IIOAB JOURNAL ISSN: 0976-3104

ARTICLE

OPTIMAL OPERATION OF MICROGRIDS INCLUDING PHOTOVOLTAIC/ WIND/ DIESEL

Shabnam Ruzbehi[1*], Alireza Fadaei Melat[1], Ehsan Amiri[2]

[1]*Department of Electrical Engineering, Hamedan Branch, Islamic Azad University, Hamedan, IRAN*
[2]*Department of Electrical Engineering, Islamabad Qarb Branch, Islamic Azad University, Kermanshah, IRAN*

ABSTRACT

Renewable energy sources (RES) technologies can provide energy solutions to some customers that are more cost-effective, more environmentally friendly, or provide higher power quality or reliability than conventional solutions. Presented in this paper, gives an optimal management strategy of PV/wind/diesel independent hybrid systems for supplying required energy in autonomous microgrids. Wind-Turbine Generators (WTG), Photovoltaic (PV) systems, battery banks and diesel generator are considered in this study. A new optimization problem is formulated for minimizing the capital investment and fuel costs of the system. The proposed model demonstrates that different renewable sources can be used simultaneously for practical applications. A novel algorithm, named GPSO-GM (Guaranteed convergence Particle Swarm Optimization with Gaussian Mutation), for the optimization problem in an autonomous microgrid is proposed. Two operators, mutation and guaranteed convergence, are added to PSO in order to help in finding an optimal solution and to assist in increasing the speed of the proposed algorithm as well as the accuracy of the results. The performance of the proposed strategy is evaluated in two case studies.

KEY WORDS
Microgrid; Renewable energy resources, Optimization; Wind generation, photovoltaic

Published: 14 October 2016

***Corresponding Author**
Email: shabnam.ruzbehi@yahoo.com

INTRODUCTION

A microgrid is seen as an interconnection of distributed generations (DGs) which is integrated with electrical and thermal loads as well as energy storages, and it operates as a single small scale system in low-voltage distribution systems. In microgrids, power quality, reliability and security can be increased by the use of power electronic interfaces and controls (Bala and Siddique, 2009). A microgrid might operate in grid-connected or islanded modes. In a grid-connected mode, the voltage and frequency of microgrids are dictated by the main grid while in an islanded mode control units of DGs along with managing active and reactive power are responsible for frequency and voltage regulation (Deshmukh and Deshmukh, 2008).

The application of renewable resources varies from the very small to large isolated, grid connected and hybrid stand-alone power systems (Eroglu et al, 2011). Additionally, the hybrid power systems show less expensive in terms of generation cost than those that use only one source as well as higher degree of reliability (Zhou et al, 2010). Accessibility and inexhaustibility of solar radiation and wind has made these renewable resources the most preferred energy sources (Saheb-Koussa et al, 2009). Multi-source hybrid power system improves energy availability considerably and it makes these systems profitable for practical applications especially for locations with not-reliable power access that need highly reliable power or those in remote areas which are far from the grids (Weisser, 2007). Reference (Bekele and Tadesse, 2010) shows that under such condition, hybrid PV-Diesel systems are competitive with diesel generation because of high costs of supply of diesel fuel.

Due to the popularity of the hybrid PV–Wind–Diesel systems with battery storage systems a large number of studies were conducted and reported in the literature (Kalantar and Mousavi, 2010). Many of studies carried out in this topic discuss the feasibility and techno-economic analysis of hybrid systems for practical applications. In (Yang et al, 2007) off-grid rural electrification in Dijon district, Ethiopia has been studied and the feasibility of application of small Hydro/PV/Wind hybrid network is shown. A cost of energy less than $0.16/kWh is calculated by the proposed results. Reference (Rehman et al, 2012) proposes the implementation of hybrid power systems for a village in Saudi Arabia and demonstrates that this system could be a feasible solution with cost of energy of 0.212 US$/kWh; the results show that the stand-alone system can prevent release of about 5000 tons/year of CO_2 gas in to the local atmosphere of the village.

In (Nfah et al, 2008) put forward hybrid solar wind power system optimization model, which mainly includes the hybrid system model, the probability of loss model, per kilowatt of power generation cost model. An analytical method for sizing and techno-economic optimization of an autonomous solar-wind hybrid energy system has been presented accounting the fraction of time for supplying the specified load and the cost of the system in (Gomaa et al, 1995).

In (Carpinelli et al, 2015) put forward hybrid solar wind power system optimization model, which mainly includes the hybrid system model, the probability of loss model, per kilowatt of power generation cost model. An analytical method for sizing and techno-economic optimization of an autonomous solar-wind hybrid energy system has been presented accounting the fraction of time for supplying the specified load and the cost of the system in (Mikati et al, 2013).

In (Ma et al, 2015) proposed the pumped hydro storage system as a promising technology for standalone photoelectric energy penetration for small autonomous system in remote using genetic algorithm, along with Pareto optimality concept to minimize system lifecycle cost and maximize power supply reliability simultaneously. In (Ekren and Ekren, 2010) projected simulated annealing algorithm based method to optimize the sizing of integrated solar-wind system with battery storage.

Authors in (Evans et al, 2009) have studied how the grid dependency is affected by integration of renewable subunits and revealing the integration of renewable distributed generation decrease grid usage and then avoids losses during large scale transformation and import of power through distribution substation. The studies of (Stoppato, 2008) proposed a more accurate method for reinforcement of solar and wind generation units into distribution network to bring the parameters close to the desired values considering wide ranges of technical and operational issues.

A novel method to solve proposed optimization problem is proposed to determine the optimum size of the sources in an autonomous microgrid. Minimizing the investment and operational costs while taking into account Life Cycle Assessment (LCA) is the objective of this study while ensuring the reliability requirements. The proposed scheme demonstrates that the hybrid systems are financially and practically reasonable as an islanded power system in remote areas where there is no access to grid.

The paper is organized as follows. Section II shows the mathematical modeling of the system design. Section III gives a proposed method to solve optimization problem. Simulation results are provided in Section IV. Finally, the conclusion remarks are discussed in Section V.

I. Mathematical Model

In the proposed autonomous microgrid four main subsystems including the solar energy system, wind turbines, the battery banks and a diesel generator are considered. Mathematical modeling of these subsystems is presented in the following.

a. PV Modules

The PV cell can directly convert the sunlight to electric power via the photoelectric phenomena. The solar radiation data can be extracted from historical data and for the following years through forecasting. For sake of simplicity and in order to have clear figures only one day of each month is selected for simulation studies. Total area available for PV panels can be limited and it will restrict the total number of PV cells that can be installed. Different types of PV panels with different characteristic and costs are considered for simulation. In a simplified model the power output of a PV panel can be determined based on (1).

$$P^{PV}(t) = I_r(t) \times S \times \eta^{PV} \times \eta_{inv} \tag{1}$$

One can improve by taking into account the impact of temperature on the power output of the PV panels. As the temperature increases, the efficiency of the panel decreases (Fthenakis and Kim, 2009) The effect temperature on the output power of a PV panel is modeled and expressed in (2).

$$P^{PV}(t) = P_{st}^{PV} \times f^{PV} \times \left(\frac{I_r(t)}{I_{r,st}}\right) \times \left(1 + \alpha^{PV}\left[T_C(t) - T_{C,st}(t)\right]\right) \tag{2}$$

The PV manufacturer provides the characteristic specifications of their product.

b. Wind power

The power output of wind generators can be determined based on the wind speed at the hub height and the output characteristic of the wind turbine generator. In this paper, the hourly power output of a wind generator is approximated by a piece-vice linear function as depicted and formulated in the following.

$$P_{w,j}(t) = \begin{cases} 0 & v_j < v_{ci,j} \\ P_{w,j}^{rated} \cdot \dfrac{v_j(t) - v_{ci,j}}{v_j^{rated} - v_{ci,j}} & v_{ci,j} \le v_j(t) < v_j^{rated} \\ P_{w,j}^{rated} & v_j^{rated} \le v_j(t) < v_{co,j} \\ 0 & v_{co,j} \le v_j(t) \end{cases} \tag{3}$$

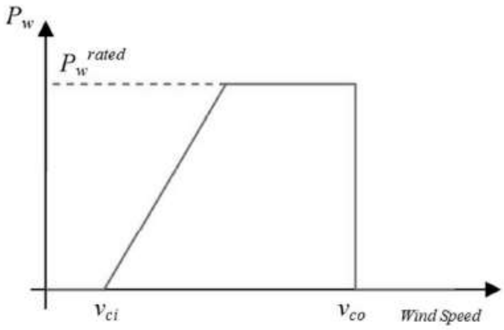

Fig. 1: Typical piece-vice approximation of wind turbine power output.

There is insufficient torque at very low wind speeds, to make the turbine blades rotate. As the speed increases, the wind turbine will begin to rotate and generate power. The speed at which the wind turbine first starts to generate electric power is called the cut-in speed (v_{ci}) and is usually between 3 and 4 m/s. With increase in the wind speed, the electric power generated by the wind turbine rises. Considering the above explanations, equation (3) gives the approximated piece-vice linear function which approximates the electrical output power of a wind turbine generator. This function is presented in [Fig. 1].

It should be noted that the efficiency of the regulator and converter should be taken into account. In section 4, the proposed framework including system operation strategies and system model will be discussed. In the area under study, the historical wind speed data are available at three different hub heights. The wind speed at the hub height can be calculated by using power-law equation (3) if the wind speed is available in a reference height (*hr*) only (Koutroulis et al, 2006).

$$v(t) = v_r(t).\left(\frac{h}{h_r}\right)^{\gamma} \quad (4)$$

c. Batteries

Battery banks are used as the energy storage units. The difference between power generated by renewable energy sources (PVs and wind turbines) and power demand of the area under study, determines whether the battery banks should be charged or discharged. At all times, during the charging process and discharging processes, the state of charge (SOC) constraint should be fulfilled. Equation (5) models this constraint and is based on the model presented in (Alsema and Wild-Scholten, 2005).

$$SOC_{\min,k} \le SOC_k(t) \le SOC_{\max,k} \quad (5)$$

The batteries are connected in series to provide the desired DC operating voltage, which is considered to be 440 volts. Therefore, the number of batteries in series ($N_{battery,s}$) can be found easily using (6).

$$N_{battery,s} = \frac{V_{DC}}{V_{battery}^{rated}} \quad (6)$$

The batteries are connected in parallel to provide the desired storage capacity. The number of batteries in parallel which retrieves the total capacity of the battery bank is one of the optimization variables. The efficiency of the regulator and convertor should be considered in battery banks' modeling and optimization. The rate of change of SOC of the battery banks limits the maximum charge and discharge rates. The same model as presented in (Alsema and Wild-Scholten, 2005) is borrowed here to models these constraints.

d. Diesel Generator

In grid-independent hybrid systems, there are times in which the sum of output power of renewable resources and the power stored at the battery banks does not meet the load demand. An independent power source as back up is required in such conditions. Fuel cell system or a diesel generator can be assigned for this task. In this study because of the medium size energy system a diesel generator is selected over fuel cell. The size and type of diesel generator is dependent on nature of the load that should be supplied. In the approach proposed in (Notton et al, 1996), in order to find the optimal size of the diesel generator, it is assumed that the diesel generator is directly connected to load and it should be able to satisfy the whole load so the rated capacity of the generator is considered equal to the maximum load.

In this study this approach is not considered and the size of diesel generator is taken into account as the optimization variable that should be optimally determined based on its installation and operational costs in comparison with the cost of reinforcing the renewable resources and battery banks.

PROPOSED OPTIMIZATION METHOD

To solve the paper optimization problem, an optimization algorithm is developed based on the PSO method. Although PSO is fast, compared with other evolutionary methods, it may converge to a local minimum value which might not be an optimal global solution and also increasing the number of iterations is not able to cope with this global convergence problem. As a consequence, in practice, it might be hard to validate the solution derived by PSO. In an attempt to address this validation problem, the study of (Sharafi and Tarek, 2014) adds a guaranteed convergence operator to PSO to make the convergence of solutions possible. This global improved algorithm called GPSO; however, it fails to deal with problems involving a small searching region because of PSO information sharing mechanism. In order to address this shortfall, this paper develops the GPSO algorithm by adopting a Gaussian mutation operator which assists in finding the optimal global solution. This new algorithm is named GPSO-GM and its scheme might be outlined as follows.

Step 1: *Initialization:* Set t = 0 and randomly make m swarms, $[y_i(0), i=1,...,m]$. For each swarm, set $y_i^*(0)=y_i(0)$ and $f^*=f_i$, $i = 1,...,m$. Look for the best value of f_{best} according to (22). Set the particle corresponding to the best value of objective function as the global best, $y_{Best}^{**}(0)$, with an objective function of f^{**}.

Step 2: *Time Updating:* Update $t = t+1$.

Step 3: *Velocity updating:* Update velocity by,

$$v_{i,k}(t) = w(t)v_{i,k}(t-1) + c_1 r_1 (y^*_{i,k}(t-1) - y_{i,k}(t-1)) + c_2 r_2 (y^{**}_{Best}(t-1) - y_{i,k}(t-1)).$$

(7)

Step 4: *Position Updating:* Update the position of each particle by the use of (30) and the value of the updated velocity.

$$y_{i,k}(t)=y_{i,k}(t-1)+v_{i,k}(t).$$

(8)

Step 5: *Gaussian Mutation:* Mutate a new position at each swarm by the use of mutation probability (P_n). Then, for each component of the particle position vector, k = 1,..., n, if Rand (0,1) < P_n, then mutate the component $y_{i,k(t)}$ by,

$$y_{i,k}(t)=y_{i,k}(t)+N(0,\sigma)y_{i,k}(t). \quad (9)$$

where the standard deviation, σ, might be defined as,

$$\sigma=0.1(y_{max,k} - y_{min,k}).$$

(10)

Step 6: *Local Updating*: If $f_{min} < f^*$ then update individual best as, (noting that each particle is appraised based on the updated position),

$$y_i(t)=y^*_i(t),\ f_i=f_i^*. \quad (11)$$

Step 7: *Global Improving:* Set ζ as the index of the global best particle, then update this particle by, (this is based on (Sharafi and Tarek, 2014)),

$$v_{\xi,k}(t)=-y_{\xi,k}(t-1)+y^{**}_{Best,k}(t-1)+wv_{\xi,k}(t-1)+\tau(t-1)(1-2r_2). \quad (12)$$

$$y_{\xi,k}(t)=y^{**}_{Best,k}(t-1)+wv_{\xi,k}(t)+\tau(t-1)(1-2r_2).$$

(13)

where $\tau(t)$ can be obtained by,

$$\tau(t) = \begin{cases} 2\tau(t-1) & if\ \#successes(t-1) > s_c \\ 0.5\tau(t-1) & if\ \#\ failures(t-1) > f_c \\ \tau(t-1) & otherwise \end{cases}.$$

(14)

In (14), the notation "# successes" and "# failures" represent the number of successes or failures, respectively. Here failure is meant $f(y^{**}_{Best}(t))= f(y^{**}_{Best}(t-1))$.

Step 8: *Global Updating:* If $f_{min} < f^{**}$ then update individual global best as $f^{**} = f_{min}$ and $y^{**}_{Best} = y_{min}(t)$.

Step 9: *Stop:* If the considered end criterion is met, then end the calculation otherwise, go to Step 2.

PROPOSED METHODOLOGY

In this section the objective function of the optimization problem is discussed. The installation, maintenance and operating costs of different parts of system are modeled appropriately in order to have a reasonable and precise model. The hybrid energy system configuration is taken from (Eroglu et al, 2011). The diesel generator is designed and utilized to play the role of backup in case renewable resources and battery banks are not able to provide electric power.

The optimization strategy of the proposed hybrid system is depicted in [Fig. 2]. The proposed conceptual flowchart summarizes the strategy that is used in this paper. In order to have a quick and brief vision, the efficiency of regulators and converters are not included in the equations shown in the flowchart, but they are considered in the simulations and optimal design determination.

In the following the proposed objective function and constraints of the optimization problem are discussed. In order to have an appropriate financial model the following factors are considered: proper planning horizon; interest rate; inflation rate; and life time of different parts of the system including PV units, wind turbines, batteries and diesel generator. Using historical data load pattern in the entire planning horizon, wind speed data, temperature and solar irradiance are forecasted. In order to have a clear vision of the planning costs at the present time it is necessary to calculate the net present value of different costs based on their occurrence year. The proposed objective function of this study includes four different parts regarding each power sources considered. The proposed objective function of the optimization problem is presented in (15). It should be noted that in order to avoid complexity the objective function presented in (15) does not include the interest rate.

$$Total\cos t = \sum_{t=1}^{T}\{\sum_{i=1}^{N_{Wind}}\left[Cost_{inv,i}^{Wind}+Cost_{ins,i}^{Wind}+Cost_{m,i}^{Wind}\right]+\sum_{i=1}^{N_{pv}}\left[Cost_{inv,i}^{pv}+Cost_{ins,i}^{pv}+Cost_{m,i}^{pv}\right]+$$
$$\sum_{i=1}^{N_{Battery}}\left[Cost_{inv,k}^{Battery}+Cost_{ins,k}^{Battery}+Cost_{m,k}^{Battery}\right]+Cost_{inv}^{Diesel}+Cost_{ins,k}^{Diesel}+\sum_{i=1}^{T}\left[Cost_{operation}^{Diesel}\left(P^{Diesel}(t)\right)\right]$$

(15)

Considering the interest rate in calculation of objective function is necessary; equation (16) can be used in this regard. Considering the occurrence of *Cost* in year *y*, the present value is calculated using this equation and is shown by *IPV*. The objective function is adjusted using (16) to include the effects of the interest rate.

$$IPV = \frac{Cost}{(1+IR)}$$

(16)

GPSO-GM begins with creating population. Population represents several numbers of swarms (solutions). Each solution includes the number of batteries, number of PV panels and number of wind turbines. In the simulation study for each month one day is considered. Therefore there are 12 days, each representing one month, in the optimization process, so for each year 284 hours is considered to model the load of the system. In the optimization procedure after initializing the optimization problem and parameters of the mutation, crossover is initiated. For each solution the time simulation is performed. At first based on wind speed and solar irradiance the power generation of PV and Wind turbine generators are calculated.

At each hour based on the load and power generation of PV and wind turbines, using (17) P_{Dif} is calculated. If (10) retrieve a positive value for P_{Dif} there is a part of load that cannot be supplied by the renewable resources. If the value of P_{Dif} is negative it shows that not only the renewable resources can supply the load but also there is extra power that can be stored in the battery banks.

$$P_{Dif} = P_L - (P_{pv} + P_{Wind})$$

(17)

IIOAB JOURNAL

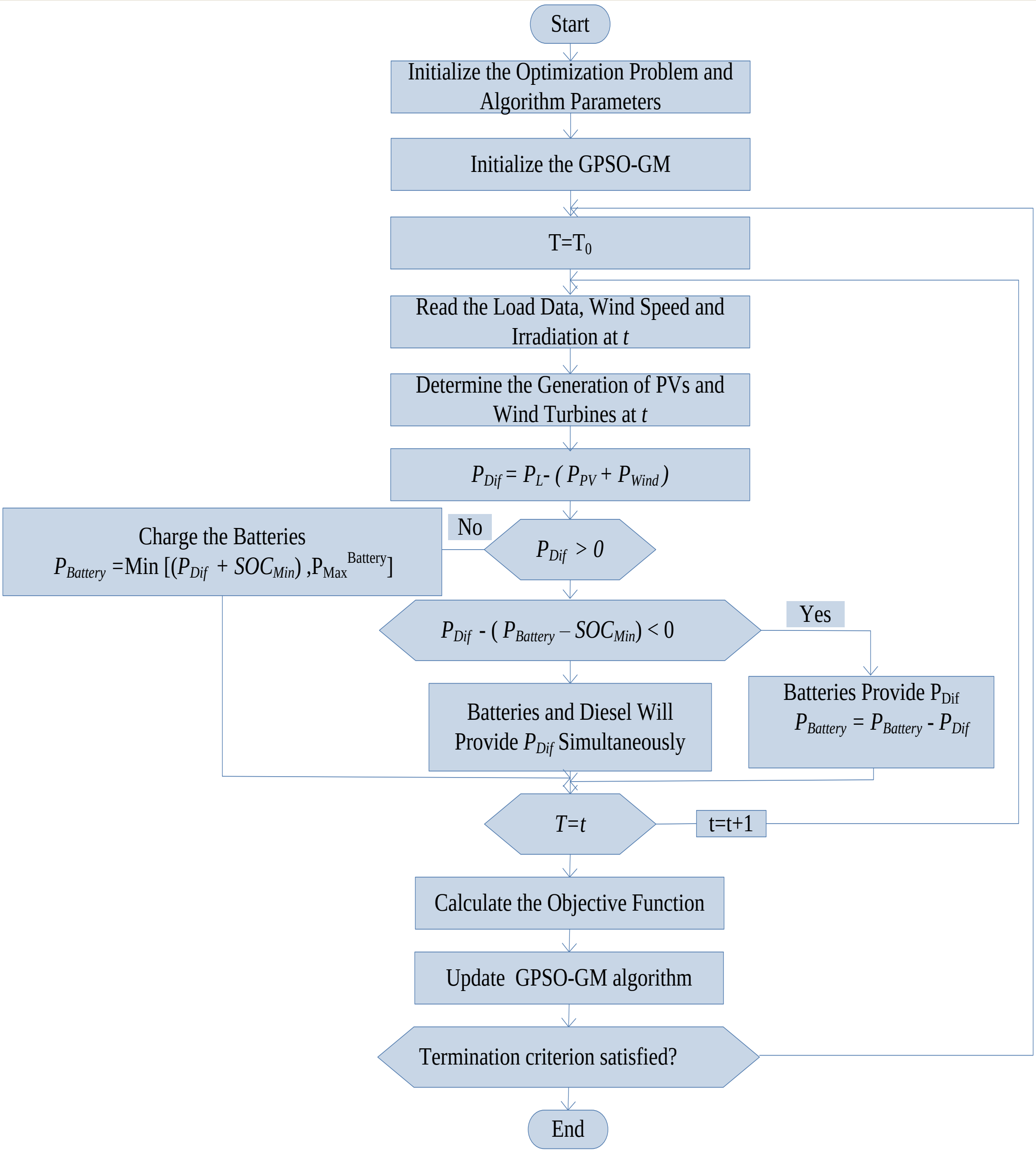

Fig. 2: The conceptual flowchart of the proposed operation strategy.

In case P_{Dif} is positive based on the operation strategy the model tries to supply the load using the power stored in the battery banks. Taking into account the SOC_{Min} constraint of the battery banks if they are able to satisfy the load the load will be supplied by battery banks and renewable resources but if the power achievable from battery banks is not sufficient diesel generator is used to provide the extra power required. This process is formulated in (18).

$$\begin{cases} P_{Dif} - (P_{Battery} - SOC_{Min}) < 0 & \textit{Battery provides the extra power required} \\ P_{Dif} - (P_{Battery} - SOC_{Min}) > 0 & \textit{Battery and DieselGen. provide the extra power required} \end{cases}$$
(18)

This simulation gives the hourly output power of the diesel generator. The maximum output of the diesel generator is selected as its capacity. Therefore, all the optimization variables are determined in the optimization procedure for each solution and therefore the objective function can be calculated. In the optimization process the constraints are handled in time simulation, including satisfaction of power demand; the wind turbine constraints; battery banks' SOC constraints; and PV panels maximum output constraints.

CASE STUDY

A 69-bus autonomous microgrid is used for simulation that shown in [Fig.3]. The locations of RES in 69-bus microgrid are at 42, 23 and 61 buses. The date of 69-bus system can find in (Venkatesh and Ranjan, 2003). The wind speed and solar irradiance data are used from (Skoplaki and Palyvos, 2009). As mentioned earlier, only one day of each month is considered for simulation and the hourly load pattern is determined for all years of the 20-year planning horizon based on the growth rate. The interest rate is considered to be 20% in this study. GPSO-GM parameters are shown in [Table 1].

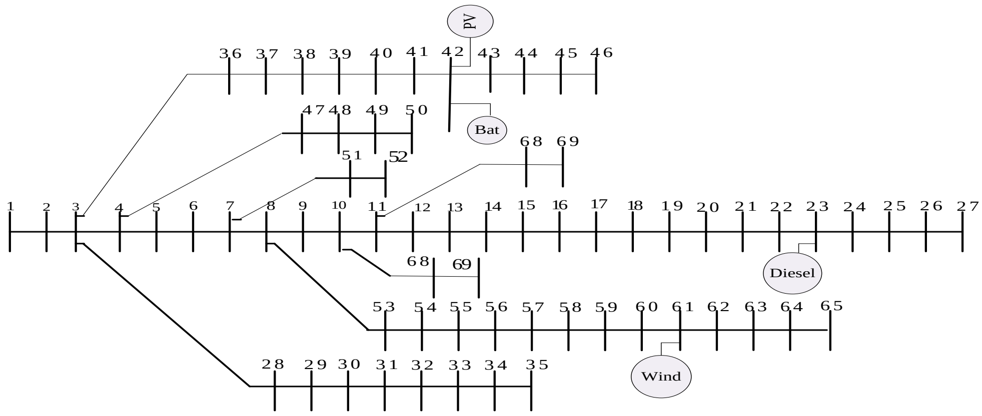

Fig. 3: 69-bus autonomous microgrid system.

TABLE 1 : GPSO-GM AND PSO PARAMETERS

Method	Pop. Size	$c_1=c_2$	$r_1=r_2$	w	$\rho(0)$			P_n
GPSO-GM	12	1	1	0.9	1.0	2	5	0.5

The load pattern of the present year is given in [Fig. 4]. Different types of wind turbine, PV panels and battery banks are available commercially. Characteristics of different types of these sources are taken from (Eroglu et al, 2011) and are demonstrated in[Table 2]. The investment and installation cost of wind turbines is studied to be 1950 $/kW of its rated power (Daly and Morrison, 2001). The maintenance cost of wind turbines is considered to be 0.06 $/kWh of output power. The total cost of 4700 $/kW is studied for investment and installation costs of PV panels. The maintenance cost of PV panels is 23 $/kW of the rated power of PV panels. PV area is restricted to 100m^2 in the simulations. The characteristic and cost of batteries are taken from (Eroglu et al, 2011), (Phaesun, 2009). The lifetime of batteries is considered to be 4 years(Phaesun, 2009). The total investment and installation costs of diesel generator is considered as 900 $/kW. The operation and maintenance costs of diesel generator are assumed to be 0.05 $/kWh and 0.02 $/kWh, respectively based on (Daly and Morrison, 2001).

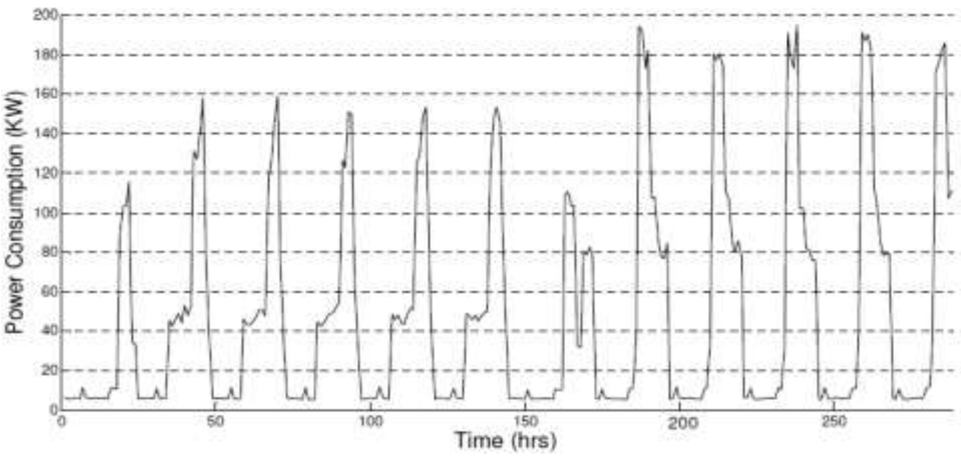

Fig. 4: Load pattern of the 69-bus (each 24 hours representing one month).

Table 2. Characteristics of different types of sources a. Wind Turbine Generator

Type	1	2	3	4
V_{ci} (m/s)	3.5	3	2.5	3
V^{rated} (m/s)	13	12	10	7.4
V_{co} (m/s)	35	28	24	26
P_w^{rated} (kw)	2.4	5	10	25
Tower height (m)	10.6	14	18	27
Rotor diameter(m)	3.72	5.5	9.7	10.8

b. PV panels

Type	1	2	3	4
V^{max} (V)	17.6	17.8	18	18.3
P_w^{rated} (kw)	0.125	0.130	0.135	0.140
Efficiency(%)	16	16	16	16
Efficiency of inverter (%)	95	95	95	95

c. Battery Banks

Type	1	2	3	4
V^{max} (V)	6	6	12	12
Capacity (Ah)	120	150	140	180
Efficiency(%)	85	85	85	85
Cost ($/kw)	348	415	521	567

The characteristic of the best solution obtained by the proposed technique is presented in[Table 3]. The power generation of the wind turbines, that includes 10 turbines from type 3 and 10 from type 4, is shown in [Fig. 5]. As mentioned earlier the wind turbine generation depends on the wind speed at different hours of the planning horizon as well as their nominal power. The power generation of the PV panels, that includes 43 panels from type 2, is depicted in [Fig. 6]. As it can be seen from [Fig. 5] and comparing it to [Fig. 4] there are times in which the output power of wind turbines is more than the load at that time. The extra power is stored in battery banks during such times. The power stored in battery banks is shown in[Fig. 7]. It should be noted that considering the $SOC_{Min}=50\%$ constraint of the battery banks only half of the power stored in battery banks is available. The initial value of *SOC* of the batteries is studied to be SOC_{Min}. Fig. 8 presents the power generation of the diesel generator. The diesel generator contributes mostly in power generation only in fall and winter as shown in [Fig. 8] due to low solar irradiance and decrease in wind speed. [Table 4] shows a compression of supplying microgrid power via hybrid of RES, diesel and grid. The result show where the use of RES for supplying microgrid power cause to generation costs has been reduced.

Table 3: Characteristics of the best solution obtained by the GPSO-GM

Source	Size(kw)	Inv. & Ins. Cost($)	Gen. Cost ($/Year)	Maintenance Cost ($/Year)
PV	5.59	26273	0	128.57
Wind	350	682500	0	81879.096
Battery	616.80	170836.1454	0	0
Diesel	195.2508	175725.7054	1638.7855	655.5142

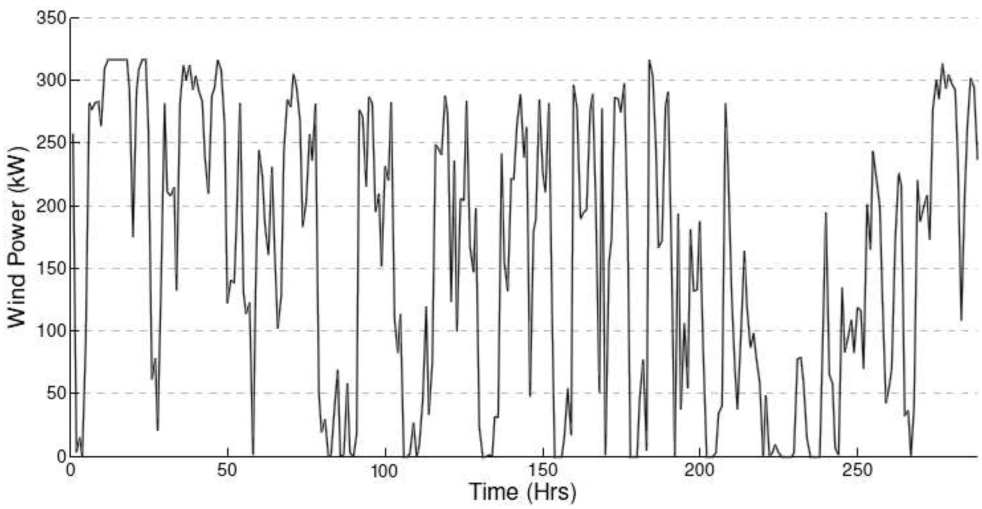

Fig . 5: Wind turbines power generation.

....

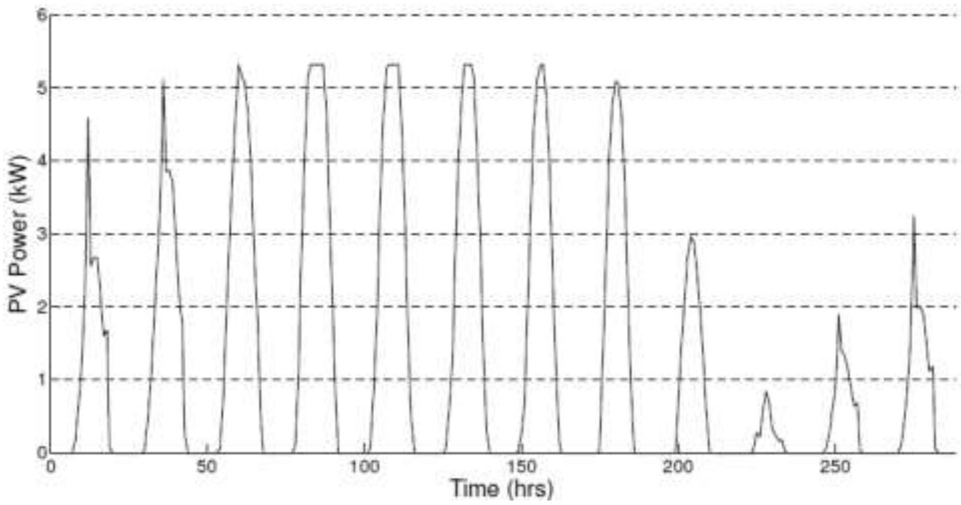

Fig. 6: Power output of the PV panels.

……………………………………………………………………………………………….

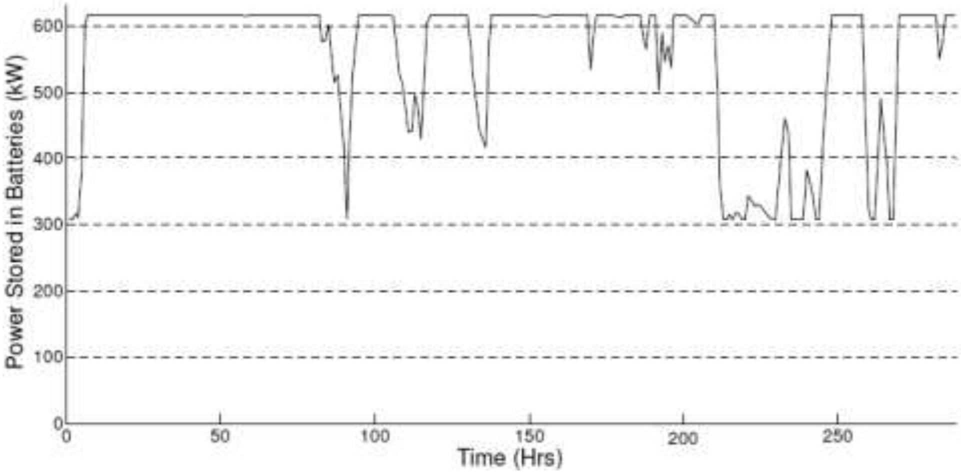

Fig. 7: Power stored in batteries.

……………………………………………………………………………………………….

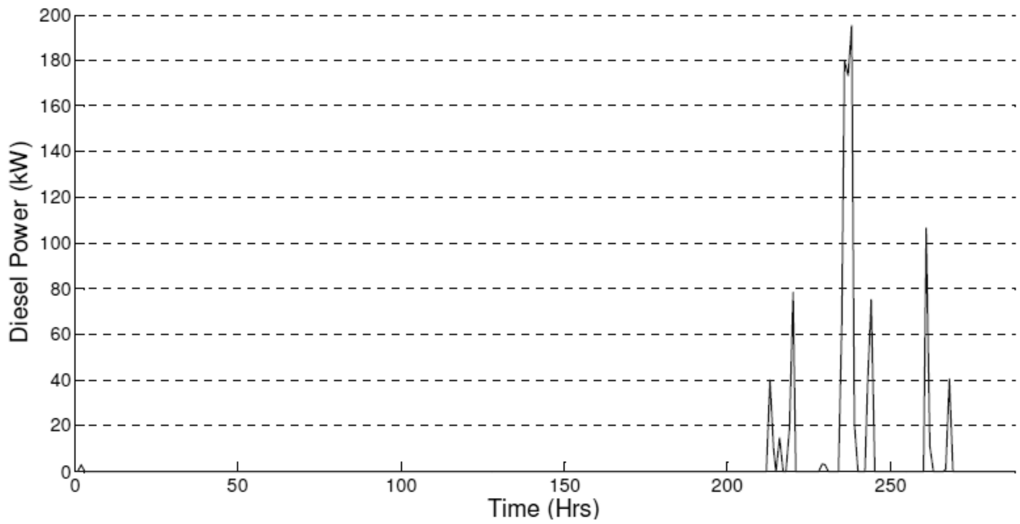

Fig. 8: Power output of the diesel generator.

……………………………………………………………………………………………….

Table 4: Characteristics of the best solution obtained by the GPSO-GM

Source	Inv. & Ins. Cost($/Year)	Gen. Cost ($/Year)	Maintenance Cost ($/Year)	Cost of Power($/kwh)
PV/ Wind / Battery/ Diesel	247629.7299	1638.7855	82663.1811	0.792055175
Diesel	36086.4212	20953.8241	8381.529640	0.156109392
Grid	1000109.897	29335.3537	4190.7648	2.466461517

CONCLUSION

In this paper, the possibility of covering the total energy needs of an autonomous microgrid exclusively with hybrid energy system including PV, wind, battery banks and diesel generator is investigated. This paper focused on the proper and precise modeling of each power source from operational and financial perspectives. An operating strategy is proposed which aims at maximization of the share of renewable sources in energy provision. According to the results of the simulations, the proposed system is able to completely satisfy the electricity demands of the microgrid. The results also demonstrate the effectiveness of proposed formulation and optimization method in finding the optimum design. The economic evaluation undertaken demonstrates that the investment is quite attractive in comparison to the other options. The socio-economic benefits of such hybrid energy production strategy can be the subject of the future works since they contribute to regional sustainable development by creation of job opportunities and by reduction of harmful emissions related with the fossil fuels' combustion. They also show that both battery banks and diesel generator together lead to a more optimum design with respect to the designs in which only diesel generator or battery banks are used to support the renewable resources. This model demonstrates that different renewable sources can be used simultaneously to power off-grid practical applications. Also, to solve the developed optimization problem a new method, GPSO-GM, was proposed.

CONFLICT OF INTEREST
There is no conflict of interest.

ACKNOWLEDGEMENTS
None

FINANCIAL DISCLOSURE
None

REFRENCES

[1] Alsema E, Wild-Scholten M de. [2005] Environmental impact of crystalline silicon photovoltaic module production. In: Material research society fall meeting, symposium G: life cycle analysis tools for ''green'' materials and process selection, Boston, MA.

[2] Azimi, Ruzbehi S, Alimoradi R..[2015] A novel Method for Designing A controller in Islanded Microgrid. International Conference Research in Science and Technology, Kualalumpur, Malaysia, CRSTCONF01_067.

[3] Bala BK, Siddique SA. [2009] Optimal design of a PV/Diesel hybrid system for electrification of an isolated island Sandwip in Bangladesh using genetic algorithm. Energy for Sustainable Development;13:137-142.

[4] Bekele G, Tadesse G. [2010] Feasibility study for a standalone solar–wind-based hybrid energy system for application in Ethiopia. Appl. Energy;87[2]:487–495.

[5] Venkatesh B.,. Ranjan R, [2009]. "data structure for radial distribution power flow analysis' *IEE* , 150:101-106.

[6] Daly PA, Morrison J. [2009]. Understanding the potential benefits of distributed generation on power delivery systems. Rural Electric Power Conference, 2001; 201–213.

[7] Deshmukh MK, Deshmukh SS, [2008] Modeling of hybrid renewable energy systems. Renewable and Sustainable Energy Reviews, 12, 235-249.

[8] Eroglu M, Dursun E, Sevencan S, Song J, Yazici S, Kilic O. [2011] A mobile renewable house using PV/wind/fuel cell hybrid power system. int. journal of hydrogen energy; 36(13):7985-7992.

[9] Fthenakis VM, Kim HC. [2010] Photovoltaics. life-cycle analyses. Sol. Energy. doi:10.1016/j.solener.2009.10.00.

[10] Carpinelli G,. Caramia P, Varilone P., [2015], "Multi-linear Monte Carlo simulation method for probabilistic load flow of distribution systems with wind and photovoltaic generation systems" *Renewable Energy,* vol. 64, no.5, pp. 1221-1228.

[11] . Yang, HX, Lu L., Zhou W.[2007] A novel optimization sizing model for hybrid solar-wind power generation system, Solar Energy, 81:76-84.

[12] Kalantar M, Mousavi G SM. [2010]. Dynamic behavior of a stand-alone hybrid power generation system of wind turbine, microturbine, solar array and battery storage. Appl. Energy;87(10):3051–3064.

[13] Koutroulis E, Kolokotsa D, Potirakis A, Kalaitzakis K. [2006] Methodology for optimal sizing of stand-alone photovoltaic/wind-generator systems using genetic algorithms. Solar Energy; 80(9): 1072-1088.

[14] Mikati M, Santos M, Armenta C., [2015]. Electric grid

dependence on the configuration of a small-scale wind and solar power hybrid system, Renewable Energy, 57: 587–593.
[15] M. Sharafi, Tarek Y.ELMekkawy, [2014], Muti-objective optimal design of hybrid renewable energy systems using PSO-simulation based approach, Renewable Energy,68,pp.67-79.
[16] Nfah EM, Ngundam JM, Vandenbergh M, Schmid J. [2008] Simulation of off-grid generation options for remote villages in Cameroon. Renewable Energy 2008;33(5)]:1064–1072.
[17] Notton G, Muselli M, Louche A. [1996]. Autonomous hybrid photovoltaic power plant using a back-up generator: a case study in a Mediterranean Island. Renewable Energy;7(4):371-391.
[18] O. Ekren, B.Y. Ekren, [2010], Size optimization of a PV/wind hybrid energy conversion system with battery storage using simulated annealing, Applied Energy, 87, pp. 592–598.
[19] Phaesun stand-alone solar solution. [2009]. Product catalogue: photovoltaic and wind generators.
[20] Rehman S, Alam M, Meyer J P, Al-Hadhrami L M, [2012]. Feasibility study of a wind-pv-diesel hybrid power system for a village. *Renewable Energy* 38:258-268.
[21] Saheb-Koussa D, Haddadi M, Belhamel M. [2009]. Economic and technical study of a hybrid system [wind–photovoltaic–diesel] for rural electrification in Algeria. Appl. Energy 2009;86:1024–1030.
[22] Gomaa S., Seoud AKA, Kheiralla HN, [1995] Design and analysis of photovoltaic and wind energy hybrid systems in Alexandria, Egypt Renewable Energy, 6,pp.643-647.
[23] Skoplaki E, Palyvos JA. [2009]. Operating temperature of photovoltaic modules: a survey of pertinent correlations. Renewable Energy;34:23-29.
[24] Stoppato A. [2008]. Life cycle assessment of photovoltaic electricity generation. Energy 2008;33:224–32.
[25] Ma T, Yang, HX L. Lu, Peng, JQ [2015]. Pumped storage-based standalone photovoltaic power generation system: Modeling and techno-economic optimization, Applied Energy, 137pp.649-659.
[26] Weisser D. [2007] A guide to life-cycle greenhouse gas [GHG] emissions from electric supply technologies. Energy 2007;32[9]:1543–59.
[27] Zhou W, Lou C, Li Z, Lu L, Yang H. [2010]. Current status of research on optimum sizing of stand-alone hybrid solar–wind power generation systems. Appl. Energy;87:380–389.