The International Journal of Engineering and Science (IJES)
|| Volume || 8 || Issue || 7 Series I || Pages || PP 06-14 || 2019 ||
ISSN (e): 2319 – 1813 ISSN (p): 23-19 – 1805

Optimal Sizing of PV/Diesel/Battery Hybrid Micro-Grid System Using Multi-Objective Bat Algorithm

D. Fadli[1], Purwoharjono[2], Hardiansyah[3*]
[1]*M. Tech. Student, Department of Electrical Engineering, University of Tanjungpura, Indonesia*
[2,3]*Department of Electrical Engineering, University of Tanjungpura, Indonesia*
[*]*Corresponding author: Hardiansyah*

ABSTRACT
This paper presents an optimal sizing of PV/diesel hybrid micro-grid system (HMGS) with battery energy storage using multi-objective bat algorithm (MOBA). The proposed method aims at finding the configuration, among a set of systems components, which meets the desired system reliability requirements, with the lowest value of levelised cost of energy. Modelling a hybrid PV/diesel/battery system is considered as the first step in the optimal sizing procedure. The second step consists to optimize the sizing of a system according to the loss of power supply probability (LPSP) and the levelised cost of energy (LCOE) concepts. Considering various types and capacities of system devices, the configurations which can meet the desired system reliability are obtained by changing the type and size of the devices systems. The configuration with the lowest LCOE gives the optimal choice. The simulation results show that the optimal configuration which meet the desired system reliability requirements with the lowest LCOE, on other hand, the device system choice play an important role in cost reduction as well as in energy production.

Keywords *- Multi-objective bat algorithm, hybrid micro-grid system, loss of power supply probability, levelised cost of energy.*

DATE OF SUBMISSION: 22-06-2019 DATE OF ACCEPTANCE: 08-07-2019

I. INTRODUCTION

Public interconnected power grids are composed of complex combinations of generation plants, substations, transformers and transmission lines, which supply electricity to cities, businesses and industry. In addition, there are smaller independent power grids that provide power to islands or remote areas, which have limited or no access to public interconnected grids. Traditionally, small stand-alone grids are electrified by diesel generators. However, the renewable energy resources are attractive sources of power, since they can provide sustainable and clean power. Hybrid plants can be an integration of diesel generators with renewable energy resources such as photovoltaic. Because of its intermittent and irregular nature, PV generation makes hybrid system management harder. Consequently, for some authors [1-2], PV production into the grid is considered to be limited [3]. One of the major challenges for PV systems remains in the matching of the intermittent energy production with the dynamic power demand. A solution is to add a storage element to these nonconventional and intermittent power sources [4, 5]. In this case, the hybrid system is composed of a PV generator, local loads, electricity storage, and the conventional source (diesel genset) [5]. In addition, integrating a battery energy storage system with the hybrid plant provides significant dynamic operation benefits such as higher stability and reliability of power supply.

Due to raising the price of petroleum product and advances in renewable energy technologies, hybrid renewable energy systems (HRES) are becoming popular in power systems for providing electricity in remote areas. A hybrid energy source consists of more than one renewable energy system which are applied with each other to excess power system efficiency as well as greater balance in energy supply [6-8]. The fundamental point of preference hybrid energy system is the improvement of unwavering quality of the hybrid power system and money saving advantage of the system. Hybrid energy system provides a high level of energy safety through the mix of generation techniques and easily combine a power storage system. Renewable energy sources such as solar and wind power are omnipresent and environment friendly. The renewable energy sources are emerging options to achieve the energy demand [9].

The collecting of combined solar, wind, diesel and battery power systems into the grid can help in reducing the overall cost and improving reliability of renewable power generation to supply its load and their system becomes more economical to run since the weakness of one system can be complemented by the strength of the other one. Combining the two sources or more is a best solution for rural electrification where the grid connection not fulfil electricity demand. Technology of hybrid energy system is economically applicable and an emerging energy option since it promises great deal of challenges and opportunities developed in developing countries [10, 11].

In this paper, an optimal sizing algorithm based on multi-objective bat algorithm (MOBA) is introduced to determine the optimum size of PV-diesel hybrid micro-grid system with battery energy storage so as to meet the load requirements by minimizing the total cost and highest reliability.

II. HYBRID MICRO-GRID SYSTEM AND OPERATION

In order to predict the HRES performance, the energy sources need to be practically designed to meet the load demand. At the same time, the power obtainable from a hybrid renewable system has significant fluctuations due to weather conditions and hence, the constant load demand may not be met. To mitigate this issue, a battery bank can be integrated to the hybrid system. However, the high cost of batteries is an issue in renewable energy systems. Thus, optimizing the size of the PV-diesel-battey system becomes essential. These contributions reduce the capital cost and increase the chances of investment in renewable energy plant installation. Therefore, the optimal combination of renewable power resources with appropriate storage sizing, as proposed in this work, will give a vital contribution for the future economic feasibility of such plants, thus making the design more attractive for investors.

The power flow of the proposed PV-diesel-battery hybrid system is shown in Figure 1. The load demand is primarily met by the sum of the PV and the battery starts discharging within its operating limits as soon as the PV do not meet the demand. If the PV output power is above the load demand, the excess of power is used to recharge the battery. The diesel generators (DGs) is used when the power from PV and the battery cannot respond to the load energy requirements. Depending on the operation strategy selected, the DG can only supply the deficit of power needed by the load or even at the same time recharge the battery. The mathematical models of the system's different components are presented in the subsection below.

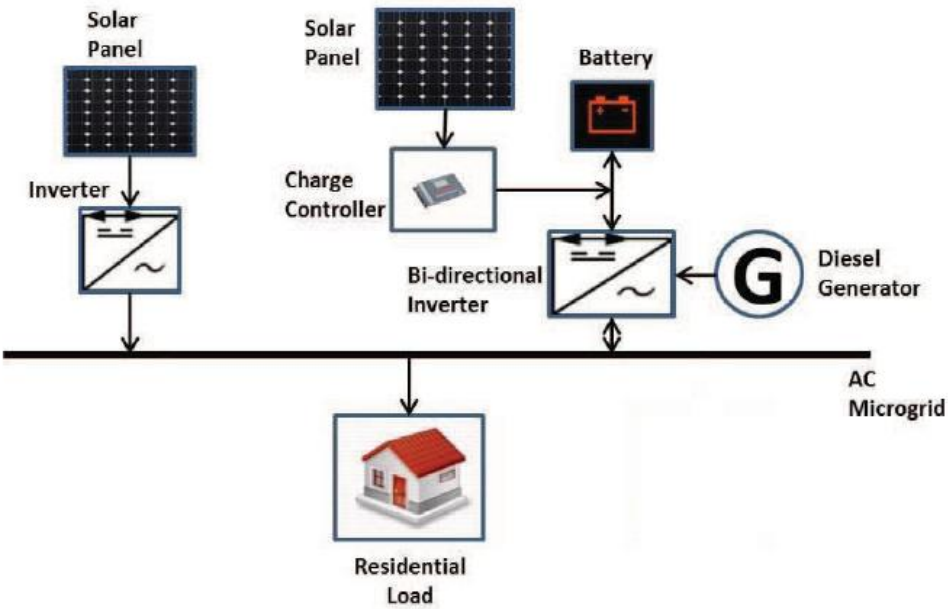

Figure 1. Typical hybrid micro-grid system (HMGS) [12]

2.1. PV Module

The output power of each photovoltaic panel, with respect to the solar radiation power, can be calculated by (1) [13, 14, 16].

$$P_{PV-Each}(t) = \begin{cases} P_R\left(\frac{r^2}{R_{SRS}\,R_{CR}}\right) & if \quad 0 \le r \le R_{CR} \\ P_R\left(\frac{r}{R_{SRS}}\right) & if \quad R_{CR} \le r \le R_{SRS} \\ P_R & if \quad R_{SRS} \le r \end{cases} \tag{1}$$

where $P_{PV-Each}(t)$ is the power generated by each PV panel, P_R is the PV rated power, r is the solar radiation factor, R_{CR} is a certain radiation point set usually as 200 (W/m^2), and R_{SRS} is the solar radiation in the standard environment set usually as 1,000 (W/m^2).

2.2. Diesel Generator

As a backup power system, diesel generator begins to work when the produced power is not enough and the storage system energy is at the lowest level. In this case, diesel begins to work and satisfies the deficit power. The fuel consumption of the diesel generator, $Cons_D$ (l/h), depends on the output power and is defined by the following equation:

$$Cons_D = B_D \times P_N^D + A_D \times P_D \tag{2}$$

where P_N^D is the rated power, P_D is the output power of the diesel generator, and B_D = 0.08145 (l/kWh) and A_D = 0.246 (l/kWh) are the coefficients of the consumption curve [13, 14].
The hourly cost of the fuel consumption can be obtained by (3).

$$C_f = P_{fuel} \times Cons_D \tag{3}$$

where P_{fuel} is the fuel price.

2.3. Battery

The output power from the DG and the load demand at any given sampling interval j, determine whether the battery is charging or discharging. The dynamics of the battery SOC (state of charge) can be expressed in discrete-time domain by a first order difference equation as follows [14-16]:

$$SOC_{(j+1)} = SOC_j - t_s \frac{\eta_{Bat}}{E_{nom}} \times P_{Bat_{(j)}} \tag{4}$$

where SOC is the state of charge of the battery, η_{Bat} is the battery charging or discharging efficiency, E_{nom} is the battery system nominal energy, P_{Bat} is the power flowing from the battery system. By induction reasoning, the dynamics of the battery state of charge at jth sampling interval can be expressed in terms of its initial value SOC(0) as follows:

$$SOC_{(j)} = SOC_{(0)} - t_s \frac{\eta_{Bat}}{E_{nom}} \sum_{j=1}^{N} P_{Bat_{(j)}} \tag{5}$$

III. OPTIMIZATION

To design a low cost and highly efficient HMGS, priority should be given to sizing the system components. The combination of generation sources and using high quality components also has a considerable influence on the life time of the system, and can decrease the cost of electricity for end-users in remote areas.

3.1. Cost Analysis

Levelised cost of electricity (LCOE) is one of the most well-known and used indicators of economic profitability of hybrid renewable energy systems [17, 18]. It is defined as the constant price per unit of energy (or cost per unit of electricity). It is calculated using the following expression,

$$LCOE\left(\frac{\$}{kWh}\right) = \frac{Total\ net\ present\ cost\ (\$)}{\sum_{t=1}^{8760} P_{load}(t)(kWh)} \times CRF \tag{6}$$

Total net present cost includes all the installed capital costs, i.e. the present cost, operation and maintenance cost, and replacement cost. $P_{load}(h)$ is the hourly power consumption. CRF is a ratio to calculate the present value of the system components for a given time period taking into consideration the interest rate. It is calculated by:

$$CRF = \frac{i(1+i)^n}{(1+i)^n - 1} \tag{7}$$

where, i is the real interest rate and n is the system life period (or Amortization period), which is usually equal to the life of the PV panel, due to its longer life expectancy as compared to other components.

3.2. Reliability Analysis

Loss of power supply probability (LPSP) is a statistical parameter, which indicates the probability of power supply failure either due to low renewable resource or technical failure to meet demand. There are two methods of calculating LPSP, i.e. chronological simulation and probabilistic techniques. The former technique uses time-series data in a given period and the latter is based on the energy accumulative effect of the energy storage system, as shown in equation (8) [17-19, 21]. It can be described by the following equation:

$$LPSP = \frac{\sum(P_{load} - P_{pv} - P_{wind} + P_{SOCmin} + P_{diesel}}{\sum P_{load}} \tag{8}$$

In this study the reliability evaluations are carried out in the worst conditions, when

$$P(t)_{load} > P(t)_{generate} \tag{9}$$

3.3. Multi-Objective Optimization

Optimization of HMGS is considered as a multi-objectives problem and there are many methods to solve such an issue. However, among them all, linear scalarization is a popular approach due to its simplicity. In this method a multi-objective problem is converted into a single objective problem in which objectives can either combine in a linear function or treated as constraints. The goal is to optimize the linear function as well as satisfy some inequality constraints to find a single point in Pareto front as the best solution [17]. The fitness function computes as:

$$fitness = min\left\{\sum_{i=1}^{k} w_i \frac{f_i(x)}{f_i^{max}}\right\} \text{ with } w_i \gg 0 \text{ and } \sum_{i=1}^{k} w_i = 1 \quad (10)$$

and the constraints define as:

$$\min g_i(x) \gg 0 \text{ for } i \in \{1, \cdots, m\} \quad (11)$$

where x is the vector of decision variables, the weights (w_i) indicate the relative importance of each objective, k is the number of objectives, f is the objective function, and f_i^{max} is the upper bound of ith objective function.

In hybrid generation systems the LCOE and LPSP are equally important concerns to achieve the optimum system which can guarantee reliable and uninterrupted supply of energy at a competitive cost with the conventional power derived from the fossil fuel and grid extension. In order to balance these two objectives the weights (w_i) are adjusted at 0.5 for both.

3.4. Multi-Objective Bat Algorithm

Amongst of several biologically inspired metaheuristics, bat algorithm (BA) proposed by Xin She Yang (2010) [22] attracted a worthy attention from several researchers who works in the field of biologically inspired optimization algorithms. The novelty was to use the echolocation of microbats (since megabats scarcely use echolocation) and was fairly used optimization for global optimization problems [22]. The typical ideology was to mimic the conceptual of: how bats administer the use of echolocation to pinpoint its prey also to avoid any impediments on their go. It is known from [22] that the micro bats emit up to 200 pulses per second while attempting to take over its prey. It is factual that bats use the echolocation to predict the distance between the prey. Another key point of amaze is that the microbats roam with a randomized velocity (v_r) and in a position (v_x) with a frequency (f_e). The frequency has a varying wavelength (V_w) and loudness (V_L) to the prey. It is to wonder that they adjust the frequency based on the proximity of the prey.

Based on the behaviors of bats, in [22], the authors proposed a multi-objective bat algorithm (MOBA) for multi objective optimization problems [23]. The basic steps of the MOBA can be summarized as the pseudo code shown in Figure 2.

Algorithm for MOBA
1. Start
2. Define V_r, V_x, F_e and the number of iterations
3. Define Frequency F_e
4. Define the wavelength (V_w) and Loudness (V_L)
5. if i<n
6. Generate new solutions and and update V_r and V_x
7. Generate local solutions
8. Generate new solutions by random flying
9. if $f(V_x < V^*_x)$
10. Accept the solution and decrease V_L
11. Sort out the solutions and obtain the pareto optimal font.

Figure 2. Pseudocode of MOBA

IV. RESULTS AND DISCUSSION

4.1. Case study

In the case study, the location of Sebubus village, Paloh sub-district, Sambas district, West Kalimantan province, Indonesia was chosen with the coordinates of 1°48'7"N 109°21'18"E. This location is a transmigration area with a total of 200 households. Daily electrical energy consumption of 775 kWh/day, peak load of 48 kW and average load of 25 kW. Electrical equipment used by residents includes: lighting, fans, televisions, rice cookers, water pumps, and others. The typical daily load profile are shown in Figure 3.

The collection of data is derived from primary and secondary sources—literature reviews and demographical distribution the case study. Data for renewable energy sources are retrieved from NASA, 2018 accessed within the NREL Database System in real time [20]. Solar radiation data for specific location can be extracted by different means; for example, solar radiation can be obtained from metrological stations that are distributed across the country in question or it can also be extracted by transporting the latitude and longitude figures of the region into the NASA (2018) portal found on the website. The global solar radiation data for Sebubus village is shown in Table 1.

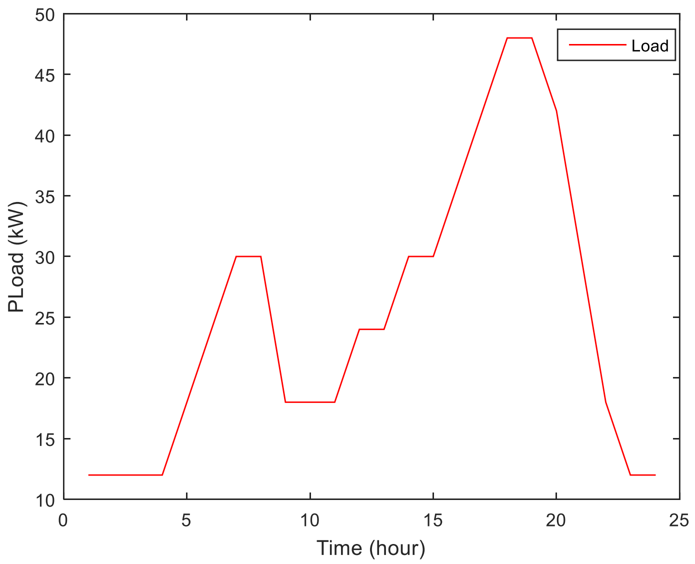

Figure 3. Typical daily load profile for Sebubus village

4.2. Simulation results

The locations in Sebubus village is used in this study to investigate the optimal sizing of a hybrid micro-grid system (HMGS). For the load profile of Sebubus village, a typical rural daily load with a peak of 48 kW and average load is 25 kW. Moreover, the community consists of 200 households. The input parameters are tabulated in Table 2.

The power management strategy for a HMGS is performed to maintain a continuous power to the load demand in different modes of operation. The multi-objective bat algorithm (MOBA) technique is applied in order to obtain the best configuration of system and for optimal sizing of the components. This technique selects one of the different solutions and makes decision on LPSP against LCOE based on the number of PV (NPV), number of diesel generator (NDG) and number of battery energy storage (NBES).

The results show that MOBA technique provides optimum solar, diesel and battery ratings. The simulation results obtained by minimum LCOE and LPSP, as well as electricity production (kWh/year) of HMGS as shown inTable 3. Average daily load, average daily output power of each component, and percentage of energy providers, respectively also shown in Figures 4 to 8.

Table 1: Monthly solar radiation and clearness index at Sebubus village

Month	Clearness Index	Average Daily Solar Radiation ($kWh/m^2/day$)
Jan	0.608	6.16
Feb	0.678	6.47
Mar	0.709	6.78
Apr	0.700	6.84
May	0.659	6.50
Jun	0.626	6.30
Jul	0.598	6.09
Aug	0.597	6.22
Sept	0.594	6.40
Oct	0.621	6.29
Nov	0.572	6.17
Dec	0.566	6.90

Table 2: Input parameters [17]

Parameter	Unit	Value
Diesel generator		
Life time	hours	24,000
Initial cost	$/kW	1000
Rated power	kW	4
Inverter		
Rated power	kW	6.5
Efficiency	%	92
Life time	year	24
Initial cost	$	2500
Battery		
Efficiency	%	85
Life time	year	12
Initial cost	$/kWh	280
Rated power	kWh	40
PV		
PV regulator efficiency	%	95
Life time	year	24
Initial cost	$/kW	3400
Rated power	kWh	7.3
PV regulator cost	$	1500
Economic parameters		
Discount rate	%	8
Real interest	%	12
O&M + running cost	%	20
Fuel inflation rate	%	5
Project life time	year	24

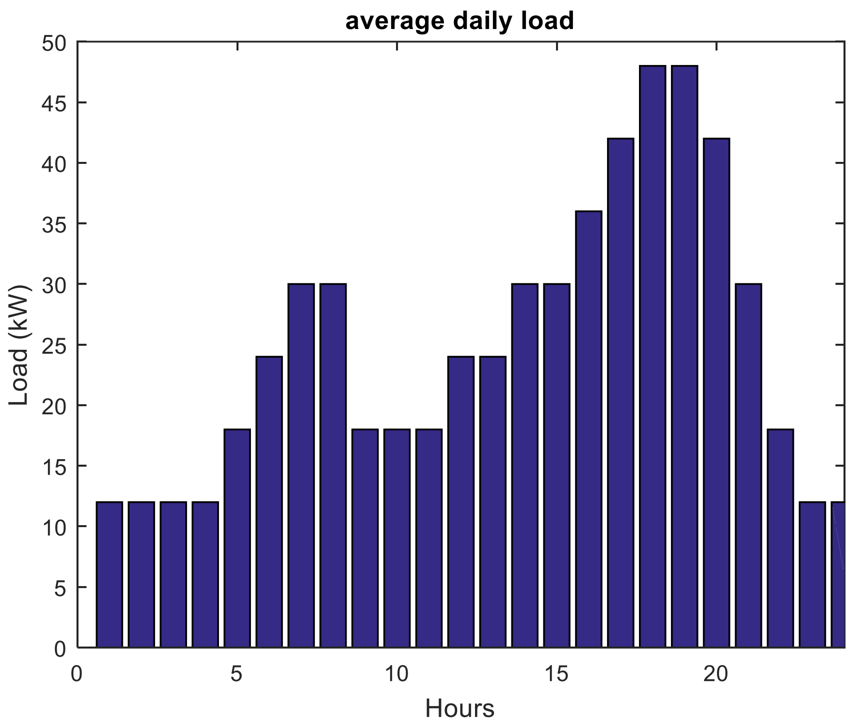

Figure 4. Average daily load

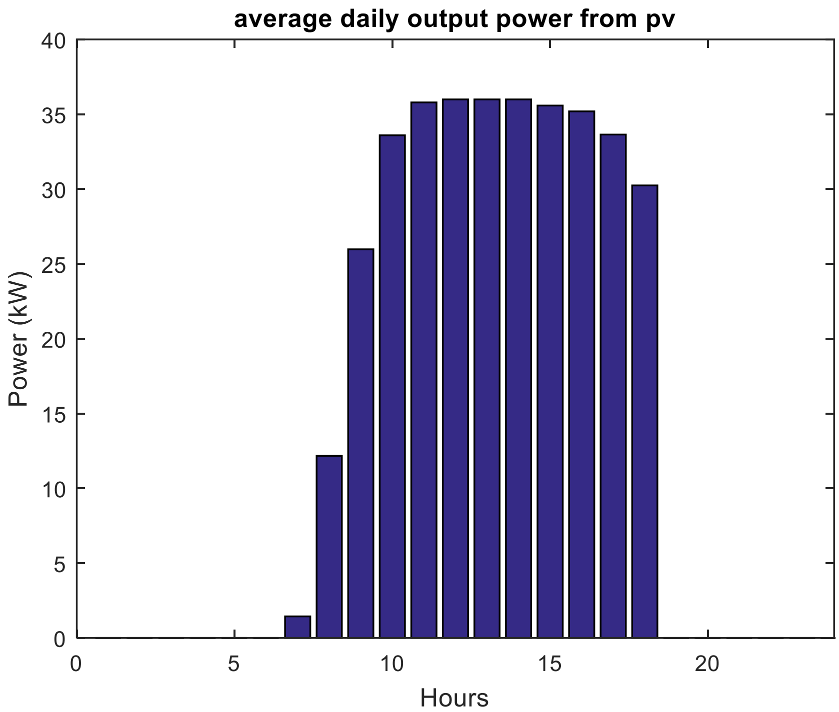

Figure 5. Average daily output power from pv

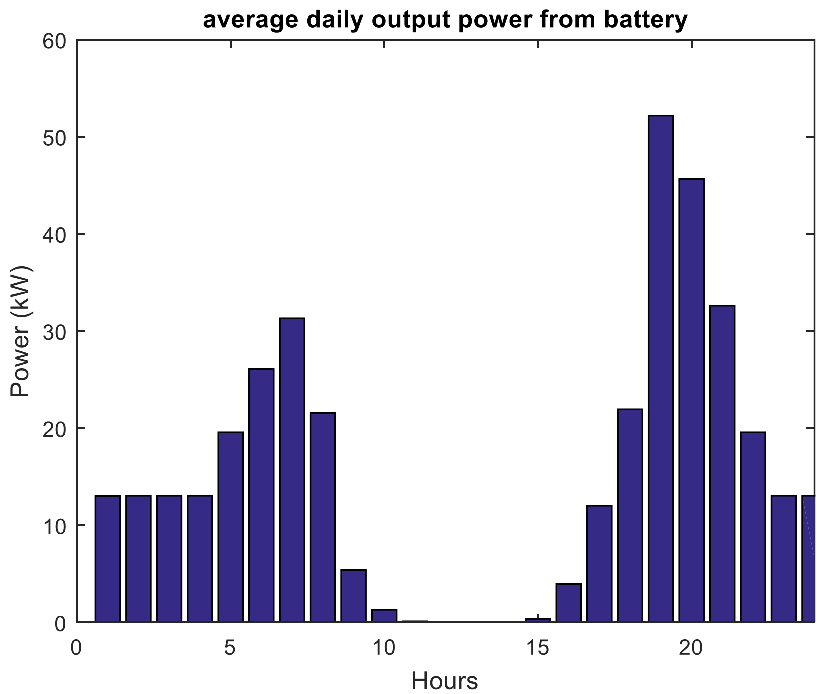

Figure 6. Average daily output power from battery

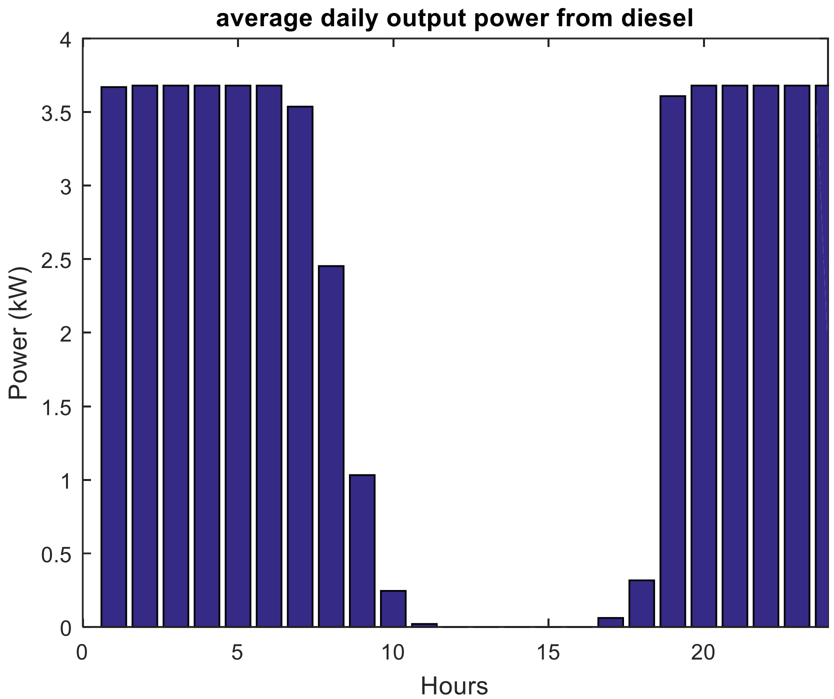

Figure 7. Average daily output power from diesel

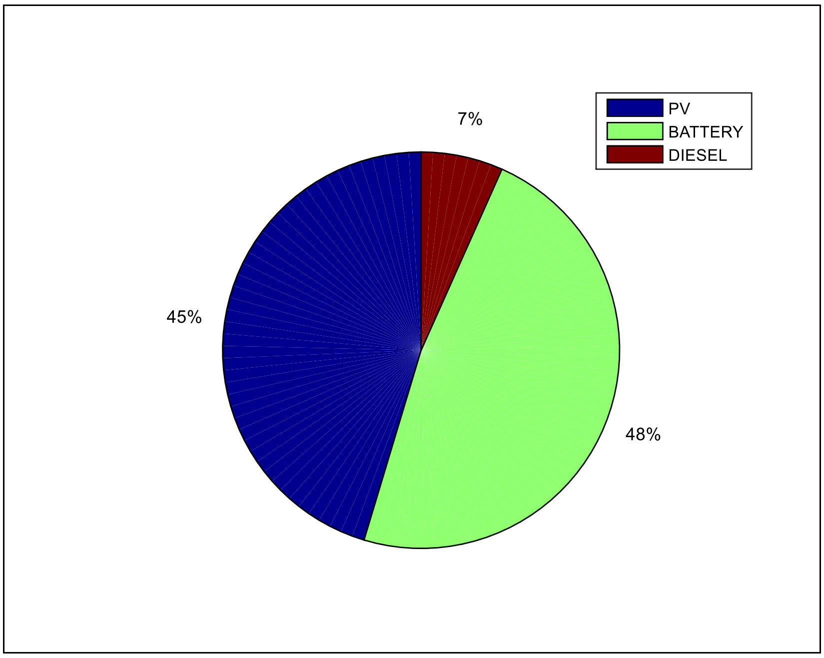

Figure 8. Percentage of energy provided by PV, diesel and battery storage

Table 3: Final Results

LPSP	=	0.1083414758
LCOE ($/kWh)	=	0.2381071944
>>>	Electricity production	<<<
Solar power	=	126565.332 (kWh/yr)
Battery storage	=	133851.714 (kWh/yr)
Diesel power	=	18628.160 (kWh/yr)

V. CONCLUSION

This paper presented the optimal sizing of PV/diesel/battery hybrid micro-grid system (HMGS) using multi-objective bat algorithm (MOBA) for a rural area settlement in Sebubus village, Sambas district, Indonesia. The hybrid micro-grid system modeling was conducted in MATLAB using case study to select the best configuration in order to find the optimum number of variables; PV/diesel/battery to minimize LPSP and LCOE. The results showed that the proposed technique was successful in supplying household load with operation strategy during the entire one-year period. As conclusion, the proposed system can fulfill the targeted constraints for rural electrification and ensure that the load demand is met.

REFERENCES

[1]. A. Woyte, V. Van Thong, R. Belman and J. Nijs, Voltage fluctuations on distribution level introduced by photovoltaic systems, IEEE Transactions on Energy Conversion, 21(1), 2006, 202-209.

[2]. P. Denholma and R. Margolis, Evaluating the limits of solar photovoltaics next term (PV) in traditional electric power systems, Energy Policy, 35, 2007, 2852–2861.

[3]. Y. Riffonneau, S. Bacha, F. Barruel and S. Ploix, Optimal power flow management for grid connected pv systems with batteries, IEEE Transactions on Sustainable Energy, 2(3), 2011, 309-320.

[4]. P. Denholma and R. Margolis, Evaluating the limits of solar photovoltaics (PV) in electric power systems utilizing energy storage and other enabling technologies, Energy Policy, 35, 2007, 4424–4433.

[5]. M. Perrin, Y. Saint-Drenan, F. Mattera and P. Malbranche, Lead-acid batteries in stationary applications: competitors and new markets for large penetration of renewable energies, Power Sources, 144, 2005, 402–410.

[6]. Khare Vikas, Savita Nema, and Prasant Baredar, Solar–wind hybrid renewable energy system: A review, Renewable and Sustainable Energy Reviews , 58, 2016, 23-33.

[7]. Badwawi Rashid Al, Mohammad Abusara, and Tapas Mallick, A review of hybrid solar PV and wind energy system, Smart Science, 3(3), 2015, 127-138.

[8]. Pawar, Shekhar K., et al., Modeling and simulation of hybrid solar-wind-grid power generation system for electrification, Advances in Engineering and Technology (ICAET), 2014 International Conference on. IEEE, 2014.

[9]. M. Ashari and C. V. Navar, An optimum dispatch strategy using set points for a photovoltaic (PV)–diesel–battery hybrid power system, Solar Energy, 66(1), 1999, 1-9.

[10]. Saheb-Koussa, D., M. Haddadi, and M. Belhamel, Economic and technical study of a hybrid system (wind–photovoltaic–diesel) for rural electrification in Algeria, Applied Energy, 86(7), 2009, 1024-1030.

[11]. Alalwan, Sami Hamed, and Jonathan W. Kimball, Optimal sizing of a wind/solar/battery hybrid micro-grid system using the forever power method, Green Technologies Conference (Green Tech), 2015 Seventh Annual IEEE, 2015.

[12]. A. M. Hasan and S. A. Chowdhury, Solar diesel hybrid mini-grid design considerations: Bangladesh perspective, in Developments in Renewable Energy Technology (ICDRET), 2014 3rd International Conference on the, 2014, 1-4.

[13]. A. Maleki, M. Ameri, and F. Pourfayz, Techno-economic analysis and optimal design of an off-grid hybrid pv/wind/diesel system with battery storage, International Journal of Engineering & Applied Sciences, 6(4), 2014, 23-39.

[14]. K. Kusakana, Operation cost minimization of photovoltaic-diesel-batery hybrid systems, Energy, 85, 2015, 645-653.

[15]. H. Ibrahim, and M. Ghandour, Optimization of energy management of a micro-grid based on solar-diesel-battery hybrid system, MATEC Web of Conferences 171, 01006, 2018, 1-7.

[16]. A. V. Anayochukwu, Simulation of photovoltaic/diesel hybrid power generation system with energy storage and supervisory contol, International Journal of Renewable Energy research, 3(3), 2013, 605-614.

[17]. H. Borhanazad, S. Mekhilef, V. G. Ganapathy, M. Modiri-Delshad, and A. Mirtaheri, Optimization of micro-grid system using MOPSO, Renewable Energy, 71, 2014, 295-306.

[18]. Y. Salwie, S. C. Gupta, and A. K. Bohre, Optimal sizing of standalone PV/Wind/Biomass hybrid energy sistem using GA and PSO optimization technique, Energy Procedia, 117, 2017, 690-698.

[19]. J. Lu, W. Wang, Y. Zhang, and S. Cheng, Multi-objective optimal design of stand-alone hybrid energy system using entropy weight method based on HOMER, Energies, 10, 2017, 1664, 1-17.

[20]. H. Moria, Techno-economic feasibility of a hybrid solar-photovoltaic and wind power system for Yanbu, Saudi Arabia, The 2017 World Congress on Advances in Structural Engineering and Mechanics (ASEM17), 28 August – 1 September 2017, Lisan (Seoul), Korea.

[21]. R. Kamble, G. Karve, A. Chakradeo, and G. Vaidya, Optimal sizing of battery energy strorage in microgrid by using particle swarm optimization technique, Journal of Integrated Science & Technology, 6 (1), 2018, 6-12.

[22]. X. S. Yang, A new metaheuristic bat-inspired algorithm, in: Nature Inspired Cooperative Strategies for Optimization (NISCO 2010) (Eds. J. R. Gonzalez et al.), Studies in Computational Intelligence, Springer Berlin, 284, Springer, 65-74 (2010).

[23]. X. S. Yang, Bat algorithm for multiobjective optimization, Int. J. Bio-Inspired Computation, 3(5), 2011, 267-274.

D. Fadli " Optimal Sizing of PV/Diesel/Battery Hybrid Micro-Grid System Using Multi-Objective Bat Algorithm" The International Journal of Engineering and Science (IJES), 8.7 (2019): 06-14