Journal of Smart Systems and Stable Energy, 1(2): 183-195 Spring 2022

ORIGINAL RESEARCH PAPER

Hybrid Modified Sparrow Search Algorithm and Sequential Quadratic Programming for Solving the Cost Minimization of a Hybrid PV/DG/BESS

***Huahui Li*[1], *Haoran Fu* [1,2*]**

[1] *School of Management, Universiti Sains Malaysia, Minden, Penang 11800, Malaysia*
[2] *School of Economics, Anyang Normal University, Anyang, 455000, China*

Received: 2021-12-25 Accepted: 2021-03-02 Published: 2022-04-01

ABSTRACT

A hybrid PV/battery/DG energy production system is configured and optimized in this study for powering a network of a remote rural of china. The target of system design is to minimize the system's fuel costs subject to the load demanded (LD) and several limitations. Thus, the concept comprises a problem of optimization which has been solved by a new optimization method using the Sequential Quadratic Programming (SQP) and a modified version of Sparrow Search Optimizer (MSSO). The achievements of the suggested technique are evaluated in various seasons and also in weekends and weekdays to indicate their impact on the operating cost of the PV/Diesel BESS system. The achievements show that in summer and winter, the costs of weekday are lower toward costs of weekend fuel. Moreover, the fuel cost of summer is lower than the fuel costs of winter that is due to lower demand in summer and also the more summer radiation levels mean less usage of auxiliary sources.

Keywords: *PV; DG; BESS; Sequential Quadratic Programming; Modified Sparrow Search Algorithm*

How to cite this article
Li H., Fu H. Hybrid Modified Sparrow Search Algorithm and Sequential Quadratic Programming for Solving the Cost Minimization of a Hybrid PV/DG/BESS. Journal of Smart Systems and Stable Energy, 2022; 1(2): 183-195.
DOI: 10.52293/SE.1.1.183195

1. INTRODUCTION

The national network's (NN) lack of access, low reliability of connecting to the NN, and transmitting lines' uneconomical construction are several reasons that leads to the system operation in an island state and separate from the main network [1, 2]. Currently, the major power source for island networks are Diesel Generators (DGs). High consistency, simplicity of installation and low cost are several superiorities of applying DGs [3-5].

Although, fuel's high cost of transmission and supply, requirement for extensive repairs and requirement for installation of fuel storage tanks lead to problems in using these diesel generators in island networks. To this end, new and available energy sources such as Photovoltaic (PV) energy is utilized for reducing of the generator fuel consumption [6, 7]. The requirement for considerably low repairs, simplicity of installation, quiet operation, and the availability of abundant free solar energy, are among the advantages of using a photovoltaic system [8-10]. Although, due to the uncontrolled and random energy generation of PV system and also heavy load alterations in island networks from highest to lowest amount, the application of photovoltaic system besides diesel generators is problematic [11, 12].

Therefore, significantly higher capacities for the PV system and the generator and the generator operation at the operational point away from the nominal point is needed [13, 14]. Then, to enhance

* Corresponding Author Email: *haoranfu@aynu.edu.cn*

performance of the system and decrease capacity of resource, the battery energy storage system (BESS) has been applied besides the PV system and generator [15]. BESS is employed to decrease consumption of the fuel [16, 17]. The battery gets system's energy while the generator is working, leading it operating at rated power with the highest effectiveness [18-20]. Also, after fully charging of the battery, the generator moves out of circuit and the load power is provided by the PV system and the load's stored energy [21].

The generator operation of the nominal load with the maximum effectiveness and off-state, gives the generator's minimum operation hours and, thus, the generator's minimum fuel use [22]. In low-usage indexes, the power load at daylight hours, while the radiation energy of the sun is at its maximum level, balancing power of generation and usage is difficult [23, 24]. Under these conditions, it is necessary for the energy storage system to get and store the extra power generated in the PV system [25, 26]. Nevertheless, the energy storage volume of the battery is restricted, and once fully charged, it cannot get the excess power of the PV system. In such a case, to make a power trade-off, it is needed to waste the generative power of the PV system in excess loads that causes to non-optimum system operation and, thus, reduced effectiveness [27-29].

Several works have been done in this subject. For instance, Fodhil et al. [30] proposed a procedure to optimize and sensitivity evaluation of a hybrid PV/DG/BESS power system (HRES). To minimize the CO2 emissions, the unmet load, and total system cost, PSO algorithm was utilized and ε-constraint method was performed to ease the multiple-criteria problem. The method has been applied to a remote village placed in Saharan, Algeria to supply the energy demand for 20 households. Simulation results were compared with HOMER to indicate its effectiveness.

Rezk et al. [31] provided a techno-economic energy management of an autonomous HRES based on photovoltaic, diesel generator, and battery. The suggested system was used for supplying a remote area in Minya city, Egypt. For better analysis, various sizes of reverse osmosis units, sizes of DGs, and energy control dispatch strategies were considered. HOMER environment was employed for accomplishing of the simulation and optimization. They also performed a comparison analysis between grid extension and installing stand-alone DG and the final results long-established that the grid connection has better achievements toward the other suggestions.

Ndwali et al. [32] proposed an optimized control strategy for a microgrid-connected PV-DG backup by considering of the tariff in Kenya. The main purpose is to reduce the cost of fuel consumption of the conventional DG and the purchased energy from the grid. FMINCON interior-point algorithm was employed for minimizing the problem. For better validation, two different scenarios have been studied. Final results showed a good efficiency for the proposed method.

Sanusi et al. [33] suggested a techno-economic assessment of a HRES for telecommunication substation in Nigeria. The study used Homer Pro software to perform the economic, environmental, and technical assessment. The results indicated that the connected DG/PV/Battery system was oversized compared with other configurations which shows its proper effectiveness for installation at the studied telecommunication substation. Also, sensitivity analysis results showed that the diesel price on the COE in the studied system indicates about 30% increasing in the COE increases by considering 100 % price increasing in diesel fuel.

Cai et al. [34] proposed a well-organized methodology for optimal sizing and location of an HRES. The study utilized a hybrid optimization algorithm to define the proper capacity to meet the load by a total-life cycle cost minimization. The method was performed to an actual-world studied case in South Khorasan to show the efficiency of the suggested agenda. The method efficiency was compared with some other well-known approaches. The achievements indicated that the proposed method has the best results.

In this paper, the assumption is not precise due to the changes of the behavior patterns of the user, a further feasible daily cost of operation has been assumed. The system includes an PV/DG/battery HRES to accomplish significant savings compared with a case that the DG provides only the load. This design helps companies of energy to have a good estimation of fuel costs on a daily, seasonal or annual basis and make it available to consumers. Also, to improve the efficiency of the optimization problem, a hybrid optimization strategy is used.

2. SYSTEM CONFIGURATION

In this study, a hybrid generation system including three sub-systems: photovoltaic, diesel generator, and battery is analyzed for supplying the electricity of the considered case study. The main idea is as follows: the battery can be charged if the PV electricity generation is further than the needed electricity for the load. If, the PV electricity generation has some shortage in supplying the electricity, the battery will be entered to the system to supply the considered electricity. In the event that both of PV and battery couldn't supply the required energy of the building, the DG as a backup system will be arrived to the system. Fig. (1) depicts the configuration of the investigated system.

2.1. The model of photovoltaic system.

Several parameters are impressive for achieving the output power of the photovoltaic system. For instance, PV generation efficiency and fill factor. The important part of PV system generation is the solar irradiance. Based on the explanations, the output power of a photovoltaic system is as follows [35]:

$$P_{pv} = \eta_{PVg} \times A_{PVg} \times G_t \tag{1}$$

where, A_{PVg} signifies the area of the PV array, G_t describes the solar irradiation incident (SII) hourly on the PV array (kW h/m2), and η_{PVg} represents the performance of the PV generator which is achieved by the following equation:

$$\eta_{PVg} = \eta^* \times \left(1 - 0.9 \times \beta \times \left(\frac{G_t}{G_t^{NT}}\right) \times \left(T_c^{NT} - T_a^{NT}\right) - \beta \times \left(T_a - T^*\right)\right) \tag{2}$$

where, the term NT describes the nominal cell operating temperature condition, T^* describes the reference cell temperature, η^* defines the PV generator's effectiveness that is defined at T^*, G_t^{NT} represents the mean hourly SII on the PV array at NT, β determines the temperature coefficient for cell efficiency, T_c^{NT} and T_a^{NT} represent the temperatures of the cell and the ambient at NT test conditions, respectively, and the mathematical model of the hourly SII on the PV array is obtained by the following [36]:

$$G_t = \left(G_B + G_D\right) \times R_B + G_D \tag{3}$$

In (3), R_B signifies a geometric factor which define the ratio of beam irradiance incident, and G_B and G_B represent the hourly global and diffuse irradiations, respectively. The calculation is applied to the mid-point of the day's every hour, on the *average day* for months. For all of the system of energy supply, the average energy demanded hourly subject to the load demanded profile for the specific utilization.

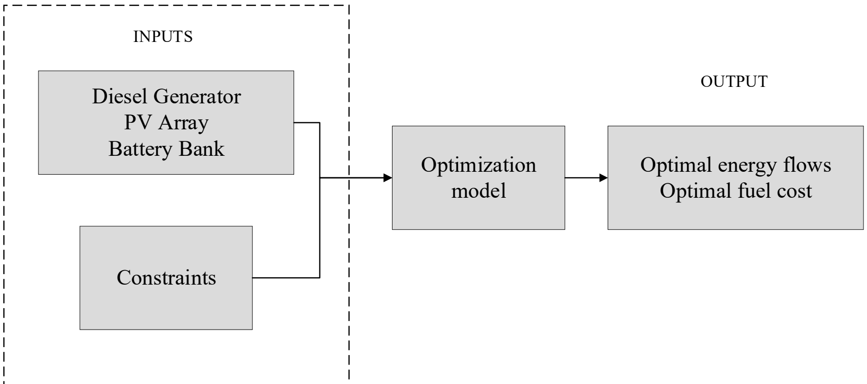


Fig. 1. The main arrangement of the studied hybrid system

Table 1. The utilized parameters in the PV model [35]

Parameter	Value	Unit
G_t^{NT}	0.8	kW h/m2
T^*	25	°C
β	0.004 – 0.005	°C
T_c^{NT}	45	°C
T_a^{NT}	20	°C

2.2. The model of battery storage system

In this study, lead-acid batteries are used to store electrical energy. High initial cost and low battery life lead to high costs to the system. The PV output power and the load demanded at hour t, define the discharge or charge electricity out of and into the power bank. t describes an integer defining in the t period. By considering $B_C(t)$ as the battery bank SOC in the period t, it depends to the SOC at the previous period $B_C(t-1)$.

Based on the above explanations, when the total power production of the generators (P_3) is more than the load demand (P_4), the batteries are in the charging mode and the battery SOC is obtained as follows:

$$B_C(t) = B_C(t-1) + \eta_B \times \left(P_3(t) - P_4(t)/\eta_{inv}\right) \quad (4)$$

where, η_B and η_{inv} define the performance of the battery charging and inverter, respectively.

In contrast, when the batteries are in the discharging mode, the power value of the batteries in the time t is obtained by the following formula:

$$B_C(t) = B_C(t-1) - \left(P_4(t)/\eta_{inv} - P_3(t)\right) \quad (5)$$

Therefore, the typical formulation of the battery dynamics for charging and discharging are respectively as follows:

$$B_C(t) = B_C(0) + \eta_B \times \left(\sum_{\tau=1}^{t} P_3(\tau) - \frac{1}{\eta_{inv}} \times \sum_{\tau=1}^{t} P_4(\tau)\right) \quad (6)$$

$$B_C(t) = B_C(0) - \frac{1}{\eta_{inv}} \times \sum_{\tau=1}^{t} P_4(\tau) + \sum_{\tau=1}^{t} P_3(\tau) \quad (7)$$

where, $B_C(0)$ describes the battery initial SOC. It should be noted that the minimum value of the battery capacity should not under the minimum allowable capacity, B_C^{min} and also should not exceeds the maximum capacity value of the battery value, B_C^{max}, i.e.

$$B_C^{min} \le B_C^t \le B_C^{max} \quad (8)$$

While the total stored power in the battery is evacuated during the discharging, the battery life will be decreased. The minimum allowed stored power is achieved by the following equation:

$$B_C^{min} = (1 - DOD) \times B_C^{max} \quad (9)$$

where, DOD describes the Depth of Discharge for the battery. In this study, DOD is set 0.8.

Also, the battery life is achieved based on its number of charging and discharging and depends to the Depth of Discharge:

$$Life\,cycle = \alpha_1 + \alpha_2 \times e^{-\alpha_3 \times DOD} + \alpha_4 \times e^{-\alpha_5 \times DOD} \quad (10)$$

where, $\alpha_1 = 1380.3$, $\alpha_2 = 6833.5$, $\alpha_3 = 8.75$, $\alpha_4 = 6746$, and $\alpha_5 = 6.216$.

2.3. The model of the DG

The diesel generator (DG) is an energy source which is usually considered as backup system. A diesel compression-ignition engine is typically intended to run on diesel fuel, but some sorts are employed for the natural gas or even other liquid fuels. The DG maximum performance depends on the DG rated power, so the DG must be applied between the specified minimum value and the rated power, as indicated by the following constraint:

$$P_1^{min} \le P_1(t) \le P_1^{max} \quad (11)$$

The strategy of this study is to use the DG while the battery and/or the PV couldn't supply the LD, which helps to improve the strategy more economical concerning use of DG energy. During this strategy, the DG generates sufficient electricity to supply the LD and not to use for charging the battery. The diesel generator usually works at high load factors to increase the DG life time and to reduce the specific fuel consumption. The present study uses a 5 kVA YUCHAI DG wherein a controller is employed for changing the output based on recognizing the load and transmitting command signal to the fuel injection system. This can help to supply the load demand at any given time.

3. PROBLEM STATEMENT

In the following, the main assumptions of the study are given:

- The BESS has been considered with the minimum and maximum accessible capacity sizes.

- The PV and the DG have been designed as controllable variable electricity resources between 0 to the highest accessible PV power in a 24-hour period for the PV and lowest and highest outputted electricity as specified previously for the DG.

- The operating cost is neglected for the PV and the battery.

- Fuel consumption is assumed as the outputted electricity's non-linear function of the DG.

During the process, the PV system supplies the load demand. If the generated electricity of the PV is more than the load demand, the surplus electricity is used for charging the battery storage system until full capacity is met by the batteries. Else if the PV can't provide enough electricity for the LD, the BESS discharges to provide enough electricity to the demand. Finally, if the integration of both BESS and PV don't meet the LD, as a backup system, the DG will be entered to the circuit. Generally, the Economic Dispatch (ED) problem is a nonlinear problem to find how much electricity should be generated by each unit for the load demand, while lessening the cost of fuel. The ED's objective function for the present study is as follows:

$$\min F = \min C_f \times \sum_{t=1}^{24} \left(\alpha \times P_1^2(t) + \beta \times P_1(t) \right) \quad (12)$$

Subject to:

$$P_2(t) + P_3(t) \le P_{PVg}(t) \quad (13)$$

$$P_1(t), P_2(t), P_3(t), P_4(t) \ge 0 \quad (14)$$

$$P_1(t) + P_2(t) + P_4(t) = P_L(t) \quad (15)$$

$$P_i(t) \in \left[p_i^{min}, p_i^{max} \right] \quad (16)$$

$$B_C^{min} \le B_C(0) + \eta_B \times \left(\sum_{\tau=1}^{t} P_3(\tau) - \frac{1}{\eta_{inv}} \times \sum_{\tau=1}^{t} P_4(\tau) \right) \le B_C^{max} \quad (17)$$

This is a non-linear optimization problem which should be solved by optimization algorithm.

where, C_f signifies the fuel price, $P_3(t)$ describes the battery energy current at the 24-hour interval, and $P_1(t)$, $P_2(t)$, and $P_4(t)$ represent the decision variables power flows respectively from the DG, PV and the BESS to the load at time t.

For the constraint Eq. (13), it implicates that the total power of the photovoltaic array is greater than or the same as the sum of the energy provided to the load from the photovoltaic array and the charging power. For the constraint Eq. (14), it implicates that the power charged and the power provided to the load from the photovoltaic array and the battery to the load are ≥ 0. For the constraint Eq. (15), it implicates that the load demand and the supplied power by the photovoltaic array, BESS, and the DG are equal at the same hour. Based on constraint Eq. (16), all of the energy sources are constrained by maximum and minimum values.

To achieve efficient results for the ED problem, a hybrid of adaptive design of the Sparrow Search Optimizer (SSO) and Sequential quadratic programming is utilized to give results with refining the shortcomings such as local optimum trapping and premature convergence.

4. ADAPTIVE SSO

4.1. The original SSO

The closest birds to humans and the human environment are Sparrows. They have small limbs and black beaks and cones; their two male and female species are different and can be easily distinguished from each other. Sparrows are commonly found in all wooded, moist and lush areas and are found in many species around the world. Their main enemy is hawks, vultures and other birds of prey, and in fact, they have taken refuge in human environments to protect themselves from these birds of prey. The native habitat of this bird is European countries, Mediterranean coasts and most Asian countries. Among all the birds in nature, sparrows are among the few birds that are accustomed to the human machine environment and are able to feed and nest in human environments. They usually start nesting during the mating season on top of trees, holes, etc. The sparrows have two main kinds of scrounger (S) and the producer (P). When, the Ps try to achieve the source of food, the Ss provide their food by requesting from the Ps. Moreover, an interactive plan is to switch between scrounging and producing sparrows; in other words, both producer and scrounger policies are used for obtaining their food. The attacker bird flocks try continuously to enhance their rate of predation to obtain more resources of food. Also, the amount of energy stored in each individual is a substantial fact to select the hunting strategies, i.e. the low energy sparrows scrounge more to the reserves. The sparrows that are located in the edge of the population, try to develop their location with moving to the

center of the flock to run from attacking the predators and to lessen their danger probability.

4.2. Mathematical modeling

The SSO begins with an individuals of sparrows randomly [37]. The individuals of this optimizer is the location of the shows the sparrows and is defined as follows:

$$X = \begin{bmatrix} x_{1,1} & \cdots & x_{1,d} \\ \vdots & \ddots & \vdots \\ x_{n,1} & \cdots & x_{n,d} \end{bmatrix} \tag{18}$$

here, n describes the sparrows' number, and d signifies the design parameters' dimension.

Due to high energy reserved in the producer sparrows, they deliver foraging regions with abundant resources of food to the scroungers. The value of the energy reserve can be obtained by the calculation of the cost amounts of individuals which is described by the following vector:

$$F_X = \begin{bmatrix} f([x_{1,1}, x_{1,2}, \ldots, x_{1,d}]) \\ f([x_{2,1}, x_{2,2}, \ldots, x_{2,d}]) \\ \vdots \\ f([x_{n,1}, x_{n,2}, \ldots, x_{n,d}]) \end{bmatrix} \tag{19}$$

The producers search for rich food resources and after finding them, they chirp signals of alarming to the rest. If the alarm value is more than the safety threshold (ST), the Ps must cause the Ss to a safe region.

Each sparrow will turn into a P in the event that achieve more proper sources of food, although, the Ss and the Ps' number should be fixed. The position of each producer is achieved by the following equation:

$$X_{i,j}^{t+1} = \begin{cases} X_{i,j}^{t} \times \exp\left(-\dfrac{i}{\delta \times iter_{max}}\right) & if\ V_A < T_s \\ X_{i,j}^{t} + Q \times L & if\ V_A \geq T_s \end{cases} \tag{20}$$

where, $iter_{max}$ defines the maximum iteration, t characterizes the current iteration, $X_{i,j}^{t}$ defines the position value of the i^{th} individuals in the j^{th} dimension at iteration t, $j = 1, 2, \ldots, d$. δ is a random number between $(0,1]$, L is a dD vector with elements inside 1, Q defines a normal distributed random number, The alarm value, V_A, includes a value between 0 and 1, and T_s defines the ST between 0.5 and 1. Here, if V_A has the value less than T_s, there is no hunter close to the wide search mode.

Dissimilarity, if V_A has greater value than (=) T_s, several sparrows have found the hunter, and all the members need a quick move to the rest secured areas. There is also a competition among the scroungers to achieve the food. After winning individuals, they can get the producer food. This is formulated in the following:

$$X_{i,j}^{t+1} = \begin{cases} Q \times \exp\left(\dfrac{X_{worst}^{t} - X_{p}^{t+1}}{i^2}\right) & if\ i > n/2 \\ X_{p}^{t+1} + \left|X_{i,j}^{t} - X_{p}^{t+1}\right| \times A^{\dagger} \times L & O.W. \end{cases} \tag{21}$$

where, X_P signifies the best position found by the producer, X_{worst}^{t} describes the global worst position at iteration t, A represents a d-dimantional vector with random elements equal to -1 or 1, and $A^{\dagger} = A^{T} \times (A \times A^{T})^{-1}$. In this position, the safe initial positions for the individuals are modeled by the following equation:

$$X_{i,j}^{t+1} = \begin{cases} X_{best}^{t} + \alpha \times \left|X_{i,j}^{t} - X_{best}^{t+1}\right| & if\ f_i > f_g \\ X_{ij}^{t} + K \times \left(\dfrac{\left|X_{i,j}^{t} - X_{worst}^{t+1}\right|}{(f_i - f_w) + \varepsilon}\right) & f_i = f_g \end{cases} \tag{22}$$

where, ε is a too small value just for avoiding from zero-division-error, α describes a random value in the range [0, 1], X_{best}^{t} defines the global optimal position at iteration t, K represents a random value in the range [-1, 1], and f_i, f_w and f_g refer to the present candidate's value of cost, worst fitness amount, and the current global best, respectively.

4.3. Modified Sparrow Search Optimizer (MSSO)

As mentioned in the previous subsection, the SSO is a recent bio-inspired optimizer which can be employed in various fields to solve problems of optimization. The sparrows' location in the search space have been distributed randomly. However, no nearby sparrow is existing about the present member, policy of random walk is done. This reduce the tendency of convergence and reduces the precision of the convergence under some iterations. Here, a modified learning factor is introduced to resolve the algorithm shortcoming. Let a qualified change rate for the individual's value of cost as follows:

$$v = \frac{\left| f\left(X_{i,j}^{t}\right) - f\left(X_{best}^{t}\right) \right|}{f\left(X_{best}^{t}\right) + \varepsilon} \tag{23}$$

where, ε is a very low amount to escape the 0-division-error, $X_{i,j}^{t}$ defines the i^{th} sparrow at iteration t, and $f\left(X_{i,j}^{t}\right)$ and $f\left(X_{best}^{t}\right)$ describe the value of cost of the i^{th} sparrow and the optimum value of cost of sparrow in iteration t, respectively. The learning factor of the i^{th} individual in iteration t is achieved as follows:

$$\gamma_i^t = \frac{1}{1 + e^{-\rho}} \tag{24}$$

where, $\rho \in (0, 2]$.

Thus, the new location of the P, the S, and the first locations of the individuals in the safe position are given below:

$$X_{i,j}^{t+1} = \begin{cases} \gamma_i^t \times X_{i,j}^t \times \exp\left(-\frac{i}{\delta \times iter_{max}}\right) & if\ V_A < T_s \\ \gamma_i^t \times X_{i,j}^t + Q \times L & if\ V_A \ge T_s \end{cases} \tag{25}$$

$$X_{i,j}^{t+1} = \begin{cases} Q \times \exp\left(\frac{X_{worst}^t - X_p^{t+1}}{i^2}\right) & if\ i > n/2 \\ X_p^{t+1} + \left|\gamma_i^t \times X_{i,j}^t - X_p^{t+1}\right| \times A^{\dagger} \times L & o.w. \end{cases} \tag{26}$$

$$X_{i,j}^{t+1} = \begin{cases} X_{best}^t + \alpha \times \left|\gamma_i^t \times X_{i,j}^t - X_{best}^{t+1}\right| & if\ f_i > f_g \\ \gamma_i^t \times X_{ij}^t + K \times \left(\frac{\left|\gamma_i^t \times X_{i,j}^t - X_{worst}^{t+1}\right|}{(f_i - f_w) + \varepsilon}\right) & f_i = f_g \end{cases} \tag{27}$$

The optimizer traps into the local optima. To avoid this problem, chaos theory can have been used. Chaos theory is the science of investigating about processes that are unpredictable and random, which simulates very sensitive dynamic systems [38, 39]. In this study, the sinusoidal chaotic map to improve the parameter K in the algorithm as follows:

$$\begin{aligned} & K = \alpha \times p_i^2 \sin\left(\pi p_i\right) \\ & p_0 \in [0,1], \alpha \in (0,4] \end{aligned} \tag{28}$$

4.4. Hybrid MSSO-SQP

The Sequential Quadratic Programming (SQP) is a classic optimization method which needs less objective and constraint function calls than the MSSO. Furthermore, due to its deterministic nature, it finds precise results for the optimization problem. With all these descriptions, due to using gradient information id SQP, it may be trapped into the local optimum in some cases. However, the MSSO provides a more globally results. The MSSO can be employed to accomplish the initial global search. Therefore, to use both advantages of precise local search of SQP and the global search ability of the MSSO together, we combined them for our study. For establishing this idea, the MSSO stopping criteria is set so as to the MSSO should be stopped prematurely, e.g. with a less population, a less generation or a more tolerance. By assuming that the MSSO finds the near global optimum, its results adopted as a first point for the SQP optimizer. Fig. (2) shows the flowchart diagram of the proposed hybrid *MSSO-SQP*.

As aforementioned and can be observed from Fig. (2), the *MSSO* first explores to the global optimal (GO) in the search space to achieve a quasi-optimum solution, and thus, the GO solution is entrusted to the SQP. The method is named GA+SQP

5. SIMULATION RESULTS

The idea behind this research is to minimize the system's costs of fuel subject to the LD and several limitations based on the proposed hybrid *MSSO-SQP* as detailed in preceding sections. In the following, the case study and the results of simulations are explained, respectively.

5.1. Case study

Here, the evaluation has been done on Fujiang Village which is a remote village in Tonggong Township, Changshan County, Quzhou, Zhejiang province, China. Its coordinates is 28.54178°N 118.29288°E. The information about radiation during the day, index of clearness, and the temperature for the PV designing are given in Fig. (3) and Fig. (4)

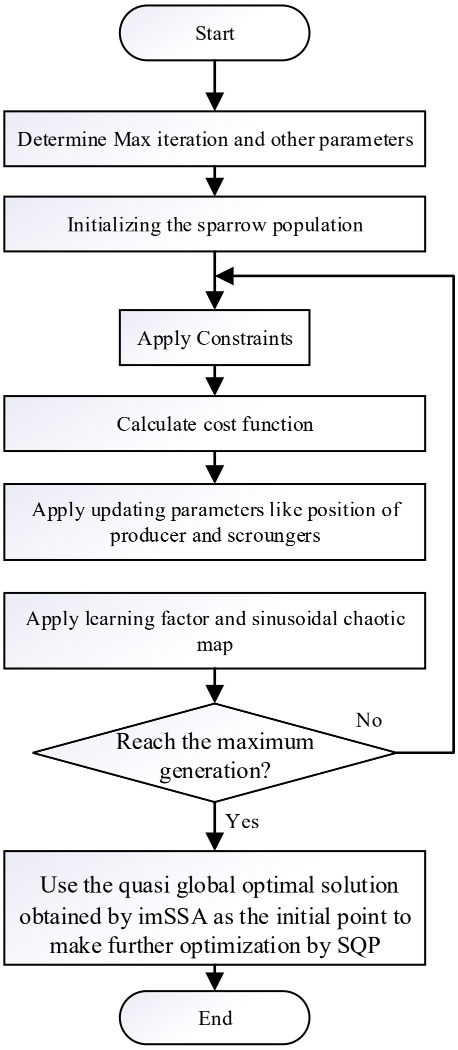


Fig. 2. The workflow of the proposed *MSSO-SQP*

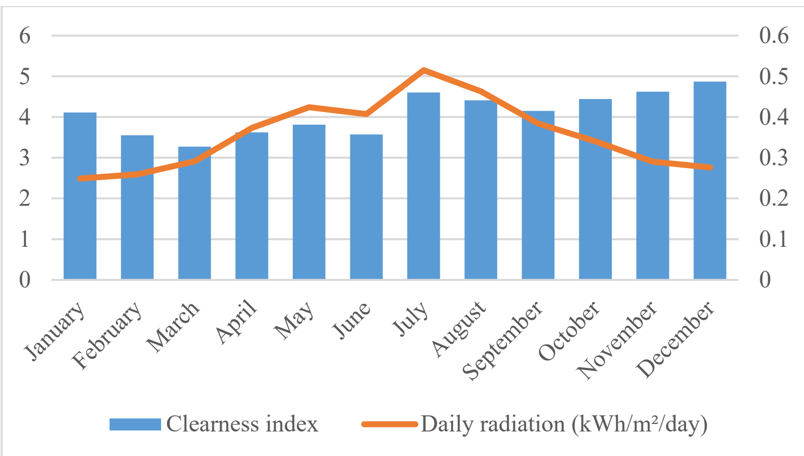


Fig. 3. The information about index of clearness and the radia tion during the day for the PV designing are given in

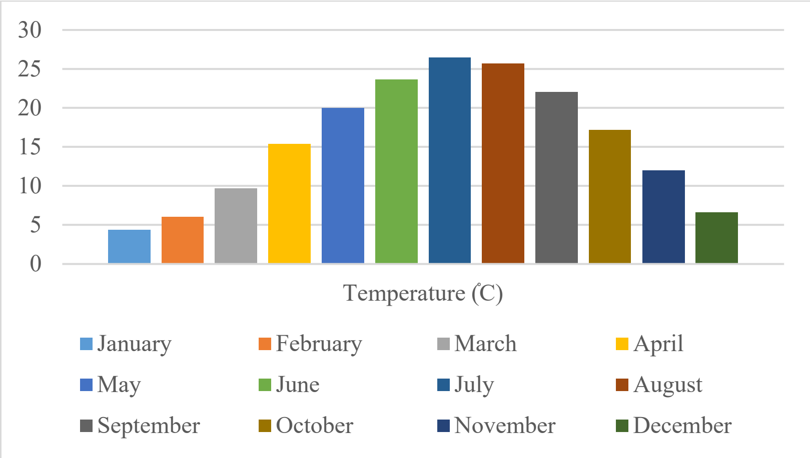


Fig. 4. The information about the temperature of the Fujiang

Table 2. The utilized parameters of this model

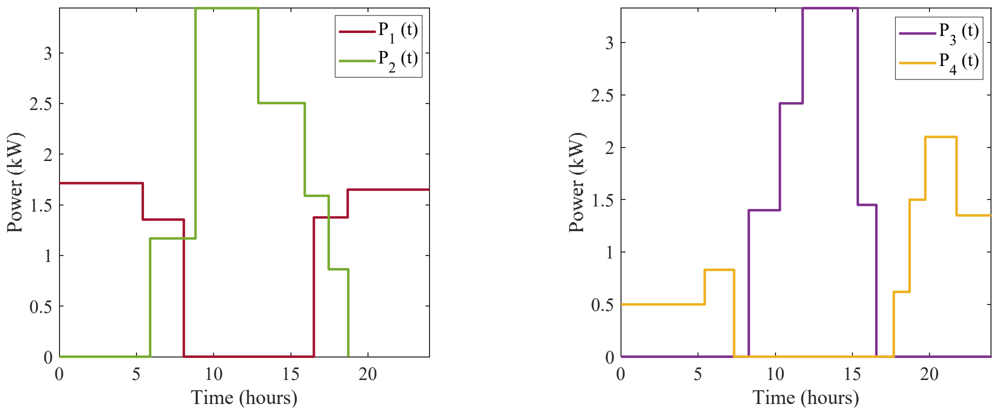
Parameter	Value
DG capacity	5kVA
A	US$ 0.246/h
B	US4 0.1/kW h
Cost of Fuel	US$1.2/l
PV array capacity	4kW
Nominal battery capacity	54.5 kW h
Efficiency of Battery charge	85%
Efficiency of Battery discharge	100%
Battery allowable discharge depth	50%

5.2. Parameters

While the cost coefficients of the generator are characterized by the PV, DG, the manufacturer, and the capacities of power bank have been selected by the model of sizing [40]. Hence, a small system may doesn't provide enough energy for the load demand and an oversized system will have some energy wasting, selection of an optimal value for the system will be increase the total efficiency. The main idea here is to optimum power management of the given design. The produced energy based on PV and DG systems is used to supply the load and the battery is charged by the PV generator based on the instant magnitude of the SOC and the load for the BESS. Also, as aforementioned, the DG will be switched on/off based on the ED of the DG, i.e. the load following policy. Table 2 tabulates the model's utilized parameters.

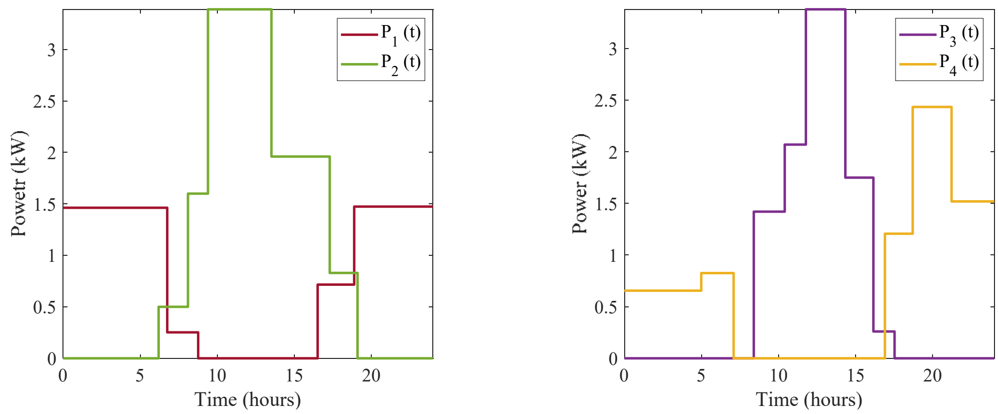
The 24-h energy power flow of the system are shown in Figs. (5)-(7). As can be observed from the figures, during the early morning and the night, battery is used to provide enough energy for the load and if the SOC has some limitations, the load can be satisfied using the DG or by an integration of these 2 resources. In Figs. (5)-(8), P3(t) and P4(t) indicate the discharge and charge the battery processes, respectively. The battery starts to charge during the daytime to supply the load demand typically in the night in the event that the PV supplies no power for the system.

Then after sunrise and towards sunset the DG, PV, and the BESS supply the load demand. Here, if the PV system or the combination of the BESS and the PV supply the LD, the DG will be switched off, otherwise, it will be switched on. The results also show that the generated electricity to the load based on PV ($P_2(t)$) doesn't satisfy the load before sunset and after sunrise. The running time for the DG and the generated power value by the DG subjects to the battery SOC and the PV generated power. Therefore, if the outputted power of the battery and (or) PV doesn't satisfy the



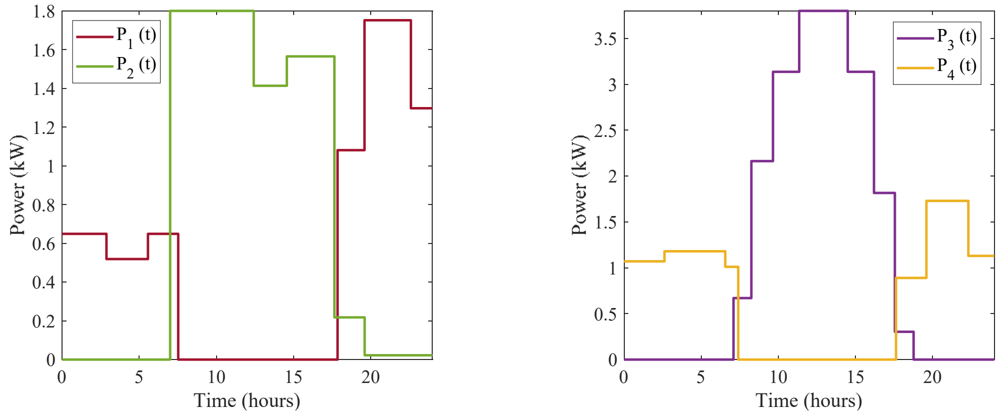
(A) (B)

Fig. 5. The power flow of June weekend



(A) (B)

Fig. 6. The power flow of June weekday



(A) (B)

Fig. 7. The power flow of September weekend

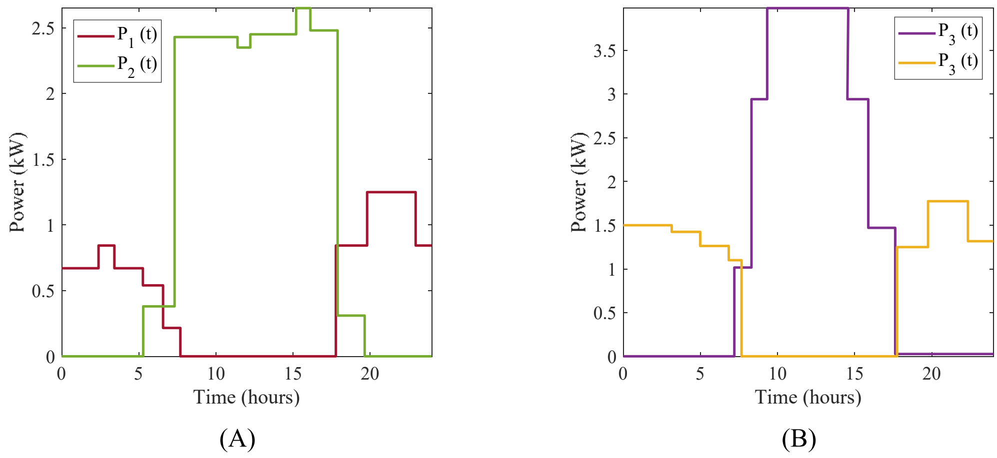


Fig. 8. The power flow of December weekly

Table 3. The typical load descriptions for summer and winter for the Fujiang village.

Time	Winter load (kW)		Summer load (kW)	
	Weekend	Weekday	Weekend	Weekday
00:30	1.6	1.6	1.6	1.6
01:30	1.6	1.6	1.6	1.6
02:30	1.6	1.6	1.88	1.88
03:30	1.6	1.6	1.97	1.97
04:30	1.6	1.6	1.88	1.88
05:30	1.97	1.68	1.52	1.52
06:30	1.97	1.68	1.67	1.18
07:30	1.68	1.68	1.67	1.27
08:30	1.37	1.37	1.72	1.31
09:30	3.28	1.37	1.77	1.33
10:30	3.28	3.2	1.77	1.36
11:30	2.17	3.2	1.77	1.33
12:30	2.17	1.97	1.28	1.28
13:30	2.17	1.97	1.34	1.34
14:30	2.17	1.97	1.38	1.38
15:30	2.17	1.97	1.38	1.38
16:30	2.17	1.97	1.47	1.47
17:30	2	1.68	2.3	2.17
18:30	2.33	3.28	2.6	2.33
19:30	3.83	3.28	4	3.27
20:30	2.33	2.33	4	3.27
21:30	2.33	2.17	2.2	2.2
22:30	2.33	2.17	1.97	1.97
23:30	1.37	1.37	1.68	1.68

load, the DG operates for further hours for further power generation. Fig. (5) and Fig. (6) depicts the power flows of weekend and the weekday in winter and Fig. (7) and Fig. (8) illustrate the weekday and weekend power flows in the summer. These show the effect of seasonal PV output variation and the load changes on the diesel dispatch policy.

Table 3 tabulates the Weekday and weekend load descriptions for summer and winter for the Fujiang village.

Table 4. The saving value for the cost of fuel

	Winter weekend	Winter weekday	Summer weekend	Summer weekday
Diesel only scenario	US$50.3	US$45.4	US$42.6	US$36.7
Hybrid model	US$12.1	US$10.2	US$7.3	US$5.7
Savings	US$37.1	US$34.1	US$34.2	US$30.1

As can be observed, in general, the weekday demand is lower than the weekend demand which is because of that within the week in the village, people are very busy with their events outdoor, but at the weekend, they are resting at home and use various appliances. It is also observed that the consumed fuel in the winter is more than the summer. Simulation results indicate that considering the seasonal demand variations during operation costs evaluations. The suggested arrangement confirms the maximum use of PV output to decrease the power wasting while the DG operates in the meantime the output meets the demanded. Table 4 tabulates the cost of the diesel fuel for the weekends and the weekdays in summer and winter compared with the diesel only scenario.

The value of the saved fuel is achieved by exploring the difference of the values of cost of fuel for the diesel just scenario where DG, and the PV/DG/BESS model satisfy the load demand for the scenarios. Therefore, it can be said that using the proposed arrangement provides better and more precise costs for the system.

6. CONCLUSIONS

In this study a new optimal energy dispatching model based on a hybrid system of Battery/PV/Diesel has been presented. The main idea in this study was to minimize the system's costs of fuel subject to the load demanded and several limitations. To solve this problem a new optimization methodology based on combination of the Sequential Quadratic Programming (SQP) and the Modified Sparrow Search Optimizer (MSSO) were employed. The suggested optimized model indicated a better saving performance than the diesel only scenario. The simulations indicated the effect of seasonal and daily changes in demand variations and their impact on the cost of operating of the Diesel/PV BESS system. simulation achievements showed that in both seasons, the costs of weekday were lower than fuel costs of weekend. Also, the results indicated that the costs of fuel in summer was lower than the costs of fuel in winter which was due to lower demand for summer and also the more summer radiation mean less usage of supplementary sources.

REFERENCES

1. Yuan, Z., et al., *Probabilistic decomposition-based security constrained transmission expansion planning incorporating distributed series reactor.* IET Generation, Transmission & Distribution, 2020. **14**(17): p. 3478-3487.
2. Ye, H., et al., *High step-up interleaved dc/dc converter with high efficiency.* Energy Sources, Part A: Recovery, Utilization, and Environmental Effects, 2020: p. 1-20.
3. TARAFDAR, H.M. and N. GHADIMI, *Radial basis neural network based islanding detection in distributed generation.* 2014.
4. Shamel, A. and N. Ghadimi, *Hybrid PSOTVAC/BFA technique for tuning of robust PID controller of fuel cell voltage.* 2016.
5. Razmjooy, N., F.R. Sheykhahmad, and N. Ghadimi, *A hybrid neural network–world cup optimization algorithm for melanoma detection.* Open Medicine, 2018. **13**(1): p. 9-16.
6. Nejad, H.C., et al., *Reliability based optimal allocation of distributed generations in transmission systems under demand response program.* Electric Power Systems Research, 2019. **176**: p. 105952.
7. Mirzapour, F., et al., *A new prediction model of battery and wind-solar output in hybrid power system.* Journal of Ambient Intelligence and Humanized Computing, 2019. **10**(1): p. 77-87.
8. Hosseini, H., et al., *A novel method using imperialist competitive algorithm (ICA) for controlling pitch angle in hybrid wind and PV array energy production system.* International Journal on Technical and Physical Problems of Engineering (IJTPE), 2012(11): p. 145-152.
9. Guo, Y., et al., *An optimal configuration for a battery and PEM fuel cell-based hybrid energy system using developed Krill herd optimization algorithm for locomotive application.* Energy Reports, 2020. **6**: p. 885-894.
10. Cao, Y., et al., *Multi-objective optimization of a PEMFC based CCHP system by meta-heuristics.* Energy Reports, 2019. **5**: p. 1551-1559.
11. Meng, Q., et al., *A single-phase transformer-less grid-tied inverter based on switched capacitor for PV application.* Journal of Control, Automation and Electrical Systems, 2020. **31**(1): p. 257-270.
12. Liu, Y., W. Wang, and N. Ghadimi, *Electricity load forecasting by an improved forecast engine for building*

level consumers. Energy, 2017. **139**: p. 18-30.
13. Thiagarajan, Y., et al., *DIGITAL GARBAGE BIN MONITORING SYSTEM (DGBMS): A SMART GARBAGE MONITORING AND MANAGEMENT CYBER-PHYSICAL SYSTEM.* database. **3**: p. 4.
14. Razmjooy, N., et al., *Comparison of lqr and pole placement design controllers for controlling the inverted pendulum.* Journal of World's Electrical Engineering and Technology, 2014. **2322**: p. 5114.
15. Tian, M.-W., et al., *New optimal design for a hybrid solar chimney, solid oxide electrolysis and fuel cell based on improved deer hunting optimization algorithm.* Journal of Cleaner Production, 2020. **249**: p. 119414.
16. Leng, H., et al., *A new wind power prediction method based on ridgelet transforms, hybrid feature selection and closed-loop forecasting.* Advanced Engineering Informatics, 2018. **36**: p. 20-30.
17. Hosseini Firouz, M. and N. Ghadimi, *Optimal preventive maintenance policy for electric power distribution systems based on the fuzzy AHP methods.* Complexity, 2016. **21**(6): p. 70-88.
18. Hagh, M.T., H. Ebrahimian, and N. Ghadimi, *Hybrid intelligent water drop bundled wavelet neural network to solve the islanding detection by inverter-based DG.* Frontiers in Energy, 2015. **9**(1): p. 75-90.
19. Gollou, A.R. and N. Ghadimi, *A new feature selection and hybrid forecast engine for day-ahead price forecasting of electricity markets.* Journal of Intelligent & Fuzzy Systems, 2017. **32**(6): p. 4031-4045.
20. Ghadimi, N., et al., *A new prediction model based on multi-block forecast engine in smart grid.* Journal of Ambient Intelligence and Humanized Computing, 2018. **9**(6): p. 1873-1888.
21. Xu, Z., Sheykhahmad, et al., *Computer-aided diagnosis of skin cancer based on soft computing techniques.* Open Medicine, 2020. **15**(1): p. 11.
22. Namadchian, A., M. Ramezani, and N. Razmjooy, *A new meta-heuristic algorithm for optimization based on variance reduction of guassian distribution.* Majlesi Journal of Electrical Engineering, 2016. **10**(4): p. 49.
23. Liu, Q., et al., *Computer-aided breast cancer diagnosis based on image segmentation and interval analysis.* Automatika, 2020. **61**(3): p. 496-506.
24. Khalilpour, R., et al. *Optimal control of DC motor using invasive weed optimization (IWO) algorithm*. in *Majlesi Conference on Electrical Engineering, Majlesi New Town, Isfahan, Iran*. 2011.
25. Gong, W. and N. razmjooy, *A new optimisation algorithm based on OCM and PCM solution through energy reserve.* International Journal of Ambient Energy, 2020: p. 1-14.
26. do Nascimento, D.A., et al., *Sustainable adoption of connected vehicles in the Brazilian landscape: policies, technical specifications and challenges.* Transactions on Environment and Electrical Engineering, 2019. **3**(1): p. 44-62.
27. Yu, D., et al., *System identification of PEM fuel cells using an improved Elman neural network and a new hybrid optimization algorithm.* Energy Reports, 2019. **5**: p. 1365-1374.
28. Yin, Z. and N. Razmjooy, *PEMFC identification using deep learning developed by improved deer hunting optimization algorithm.* International Journal of Power and Energy Systems, 2020. **40**(2).
29. Yanda, L., et al., *Optimal Arrangement of a Micro-CHP System in the Presence of Fuel Cell-Heat Pump based on Metaheuristics.* International Journal of Ambient Energy, 2020(just-accepted): p. 1-24.
30. Fodhil, F., A. Hamidat, and O. Nadjemi, *Potential, optimization and sensitivity analysis of photovoltaic-diesel-battery hybrid energy system for rural electrification in Algeria.* Energy, 2019. **169**: p. 613-624.
31. Rezk, H., et al., *Optimization and Energy Management of Hybrid Photovoltaic-Diesel-Battery System to Pump and Desalinate Water at Isolated Regions.* IEEE Access, 2020. **8**: p. 102512-102529.
32. Ndwali, P.K., J.G. Njiri, and E.M. Wanjiru, *Optimal Operation Control of Microgrid Connected Photovoltaic-Diesel Generator Backup System Under Time of Use Tariff.* Journal of Control, Automation and Electrical Systems, 2020: p. 1-14.
33. Sanusi, Y.S., H. Dandajeh, and H. Mustapha, *Techno-economic analysis of hybrid diesel generator/PV/battery power system for telecommunication application.* ATBU Journal of Science, Technology and Education, 2020. **8**(3): p. 77-91.
34. Cai, W., et al., *Optimal sizing and location based on economic parameters for an off-grid application of a hybrid system with photovoltaic, battery and diesel technology.* Energy, 2020: p. 117480.
35. Ali, E., S. Abd Elazim, and A. Abdelaziz, *Ant Lion Optimization Algorithm for optimal location and sizing of renewable distributed generations.* Renewable Energy, 2017. **101**: p. 1311-1324.
36. Collares-Pereira, M. and A. Rabl, *The average distribution of solar radiation-correlations between diffuse and hemispherical and between daily and hourly insolation values.* Solar energy, 1979. **22**(2): p. 155-164.
37. Xue, J. and B. Shen, *A novel swarm intelligence optimization approach: sparrow search algorithm.* Systems Science & Control Engineering, 2020. **8**(1): p. 22-34.
38. Zhang, G., et al., *Optimal Parameter Extraction of PEM Fuel Cells by Meta-heuristics.* International Journal of Ambient Energy, 2020(just-accepted): p. 1-22.
39. Yuan, Z., et al., *A new technique for optimal estimation of the circuit-based PEMFCs using developed Sunflower Optimization Algorithm.* Energy Reports, 2020. **6**: p. 662-671.
40. Hove, T. and H. Tazvinga, *A techno-economic model for optimising component sizing and energy dispatch strategy for PV-diesel-battery hybrid power systems.* Journal of Energy in Southern Africa, 2012. **23**(4): p. 18-28.