution to manage the intermittency of Green energy sources but is still has the limitation of availability and life cycle cost [11]. By integrating energy storage devices in a micro-grid peak demand management becomes quite easy [12]. The output power profile of renewable energy sources and the load profile are two critical factors for deciding the capacity of energy storage sub-system [13]. Hybrid system for energy involves at least two of the following: energy storage systems, generation systems, equipment for power conditioning and controllers. It could or could not be connected to the grid. Commonly used energy systems in configuration of hybrid are photovoltaic systems, wind turbines, biogas based IC engine, micro hydro, fuel cells and diesel generator [14-17]. The advantages of a hybrid system include high scalability and power management capability [170]. It is widely accepted that it is necessary to optimize the efficiency of distributed generation [18]. The vital issues to be handled include continuity of the supply with reduced –size storage sources, integration of different thermal and electrical generation system, etc. [19]. A sustainable micro-grid should enable the optimal dispatching of distributed generators and storage systems [20]. Research efforts are also needed in the direction of reducing the size of distributed energy sources with optimum availability.

The impact of renewable energy sources on micro-grid planning is two-fold. The lifecycle power generation cost in a micro-grid can be reduced by utilizing renewable energy sources combined with an IC engine (a hybrid system). And the Micro-Grid availability can be enhanced by including some energy storage (batteries). Given the stochastic nature of power demand and supply in a micro-grid, stochastic optimization tools should be used to take into account the statistical uncertainties and to make optimal design and planning decisions [21, 22].

PROBLEM STATEMENT

Optimal size of renewable energy sources and energy storage subsystem should be considered on the basis of the maximizing cost benefit with optimum availability of power [23]. Small scale generation of power near customer's premises had greater focus in the recent years for usage in rural and remote communities because of complexity and cost in the extension of grid. Thus, it is appropriate that stand-alone systems are needed and that could be developed using available sources of renewable energy which has become the most used option. There are 2 approaches that are utilized for harnessing available sources of renewable energy such as hybrid and integrated systems. Different systems for distributed energy need various topologies for power electronics to convert the generated power to the power of utility compatible [24]. Therefore, this particular study intends to focus on enhancing the multi-objective optimization design of photovoltaic, wind and biogas based IC engine hybrid system for community smart DC Micro-grid using particle swarm optimization. This study also evaluates the availability and cost for photovoltaic, biogas based IC engine and wind.

AIM AND OBJECTIVES OF THE RESEARCH

Aim of the research is to enhance the multi-objective optimization and design of photovoltaic, wind and biogas based IC engine hybrid system for community smart DC Micro-grid using particle swarm optimization.

Following are the objectives of the research:

i. To design a photovoltaic, wind and biogas based IC engine hybrid system for community smart DC Micro-grid using particle swarm optimization.
ii. To evaluate the cost and availability for photovoltaic, wind and biogas based IC engine turbines.
iii. To compare the effectiveness of particle swarm optimization algorithm with multi-objective optimization algorithm.

LITERATURE REVIEW

Rashtchi, Rohani and Kord [19] examined the optimum design and hybrid energy system. This research used Chaos optimization technique for solving unit sizing of system for hybrid generation that involves photovoltaic generator, an electrolysis device, fuel cell and a battery. Hence the particular system was simulated and outcomes were discussed. Outcomes of simulation were used to identify the configuration's optimal sizing. It was observed that chaos optimization algorithm

(COA) is able to identify the optimum parameters of design regarding the model for stochastic simulation, and then COA has the potential to determine the global optimal answer or solution for such an issue of unit sizing. It is easy for studying and has simple structure. Optimized system's total cost indicated that the system is able to deliver energy in an installation that would stand-alone with an acceptable and reasonable cost and also obtain proper system reliability. Thus it can be concluded that COA has the potential to determine the global optimal answer or solution for such an issue of unit sizing. It is easy for studying and has simple structure.

Tavakkoli, Radan and Hassibi [20] discussed about the applicable techniques which minimize the driving circuits in inverter of parallel power used in micro-grid system particularly concentrated on distributed generation with specific reference to islanded mode. Electrification to home load, commercial building, market or villages have sufficient space and still there is insufficient land for installing the system, therefore compact system is essential. One such area is distributed generation micro-grid. It could remove the DC (Direct current)/AC (Alternative current) or AC/DC stage of conversing power and thus has benefits in the stand of cost, efficiency and size of the system. Therefore, such idea has been introduced in the proposed research that the direct current system would be smaller. Compressing can reduce using the circuits and system properties, which have similar functions the electronic infrastructure. Thus it can be concluded that the electrification to home load, commercial building, market or villages have enough space and still there is insufficient land for installing the system, thus compact system is essential. One such area is distributed generation micro-grid.

Reza et al [21] has developed a new and novel smart distributed direct current micro-grid system particularly in rural areas for utilizing energy available from renewable, distributed generators. It was observed that, such direct current micro-grid could assure reliable supply of power to the customers and thus gives the service continuity. It is noticed that the power and efficiency flow strategy of photovoltaic-diesel hybrid system particularly for micro-grid has to be examined. By deploying such photovoltaic-diesel hybrid direct current micro grids especially in the rural areas; nation grid dependency could be minimized and proper, efficient usage of renewable energy could be assured for having an environmentally sound region or society. Few independent grids could play a main part for solving the electricity crisis in rural areas. Thus it is concluded that nation's grid dependency could be minimized and proper, efficient usage of renewable energy could be assured for having an environmentally sound region or society.

Bhowmik [22] designed and scheduled the hybrid power system which involves photovoltaic generator, wind turbine, diesel generator and battery bank using algorithm namely area based observation and focus. From the findings of the analysis, it is observed that area based observation and focus algorithm were most effective and efficient acquired from hybrid system.

Shadmand and Balog [23] designed wind-photovoltaic hybrid system for community smart direct current micro-grid using multi-objective optimization. This study provided a general model which quantifies the cost and availability of hybrid systems for renewable energy for smart direct current micro-grid. It is noticed that high temporal data of resolution for photovoltaic system is used for optimizing the hybrid system on the basis of MOGA (Multi-objective genetic algorithm). Such algorithm is used for plotting the pareto front for visualizing the issue of engineering tradeoffs. Utility function is on the basis of cost and availability formulated for finding the final optimal solution. In addition to this, optimization is done with uncertainty and certainty on available resources. Cost differences between traditional energy and clean energy are less extreme rather than issues or critics that mostly imply and then differences continually reduce steadily. Proposed study integrated the load profiles and resources with economics for providing an optimal solution that has minimal cost of investment. Thus it is concluded that cost differences between traditional energy and clean energy are less extreme rather than issues or critics that mostly imply and then differences continually reduce steadily.

RESEARCH DESIGN

PSO is an optimization and self-educating algorithm that could be implemented to any issue of non-linear optimization. In PSO method, particles namely potential solutions fly through the space of problem by following the particle's best fitness [30]. It involves some attributes of evolutionary computation like initializing with inhabitants of random solutions as well as seeks for optima by upgrading generations. Particle's updates reach based on the following equation 1, below. Equation

(1) estimates a new velocity for every particle namely *v*, on the basis on its previous velocity (P_{ve}), location of particle at which the best fitness (BF) could be accomplished (R_{bestv}) and N_{best} (best particle among neighbors) at which the BF could be accomplished. Apart from these, learning factors l_1 and l_2 are denoted as the acceleration constants that modify the particle's velocity towards R_{bestv}R and N_{best}N and r_1 and r_2 are equally distributed random numbers in [0,1]. Next to that, each position of the particle is updated using equation 2 in the hyperspace of solution. And then, it is also noticed that the PSO method with a Lineraly Decreasing (LD) inertia weight i^e in each iteration v, from high value that is maximum value i_{max} to low value that is minimum value i_{min} as shown in 3.3 could make an enhancement on convergence to global optimum inside the acceptable quantity of iterations.

$$P_v^{e+1} = i^e P_v^e + l_1 r_1 * (R_{best}^e - S_v^e) + l_2 r_2 (N_{best}^e - S_v^e) \tag{1}$$

$$s_v^{e+1} = s_v^e + P_v^{e+1} \tag{2}$$

$$i^e = i_{max} - i_{min} / e_{max} * e \tag{3}$$

Where *e* is the iteration counter and also maximum iteration number is denoted as e_{max}.

The velocity update equation (1) could be described as follows,

$$P_v^{e+1} = i^e P_v^e + l_1 r_1 * (R_{best}^e - S_v^e) + l_1 r_2 (N_{best}^e - S_v^e)$$

as mentioned by Yoshida et al [30]. Without the 2nd and 3rd terms, the 1st term represents inertia. It would maintain a particle flying in specific direction that is same position unless it hits the boundary. Thus, 1st term attempts to expand new areas and moves to the difference in the search procedure. On the other hand, without the 1st term, the flying particle velocity is only identified by using its best positions and current positions in the history. 2nd term represents memory and 3rd term represents cooperation which attempts to converge the particles to their R_{bestv}R and/or G_{best}G and correspond to search procedure intensification. The PSO method has a mechanism that could be well-balanced for utilizing the intensification and diversification in the procedure of search efficiently.

To summarize: The main aim of the research is to reduce the cost which reduces the size of system with highest possible availability.

Apart from these, output power of photovoltaic, wind and biogas based IC engine generators has the highest priority for feeding the direct current bus and if the generated power is not adequate, a battery bank could be discharged to specific amount for feeding the bus. Furthermore, if there is still no sufficient power, few amount of power could be bought from grid for feeding the load.

Cost

Main system component cost involves the price of photovoltaic panels, battery bank, wind turbines and biogas based IC engine generators. The total system cost encompasses maintenance, operational cost and initial cost per year could be described as

$$cost = T_{grid} + \Sigma_{K=P.w.b.ba} (L_k + S_k)A \tag{4}$$

Where P denotes photovoltaic, W denotes wind, B represents biogas based IC engine, Ba denotes battery bank, L_k denotes the initial cost and S_k indicates operation and maintenance cost. A and T_{grid} are the life cycle of the system and cost of power imported from grid respectively. In the optimization, the objective function is formulated to minimize the cost of the main system components.

$$\mathrm{Cost}^{\mathrm{Min}} (\mathrm{D_P}, \mathrm{D_W}, \mathrm{D_B}, \mathrm{E_{CB}}, \beta) \tag{5}$$

Where D_P, D_W, D_B and E_{CB} are the design parameters in the research corresponding to photovoltaic, wind, biogas based IC engine, battery respectively, and β is the capacity ratio of power imported from grid to load. D_P is PV surface area, D_W is the wind foot print area, E_{CB} is the capacity of the battery.

For the photovoltaic sub-system, the initial and Operation & Maintenance cost is computed as follows:

$$L_P = \tau_{PV} * D_P \tag{6}$$

$$S_P = S_{annual} * D_P * \sum_{n=1}^{A} \left(\frac{1+\mu}{1+\epsilon}\right)^n \tag{7}$$

For the wind turbine set up, the initial and Operation & Maintenance cost is computed as follows:

$$L_W = \tau_W * D_W \tag{8}$$

$$S_W = S_{annual} * D_w * \sum_{n=1}^{A} \left(\frac{1+\mu}{1+\epsilon}\right)^n \tag{9}$$

Where μ is the rate of escalation, ε is rate of interest, and S_{annual} is the annual Operation & Maintenance cost.

For the battery, the initial and Operation & Maintenance cost is computed as follows:

$$L_{Ba} = \tau_{Batt} * E_{CB} \tag{10}$$

$$S_{Ba} = S_{bat\_annual} * E_{CB} * \sum_{n=1}^{A} \left(\frac{1+\mu}{1+\epsilon}\right)^{(n-1)T_{batt}} \tag{11}$$

T_{batt} is the lifespan of the battery which represents number of times the battery is replaced during the lifecycle of the micro-grid set up.

For the Biogas based IC engine generator the initial and Operation & maintenance cost is given as follows:

$$L_B = \tau_B * D_B \tag{12}$$

$$S_B = S_{annual} * D_B * \sum_{n=1}^{A} \left(\frac{1+\mu}{1+\epsilon}\right)^n \tag{13}$$

Where D_B is the output power of the biogas based IC engine generator.

τ in all the above equations represents initial cost per unit associated parameter of different energy sources.

The cost of purchasing power from the utility is computed as:

$$T_{grid} = \sum_{n=1}^{A} E_{Grid,n} * \rho_{grid} \tag{14}$$

Where ρ_{grid} is the price of the utility power per unit.

E_{grid} is computed by multiplying β by load power supplied by Utility grid power.

Availability

Availability is referred as time fraction when energy is present or available, is a merit's key figure for the proposed research. It is significant to make an opaque distinction between reliability and availability.

Reliability is system's ability for operating without failure; on the other hand availability is the system's ability for supplying power to the load. As illustrated, a high reliable system for photovoltaic energy the components were not prone to failure and could have a minimal availability, if there is no sufficient storage of energy for supporting the power of load needed during an overcast day or night. Mathematical modeling of cost and availability constraints of a micro-grid is necessary for evaluating its stability and efficiency [23].

A specified availability level could be reached with many system configurations. Availability formulated for the proposed system for the duration (d) is explained as:

$$D = 1 \frac{ND}{M} \quad (15)$$

$$ND = \sum_{d=1}^{A} E_{min}^{Ba}(d) - (E_P(d) + E_W(d) + E_{Grid}(d) + D_B(d) + E_{ba}(d) - E_D(d)) * v(d) \quad (16)$$

Where v (d) is a step function which would be 0 if the power of supply is equal or greater demand and 1 is the demand not satisfied.

The imported power found from the grid is explained as:

$$E_{Grid} = \beta * (E_D(d) - E_P(d) - E_W(d) - D_B(d) - E_{ba}(d)) \quad (17)$$

$$E_W = E_Y * D_W * y_W \quad (18)$$

$$D_B = E_G * F_b * y_b \quad (19)$$

$$E_p = \text{Insolation} * D_p * y_p \quad (20)$$

$$E_{ba}(d) = E_{CB} * \varphi \quad (21)$$

D^{Max} (D_P, D_W, D_B, E_{CB}, β)

Where; D is the Index of Availability, ND is the demand that could not be met, M is the yearly demand, β is the ratio of power imported from grid to the load, E_{Grid} Power purchased from grid for the duration d, D_W is the wind footprint area, D_P is the surface area of PV panel, E_Y power produced by wind turbine per unit area, F_b is the fuel cost for biogas based IC engine, D_B is the biogas based IC engine generators power output per unit of fuel cost, $Y_{W.b.;}$ are the efficiencies of wind, biogas based IC engine and PV panel respectively, φ is the battery usage factor, $E_{min}^{Ba}(d)$ is minimum allowable storage level for the duration d. The specified values of certain parameters used in the problem formulation and the search space value limits for the design variables are given in Table 1 and Table 2 respectively from Mysore pilot project.

Table 1: System parameters values

Parameters	Specified value for this study
Rate of Interest ε	14%
Rate of Escalation μ	9.5%
Life span of the battery T_{batt}	4 years
Micro-grid life cycle A	18 years

Table 2: Search Space limit for design variables

Design Variables	Search Space Value Limit
$D_{B\ min}$	11 kW
$D_{B\ max}$	75 kW
$E_{CB\ min}$	75 kWhr
$E_{CB\ max}$	350 kWhr
β_{min}	0.00
β_{max}	0.50
D_w,max	4,389 m^2
D_w,min	95 m^2
D_P,max	4,389 m^2
D_P,min	07 m^2

The cost and availability objective functions should be optimized to minimize the operational cost and maximize the benefit of islanded micro-grid [17]. PSO concept involves each time step, modifying the velocity or acceleration of each particle towards its R_{best} and N_{best} locations. Acceleration would be weighed by the term of random one, with isolated random numbers being produced for acceleration toward R_{best} and n_{best} locations.

The proposed PSO algorithm is as follows:

1) Initializing the array or population of particles with random velocities and positions on x=5 dimensions (D_P, D_W, D_B, E_{CB}, β) in the space of problems.

2) For each particle, estimate the desired fitness function of optimization in 5 variables (D_P, D_W, D_B, E_{CB}, β) which would be Cost and Availability functions here.

3) Compare the evaluation of fitness of particle with particle's r_{best}. Suppose if present value is better than r_{best} then, set value of r_{best} equal to present value and location of r_{best}equal to the present location in x-dimensional space.

4) Compare the evaluation of fitness with the population's overall prior best. If present value is better than n_{best} then reset n_{best} to the present array value and index of the particle.

5) Change the position and velocity of the particle based on equations (1) and (2), respectively:

6) Loop to step 3 until a criterion is satisfied, usually a good enough fitness or maximum generations (number of iterations).

LIMITATIONS OF THE RESEARCH

Following are Limitations of the Research

i) This study focuses only on the particle swarm optimization algorithm.

ii) This research designs photovoltaic, wind and biogas based IC engine hybrid system specifically for community smart DC Micro-grid.

iii) This study exclusively considers about enhancing the multi-objective optimization and design of photovoltaic, wind and biogas based IC engine hybrid system for community smart DC Micro-grid using particle swarm optimization.

iv) Findings of the study is restricted to cost and availability of photovoltaic, wind and biogas based IC engine.

There could be many constraints to be considered while optimizing cost and availability of a hybrid micro-grid consisting of multiple sub-system photovoltaic systems, wind turbines, biogas based IC engine, micro hydro, fuel cells and generator of diesel [28-30]. Future work would design this hybrid system with ramp up and ramp down constraints. Further, it would be based on the energy efficiency of energy generators.

ANALYSIS OF RESULTS

Figure 1 describes the Optimized Parameters VS Iterations graph for Cost and Availability. It also indicates the cost and availability of photovoltaic, biogas based IC engine and wind generators. The thin line indicates the cost of the photovoltaic, wind and biogas based IC engine generators. Bold dark line represents the availability of the photovoltaic, biogas based IC engine and wind generators. Dashed (- - -) line is Availability without utility grid insertion (Islanded mode).

Figure 2 shows Pareto Front of Availability vs. Cost of the Hybrid Energy micro-grid that was used for visualizing the issue for tradeoffs in engineering. By analyzing both Figure 1 and Figure 2 it was observed that 1,200,000 US dollars and 500 kW are the boundary values for Cost and Availability respectively for the pilot micro-grid being optimized.

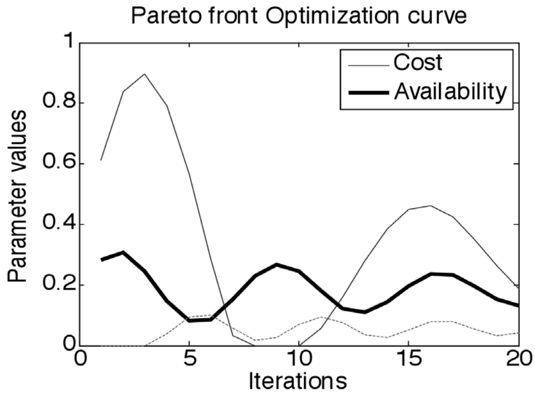

Figure 1.
Optimized Parameters vs. Iterations Graph for Cost and Availability

The synchronism of both the figures is evident from the observation that a cost of 1.15 million US dollars for 80 kW availability is the optimal point, which close to the practical values for a similar micro-grid stationed in Mysore, India [31]. The same conclusion can be drawn from Figure 1 at second intersection of the two graphs in 12 iterations showing the optimum point of operation with a faster convergence.

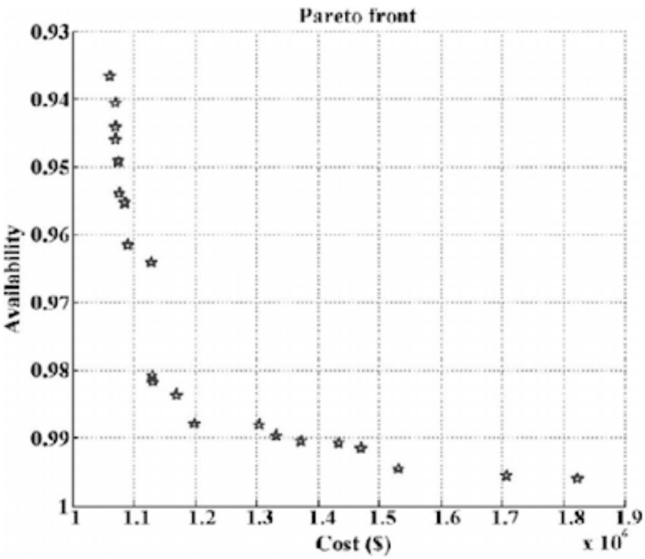

Figure 2.
Pareto Front of Availability vs. Cost of the Hybrid Energy Micro-grid

CONCLUSION AND FUTURE WORK

PSO was seen as a mid-level form of biology or A-life derived algorithm which occupies the space in nature between searches of evolution that need neural processing and eons that occur on the milliseconds order. In addition, it was noted that social optimization happens in the ordinary experiences time frame and that would be an ordinary experience. Moreover, this ties with A-life; PSO has opaque ties with computation of evolution. Thus it seems to lie between evolutionary programming and genetic algorithms.

It was noticed that the PSO algorithm had utilized a utility function for finding the optimal solution. It found the reliable supply of energy with minimal investment, i.e. a cost of 1.15 million US dollars for 80 kW availability is the optimal point, which close to the practical values for a similar micro-grid stationed in Mysore, India. The same conclusion can be drawn from Figure 1 at second intersection of the two graphs in 12 iterations showing the optimum point of operation with a faster convergence.

Particle swarm optimization algorithm is an extremely simple algorithm, which is more effective and efficient to optimize a wide range of functions. The main aim of the research is to increase the availability of power and reduce the cost which reduces the size of system with highest possible availability. It is highly and significantly dependent on stochastic processes such as evolutionary programming. Apart from these, adjustment towards R_{best} and N_{best} by the optimizer of particle swarm is similar to the operation of crossover that was used by genetic algorithms. Thus, it can be concluded that when comparing PSO with the multi-objective genetic algorithm, PSO algorithm is more effective. When adopting the PSO algorithm the cost of photovoltaic panels, battery bank, wind and biogas based IC engine turbines are less than results obtained using a multi-objective genetic algorithm.

Future work would design hybrid system with photovoltaic, wind and biogas based IC engine generators considering the Up-time and ramp up and ramp down constraints of biogas based IC engine and then optimizing such a distributed generation based system for community smart direct current micro-grid using Multi Objective Genetic Algorithm. Further it would be based on the energy efficiency of energy generators. In addition to that, future work would also compare the effectiveness of proposed algorithm with existing PSO algorithm.

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Nomenclature

Symbols /Acronyms	Definition
ϵ	Interest rate
ρ_{grid}	price of the utility power per unit
S_{annual}	annual Operation and Maintenance cost
R_{bestv}	Best known position for the individual particle
P_{ve}	Previous Velocity
N_{best}	best particle position among neighbours
E_{Grid}	Power purchased from grid for the duration d
φ	Battery usage factor
. T_{grid}	Cost of power imported from grid
μ	Escalation rate
A	Life cycle of the system
AC	Alternating current
B	Represents biogas fired IC engine
Ba	Denotes battery bank
BF	Best Fitness
COA	Chaos Optimization Algorithm
D	Index of Availability
D_B	design parameters in the research corresponding to biogas based IC engine
D_b	biogas based IC engine generators power output per unit of fuel cost
DC	Direct Current
D_P	design parameters in the research corresponding to photovoltaic
D_p	the surface area of PV panel
D_W	design parameters in the research corresponding to wind
E_{CB}	design parameters in the research corresponding to battery respectively
E_{grid}	multiplying β by load power supplied by Utility grid power
$E_{min}{}^{Ba}(d)$	minimum allowable storage level for the duration d
E_y	power produced by wind turbine per unit area
F_b	the fuel cost for biogas based IC engine
IC	Internal Combustion
i^e	inertia weight
i_{max}	maximum value of Inertia weight
i_{min}	minimum value of Inertia weight
l_1 and l_2	Learning factors
LD	Lineraly decreasing

L_k	Initial cost
M	Yearly demand
MOGA	Multi Objective Genetic Algorithm
ND	Demand that could not be met
P	Denotes photovoltaic
PSO	Particle Swarm Optimization
S_k	Operation and maintenance cost
v	Particle Velocity
$v(d)$	A step function which would be 0 if the power of supply is equal or greater demand and 1 is the demand not satisfied.
W	Subscript, denotes wind
Y_b	Efficiencies of biogas based IC engine
Yp	Efficiencies of PV panel
Y_w	Efficiencies of wind
β	Capacity ratio of power imported from grid to load
τ	initial cost per unit associated parameter of different energy sources.

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