Intelligence Technique Based Design and Assessment of Photovoltaic-Battery-Diesel for Distributed Generation System in Campus Area

Subiyanto[1], Mohamad A. Prakasa[2], P. Wicaksono[3], Mega A. Hapsari[4]

Abstract – *Several studies have discussed the optimal designing methods of distributed generation (DG) based on intelligent algorithms. However, the feasibility of an intelligent algorithm-based DG system has not been investigated further, especially for DG in the campus area. Moreover, the DG that operates in two modes (grid-connected and micro-grid mode) has unique characteristics. This paper presents a design and assessment of the PV-battery-diesel DG system in the campus area based on a powerful intelligence technique. The designed DG consists of a PV system (PV array, battery, and inverter) and a diesel generator is used as backup power supplies to cover the loads during grid blackouts. The intelligence technique is used to determine the optimal size and configuration of PV array. In this work, a new variant modified AHP with fuzzy logic is developed to solve the problem. The developed algorithm is implemented by using MATLAB software. Then, the optimal size and configuration results have been evaluated and assessed in HOMER software. HOMER simulation results show that DG can operate in both grid-connected and micro-grid mode properly. Based on the case study site data, the net present cost of DG system is $291.073,43. The energy cost of the DG system is $0,12 for E6+E8 building system and $0,06 for E11 building system. The DG system has produced some pollutants from fuel consumption.* ***Copyright © 2009 Praise Worthy Prize S.r.l. - All rights reserved.***

Keywords*: Analytical hierarchy process, Fuzzy logic, Intelligence technique, Distributed generation, Renewable energy*

Nomenclature

AHP	Analytical Hierarchy Process
BAPV	Building-attached PV
CdTe	Cadmium telluride
CIS	Copper indium gallium selenide PV type
CO2	Carbon dioxide
COE	Cost of Energy
DG	Distributed Generation
GHI	Global Horizontal Irradiance
HIT	Heterojunction PV type
kW	kilowatt
kWh	kilo watt hour
kWp	kilo watt peak
M-si	Mono-crystalline PV type
NPC	Net Present Cost
P_{annual}	Annual Average Load
P_{daily}	Daily Load
$P_{weekend}$	Weekend Load
PV	Photovoltaic
P-si	Poly-crystalline PV type
RES	Renewable Energy Sources
TFN	Triangular Fuzzy Number
W	watt

I. Introduction

Attention in renewable energy sources (RES) empowerment has grown significantly during last decades [1]. It can be seen from that the increase of the global RES investment has reached a total of $189.7 billion [2]. The RES has important roles due to various benefits, such as uncontaminated energy, zero carbon emission, independent from fossil energy, etc. [3]. In Southeast Asia, total project investments for RES have increased by 8% in 4 years [4]. The International Renewable Energy Agency (IRENA) had reported that the Association of Southeast Asian Nations (ASEAN) targeting will reach 23% in 2025 [5]. Several countries have started to make regulations that optimize RES utilization. For example, The Indonesian Ministry of Energy and Mineral Resources plans that RES utilization will reach 31% of the national energy mix in 2050 [6].

Many previous studies have discussed efforts to optimize RES utilization. The distributed generation (DG) system is developed because it seems optimal, worthy, secure, and trusted paradigm in order to overcome the increasing demand for RES utilization [3]. The DG technology can combine the existing conventional energy grid and the potential RES in DG location [7], [8]. The RES that can be used in DG system are solar photovoltaic (PV), wind turbine, hydro with the dam, hydrokinetic with the river streams, wave energy harvester, fuel cell system, etc. [9]–[12].

The DG system can operate in two modes, grid-connected and micro-grid [13]–[15]. The first one will operate RES generation hybrid with main grid, while the second one will operate in blackout condition when the main grid cannot provide electricity for loads [7], [13]. One of the advantages of the DG system over the conventional ones is that it does not depend on the energy source from the grid. Besides that, the DG system allows not only taking place as consumers, but also as

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consumers and producers [16]. The DG is suitable for rural areas, industrial areas, shopping center areas, reparation center areas, campus areas, etc. with high productivity. Among various object cases research, campus area has become an ideal place for previous researchers to develop the DG system [17]. It can be used as a place for test-bed experiment to know and optimize its own distributed energy resources configured as micro-grid to optimize and improve the use of energy [18].

Besides many advantages, variabilities and uncertainties of RES are the main problems in managing DG system. The characteristics of DG system that operate in two modes need crucial technical and economic analysis for efficient RES utilization in the campus area [14]. Therefore, the DG system is expected to be able to supply electrical demand with uncertain energy resources [19]. For example, the PV system will work optimally at certain solar irradiation and temperature and wind turbine will work optimally at certain wind speeds.

It causes problems, so the reliable planning method is needed for the DG system that operates in two modes in the campus area. There are many software tools have been used to help the researchers for planning DG system, such as HOMER, RETScreen, H2RES, etc. From many existing software, HOMER is the most widely because it is user-friendly [20]. It is also powerful for designing, sizing, planning DG and provides techno-economic analysis for grid-connected and stand-alone systems [21].

In previous studies, HOMER has been used for planning and evaluating DG in various cases. Alsafasfeh (2018) in [15] has analyzed the performance of large scale grid-connected PV-wind turbine system for four cities in Jordania. The result of Alsafasfeh's study is the hybrid PV-diesel-battery system shows the best performance to supporting 24 hours of energy access.

Halabi, et al. (2017) in [22] have discussed the performance analysis of a hybrid PV-diesel-battery system for a rural area in Sabah, Malaysia. Shahzad, et al. (2017) in [21] have made a techno-economic and feasibility analysis based on a solar-biomass off-grid system for a remote rural area in Pakistan. Shahzad's study has concluded that hybrid renewable systems are more effective and reliable source of energy. Phurailatpam, et al. (2018) in [23] have planned and optimized autonomous DG micro-grid for rural and urban applications in India. Iqbal, et al. (2017) in [8] have analyzed optimal configuration for campus micro-grid. Iqbal's study has concluded that RES generation has NPC, COE, and CO_2 less than other topologies. Magarappanavar, et al. (2016) in [12] have optimized wind-solar-diesel hybrid for BEC campus. The result is that the campus stand-alone RES system is a feasible and economical option. Ahmad, et al. (2018) in [3] have optimized sizing and analyzed PV-wind-battery hybrid system for campus micro-grid. Sheilla, et al. (2014) in [24] have made techno-economic analysis by MATLAB and evaluated the model in HOMER.

HOMER has been also combined with intelligent algorithms in order to optimize sizing components and configuration. Kumar, et al. (2019) in [10] have used a Fuzzy Analytical Hierarchy Process algorithm to design PV hybrid system and evaluated it by HOMER. An AHP algorithm has also been used for other energy planning, resources management, component selection, and micro-grid planning [25]–[29]. Hapsari and Subiyanto in [30] have developed a Fuzzy AHP algorithm for optimal planning the building-attached PV system in educational area. That study has obtained a suitable design for a grid-connected BAPV system with battery storage. AHP algorithm is chosen because of its simplicity, flexibility, and intuitiveness with more complex criteria considered [29],[30]. Fuzzy logic can improve calculation results and can represent human assessment and perception behavior in choosing preferences [31].

Based on the literature above, it can be concluded that there are many studies for the optimal design of DG based on intelligence technique. However, the feasibility of an intelligent algorithm-based DG system has not been investigated further, especially for DG in the campus area. Moreover, the DG that operates in grid-connected and micro-grid mode has unique characteristics. Therefore, this paper presents a design and an assessment of PV-battery-diesel for DG in the campus area based on a powerful intelligence technique. DG system is designed to be operated in grid-connected and micro-grid mode as experiment scenarios. The intelligence technique has been used to determine the optimal size and the configuration of the PV array. In this work, a new variant modified AHP with fuzzy logic is developed to solve the problem. The developed algorithm is implemented in MATLAB software. The results are used for designing the DG system to be evaluated and assessed in HOMER software.

This paper is organized as follows. In Section 2, the site profiles and conditions of this study are described. Section 3 shows how the DG system is designed. In section 4, optimal PV design based on a new variant algorithm has shown. Then, in Section 5 shows the assessment by HOMER simulation and discussion. Finally, the conclusions are presented in Section 6.

II. Case Site Profiles

The case site of this study is *Universitas Negeri Semarang* (Semarang State University); it is located in Sekaran, Gunungpati, Semarang City. The university has a tropical climate with coordinates of 7.05o south latitude, 110.40o east longitude, and elevation 187 meters above sea level [32]. The university has eight faculties. One of them is the Faculty of Engineering, that has five Departments: there are Civil Engineering (E3, E4, and E12 buildings), Mechanical Engineering (E5 and E8 buildings), Electrical Engineering (E6, E8, and E11 buildings), Vocational Engineering (E5 and E8 buildings), and Chemical Engineering (E1 and E2 buildings). The buildings of Electrical Engineering are

used for this study. Fig. 1 shows the location of E6, E8, and E11 buildings in Google Maps.

The PV array works considering solar global horizontal irradiance (GHI) and temperature. Solar GHI and temperature data have been downloaded from NASA Surface Meteorology and Solar Energy Database that was built in HOMER as shown in Fig. 2. Pradita (2018) in [33] has observed the load demand estimated in the Department of Electrical Engineering at Universitas Negeri Semarang as shown in Table 1.

Fig. 1. E6, E8, and E11 buildings location [34]

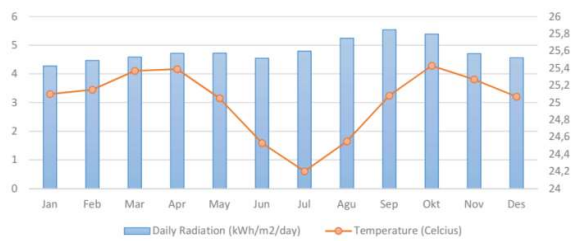

Fig. 2. Solar GHI and temperature profiles in site location

TABLE I
LOAD DEMAND IN CASE STUDY

Building	Load Demand (kWh)
E6	31,80
E8	35,70
E11	179,00

The daily load profile depends on the behavior of consumers. In the campus area, the main load is lighting, air conditioner, computer, and study appliances such as projector, sound system, and electrical trainer set. The load profile obtained from the calculation in (1) as follows:

$$P_{annual} = (P_{daily}\, x\ weekdays) + (P_{weekend}\, x\ weekend) \quad (1)$$

where P_{annual} is annual average load in kWh. P_{daily} is daily load in kWh that obtained from Table 1. $P_{weekend}$ is weekend daily load that assumed 15% from weekday daily load. In one calendar, there are 262 weekdays and 98 weekends. P_{annual} is obtained 18.674,80 kWh/year for E6+E8 buildings and 49.529,30 kWh/year for E11 building. The results are used for simulating load profiles in the site project. Fig. 3 presents the daily load profile in E6+E8 and E11 buildings based on simulation.

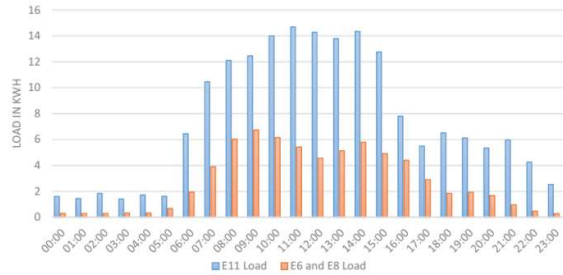

Fig. 3. Daily load profile in E6+E8 and E11 buildings

III. Designing and Sizing Distributed Generation

The block diagram of the designed DG system is illustrated in Fig. 4. The designed DG system includes PV array, batteries, diesel generator, electric conditioning units, control system, and grid unit. In this case, the DG system designed for operating in grid-connected and micro-grid mode. The grid-connected mode has PV system as main energy supplier. The excess energy produced will be stored in batteries and injected into the grid if possible. Micro-grid mode is activated when grid blackout occurs. PV system supplies load with a diesel generator as support Then, the energy stored in batteries will cover the lack of energy needed if energy from PV system and diesel generator is insufficient.

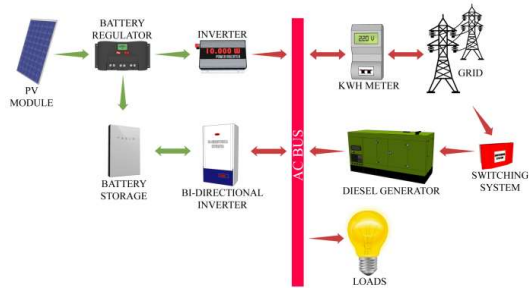

Fig. 4. Schematic diagram of the designed DG system

The PV system consists of PV array, battery storage, and inverter. The developed algorithm is used to determine optimal size and configuration based on technical, economic, and environmental factors as criteria [27]. Fig. 5 shows the framework for designing DG in this study. It is divided into two levels. Level 1 presents the designing DG method and level 2 discusses an assessment method. Level 1 starts with surveying electrical load demand data in the site project. The next step is determining criteria, sub-criteria, and alternatives for reaching goals. Four criteria are considered to plan the PV system, i.e. sizing, technical, economic, and environmental criteria. The alternatives are built from different PV array types. Then, the alternative is assessed by the experts. The expert's assessment is used for the calculation of the developed algorithm in MATLAB.

Level 2 is executed after that an acceptable optimal PV system from level 1 has been obtained. The optimal size and the configuration of the designed DG are modeled by using HOMER software. The simulation model consists

of an optimal PV system, diesel generator as backup, and grid unit. The HOMER simulation will evaluate and assess based on techno-economic parameters. The scenario of the simulation is DG in grid-connected and micro-grid mode. The simulation results have been obtained are used for discussing about the feasibility of DG design considering several aspects, i.e. economic parameters, energy production and consumption characteristics, and emissions produced.

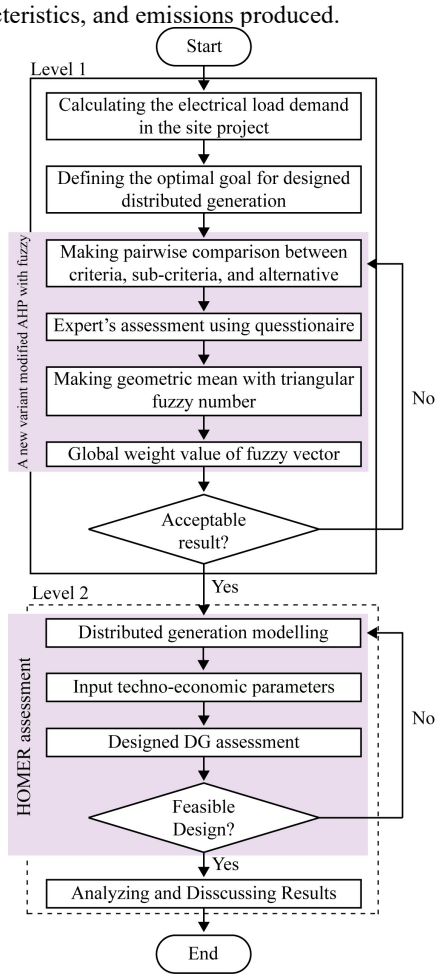

Fig. 5. Framework for design and assessment DG

III.1 PV System Components

The PV system is divided into two installations; E6+E8 and E11. E6+E8 buildings are merged because the electrical system integrates each other. The E6+E8 building installation consists of 30 kWp PV array, 31,5 kW inverter, and 30 kVA diesel generator, while the E11 building installation consists of 70 kWp PV array integrated with battery storage, 73,5 kW inverters, and 60 kVA diesel generator. The optimal PV array size and the configuration are calculated in MATLAB using the developed algorithm. The best alternative is conducted by the developed algorithm that consists of several different types of PV specifications. The alternative design are built from four criteria as follows:

1. Sizing criteria, which consist of type, amount, unit price, and area covered by PV modules.
2. Technical criteria, which consist of performance ratio, total energy produced, energy supplied load, and amount of excess energy for injecting to the grid.
3. Economic criteria, which consist of life cycle cost and cost of energy.
4. Environmental criteria, which consist of the amount of CO_2 reduced.

Poly-crystalline (p-si), mono-crystalline (m-si), CIS, HIT, CdTe PV types were selected because have the higher efficiency of 15-20 % than other types of PV [35]–[39]. Table 2 and Table 3 show the detail specification of PV alternative design.

TABLE II
ALTERNATIVES PV DESIGN FOR 30 KWP E6+E8 BUILDINGS INSTALLATION
(See in Table 2 below this article)

TABLE III
ALTERNATIVES PV DESIGN FOR 70 KWP E11 BUILDING INSTALLATION
(See in Table 3 below this article)

The PV system needs the power conditioner including inverter to work properly. The inverter has an important role in frequency and voltage control [40]. It can convert DC input power of PV array to AC power to supply load and inject the excess power into main-grid [41]–[43]. The PV inverter requires algorithms for controlling maximum power point tracking (MPPT), synchronization, and anti-islanding algorithm to safe the system during grid cut-off [13]. The grid-tie inverter has been chosen because it can adjust the voltage and frequency of the main-grid [43]. The detail specification of the inverter used is shown in Table 4.

TABLE IV
SPESIFICATION OF INVERTER USED

Parameters	E6+E8 Inverters	E11 Inverter
Total Capacity (kW)	31,50	73,50
Capital Cost ($)	2.939,00	8.450,00
O & M Cost ($/year)	35,07	35,07
Replacement Cost ($/W)	2.939,00	8.450,00
Life time (years)	5,00	5,00

The PV system also needs a battery storage system to store excess energy. In this case, the rechargeable lithium-ion battery AC battery is chosen as the storage system. The storage system consists of storage for solar self-consumption and a time-based control unit. The battery storage is only installed for 70 kWp PV array in the E11 building because the building needs more electricity available, which is full of class for students on weekdays, and sometimes for student's organization meeting at the weekend. Table 5 presents the specification of the battery storage used.

TABLE V
SPECIFICATION OF BATTERY STORAGE USED

Parameters	Specification

Capacity (kWh)	39,60
Amount Used	3 batteries
Capital Cost ($)	26.250,00
O & M Cost ($/year)	35,07
Fuel Cost ($/operating hours)	0,69
Replacement Cost ($/W)	26.250,00
Life time (years)	10,00

III.2 Diesel Generator

The diesel generator is required to back up the DG system when power from PV is insufficient to supplying load if blackout occurred. This study is used diesel generator that available in the site project. There are 60 kVA and 30 kVA diesel generator with specification detail in Table 6.

TABLE VI
SPESIFICATION OF DIESEL GENERATOR USED

Parameters	60 kVA Diesel Specs.	30 kVA Diesel Specs.
Capital Cost ($)	18.977,63	13.290,45
O & M Cost ($/operating hours)	0,06	0,03
Fuel Cost ($/L)	0,69	0,69
Replacement Cost ($/W)	18.977,63	0,44
Life time (hours)	15.000,00	15.000,00

III.3 Grid Regulation

The electricity tariffs in the site project are 0,073 $/kWh for 1,7 MVA grid power rated [44]. The state-owned corporation that regulates all the regulations regarding electricity in Indonesia has allowed its consumers to sell energy to the grid. Based on regulation, the sell-back tariffs for the rooftop PV system are 65 % of the electricity tariffs in the site project [45]. Therefore, the sellback tariffs are 0,047 $/kWh.

III.4 Controller and Energy Management System

HOMER has Cycle Charging (CC) controllers for an optimal controller in the DG system. The best scenario will be conducted by HOMER based on higher RES generation with minimal costs [14]. CC dispatch strategy is a dispatch whenever a generator needs to supply the load, a generator operates at full power output. Excess energy from the generator goes toward the lower priority, such as charging the battery and inject to the grid [46].

IV. Optimal PV Design based on A New Variant Modified AHP by Fuzzy Logic

The developed algorithm is used to calculate the optimal size and the configuration for the alternatives listed in Table 2 and 3. The alternatives have been conducted in a previous study presented in [30]. Following the pairwise comparison questionnaire rated by experts, priorities for criteria and sub-criteria have been obtained as shown in Table 7. The linguistic assessment is converted to numeric scale based on [47] as shown in Fig 6.

The next step is converting the pairwise comparison matrix into the Triangular Fuzzy Number (TFN) matrix form. The TFN of each assessment value consists of lower value (l), middle value (m), and upper value (u) that established based on the TFN scale in Table 8. The TFN is written as a triplet number, and the membership function of criteria C(x) can be expressed in (2) [48], [49]:

$$C(x)\begin{cases} 0 & x < c^l \\ \dfrac{x - c^l}{a^m - a^l} & a^l \le x \le a^m \\ \dfrac{c^u - x}{a^u - a^m} & a^m \le x \le a^u \\ 0 & x > c^u \end{cases} \tag{2}$$

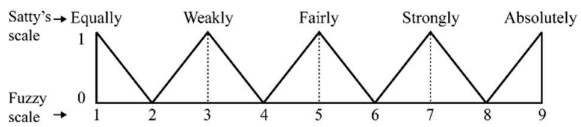

Fig. 6. Fuzzy scale based on Saaty's scale

TABLE VII
DETAILS OF EXPERT'S ASSESSMENT IN PAIR-WISE COMPARISON MATRIX FORM

Expert 1 (E_1)	Sizing Criteria (C_1)	Technical Criteria (C_2)	Economic Criteria (C_3)	Environmental Criteria (C_4)
(C_1)	1	1/7	1	5
(C_2)	7	1	5	7
(C_3)	1	1/5	1	9
(C_4)	1/5	1/7	1/9	1
E_2	(C_1)	(C_2)	(C_3)	(C_4)
(C_1)	1	1/5	1/6	1/5
(C_2)	5	1	2	½
(C_3)	6	1/2	1	2
(C_4)	5	2	1/2	1
E_3	(C_1)	(C_2)	(C_3)	(C_4)
(C_1)	1	1/5	1/7	1/9
(C_2)	5	1	1/4	1/7
(C_3)	7	4	1	1/5
(C_4)	9	7	5	1
E_4	(C_1)	(C_2)	(C_3)	(C_4)
(C_1)	1	3	5	7
(C_2)	1/3	1	3	5
(C_3)	1/5	1/3	1	3
(C_4)	1/7	1/5	1/3	1

TABLE VIII
TRIANGULAR FUZZY NUMBER SCALE

Saaty's Scale	Fuzzy Scale	TFN Scale
Equally	1	(1, 1, 1)
Weakly	3	(1, 3/2, 2)
Fairly	5	(2, 5/2, 3)
Strongly	7	(3, 7/2, 4)
Absolutely	9	(4, 4/5, 5)
Intermediate	2, 4, 6, 8	(1/2, 1, 3/2); (3/2, 2, 5/2); (5/2, 3, 7/2); (7/2, 4, 9/2)

Then, the TFN-form assessment of experts is blended into geometric means to combine all of the expert's preferences in one form. The geometric means can be calculated in (3) as follows:

$$l_{pq} = \left(\prod_{r=1}^{R} l_{pqr}\right)^{\frac{1}{R}}$$
$$m_{pq} = \left(\prod_{r=1}^{R} m_{pqr}\right)^{\frac{1}{R}} \quad (3)$$
$$u_{pq} = \left(\prod_{r=1}^{R} u_{pqr}\right)^{\frac{1}{R}}$$

Where p represents value in a row of the matrix, q represents value in a column of the matrix, and r represents the number of the expert. If the value of l, m, and u meet the terms of $l \leq m \leq u$, it means the pairwise comparison is consistent. Table 9 shows the geometric means of the expert's assessment in the TFN form.

TABLE IX
TRIANGULAR FUZZY NUMBER FORM OF EXPERT'S ASSESSMENT IN PAIR-WISE COMPARISON MATRIX
(See in Table 9 below this article)

The TFN matrix is normalized through synthesis and defuzzification to produce the fuzzy vector weight of the criteria. Table 10 shows the synthesized values of the criteria. The synthesized values of the criteria are established in (4) as follows:

$$S_i = \sum_{j=1}^{m} M_{gi}^{j} * \left(\sum_{i=j}^{m} \sum_{i=1}^{n} M_{gi}^{j}\right)^{-1} \quad (4)$$

Where $\left(\sum_{i=j}^{m} \sum_{i=1}^{n} M_{gi}^{j}\right)^{-1}$ is obtained by summing the fuzzy number in TFN matrix as follows in (5):

$$\left(\sum_{p=q}^{m} \sum_{p=1}^{n} M_{gp}^{q}\right)^{-1} = \frac{1}{\sum_{p=1}^{n} u_p}, \frac{1}{\sum_{p=1}^{n} m_p}, \frac{1}{\sum_{p=1}^{n} l_p} \quad (5)$$

The degree of possibility (P^o) is determined according to the synthesized values in the defuzzification process with (6) as follows:

$$P^o\,(C_2 \geq C_1) = \frac{l_1 - U_2}{(m_2 - u_2) - (m_1 - l_1)} \quad (6)$$

Some defuzzification values are shown in Table 11. Table 12 shows the ranking of criteria and sub-criteria based on weight values. Finally, the global ranking for alternatives is calculated by multiply criteria and sub-criteria vector weight with alternatives assessment results. Table 13 shows the final ranking of alternatives PV design.

TABLE X
THE SYNTHESIZED VALUES OF CRITERIA

Criteria	Value		
	l	*m*	*u*
Sizing	0.14	0.20	0.30
Technical	0.19	0.30	0.47
Economic	0.17	0.27	0.43
Environment	0.15	0.22	0.34

TABLE XI
DEGREE OF POSSIBILITY AND DEFUZZIFICATION VALUES

Condition	^oP	Defuzzification Value
$C_1 \geq C_2$	0.50	
$C_1 \geq C_3$	0.63	0,50
$C_1 \geq C_4$	0.87	
$C_2 \geq C_1$	1.44	
$C_2 \geq C_3$	1.11	1,00
$C_2 \geq C_4$	1.32	
$C_3 \geq C_1$	1.33	
$C_3 \geq C_2$	0.89	0,89
$C_3 \geq C_3$	1.22	
$C_4 \geq C_1$	1.13	0,65
$C_4 \geq C_2$	0.65	
$C_4 \geq C_3$	0.77	

TABLE XII
WEIGHT OF CRITERIA AND SUB-CRITERIA

Criteria	Weight of criteria	Sub-criteria	Weight of sub-criteria
Technical	0,32	Performance ratio	0,37
		Energy supplied to load	0,24
		Total energy produced	0,19
		Grid feed-in	0,18
Economic	0,29	Cost of energy	0,50
		Life cycle cost	0,50
Environmental	0,21	CO_2 reduction	0,21
Sizing	0,16	PV type	0,24
		Amount of PV needed	0,23
		PV price	0,18
		Covered area	0,17
		PV weight	0,16

TABLE XIII
FINAL RANKING OF ALTERNATIVES PV DESIGN
(See in Table 10 below this article)

The results of the developed algorithm calculation are compared with conventional AHP to validate the result. Both the developed algorithm and the conventional AHP present the same final ranking, but the results of the developed algorithm present more consistent results than conventional AHP in two different installations. The developed algorithm's results are more consistent because it uses TFN involving lower, middle, and upper value. Conventional AHP only depends on a single number scale for calculation.

Alternative II has the highest ranking with various advantages than others. Even though the m-si PV type relatively cheap than another alternative, m-si PV type has the highest performance ratio (PR) of 76 %. Because of cheaper price and high PR, m-si PV type has a cheaper cost of energy (COE) relatively. The m-si PV type also needs less space in rooftop installation than other types. It has a temperature coefficient of -0.23 %/^{o}C [37], a higher coefficient compared to other PV types. The temperature coefficient becomes an advantage because PV system will be implemented in a tropical area that has a hotter temperature.

V. Assessment and Evaluation of the Designed Distributed Generation System in HOMER Simulation

The best PV alternative design is combined with battery storage and diesel generator to be evaluated in HOMER as shown in Fig. 7.

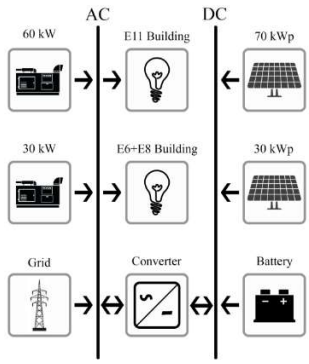

Fig. 7. Simulation diagram in HOMER

HOMER makes an assessment based on techno-economic parameters to investigate the design feasibility when operate in grid-connected and micro-grid mode. HOMER simulation takes a 25-year based project life. In order to anticipate cash flow fluctuating over time, a 3,32 % discount rate [50] and a 5,50 % inflation rate [51] are taken based on the discount rate and inflation rate in the site project.

This section will discuss about the feasibility of the designed DG system according to specified parameters. Economic parameters are analyzed to obtain the costs of the designed DG system. Energy production and consumption characteristics show the performance of the designed DG to supply load demand in the site project. The total emissions produced are presented in this section.

V.1 Electrical Results

Based on the HOMER simulation, the designed DG is capable to supply the load demand in the site project. Fig. 8 and Fig. 9 show the monthly energy produced by the designed DG system. Fig. 8 and Fig. 9 show that the designed DG can optimize the installed PV performance in the site project. The PV system can produce up to 128 MW/year or 79% from total annual energy production. This system only needs 29 MW/year or 18% from grid purchase and diesel generator only produces 3% from annual energy production.

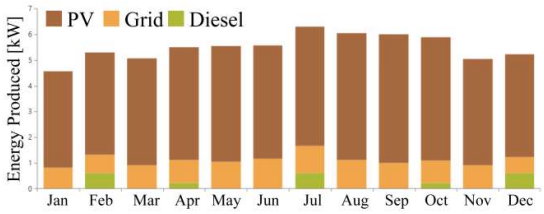

Fig. 8. Monthly electric production in E6+E8 buildings

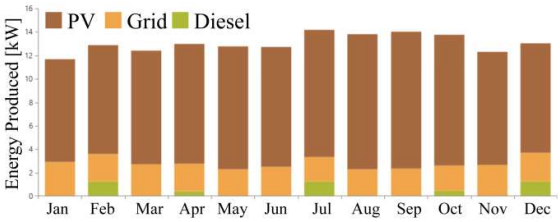

Fig. 9. Monthly electric production in E11 building

Based on the simulation results, DG system performance characteristics depend on the solar GHI level in the simulation time series. Fig. 10 shows the performance of the designed DG on grid-connected mode and low GHI level. From Fig. 10 it can be observed that when the solar GHI level is low, PV system cannot work optimally, so the load demand supplied by a grid in major. However, when the solar GHI level is high (Fig. 11 at 10.00 until 13.00 in time simulation series), PV system can work optimally to supply the load demand as shown in Fig. 11. The excess energy produced by PV system will be stored in battery storage and inject into the grid.

At a blackout condition, the designed DG operates in micro-grid mode. At low solar GHI level, PV system cannot work optimally, so diesel generator will backup DG system as the main supplier to load demand as shown in Fig. 12. When the energy produced from diesel generator is insufficient, the energy stored in batteries will cover the lack of energy needed, as shown in Fig. 13(b) (Fig. 12.b at 10.00 until 12.00 in time simulation series).

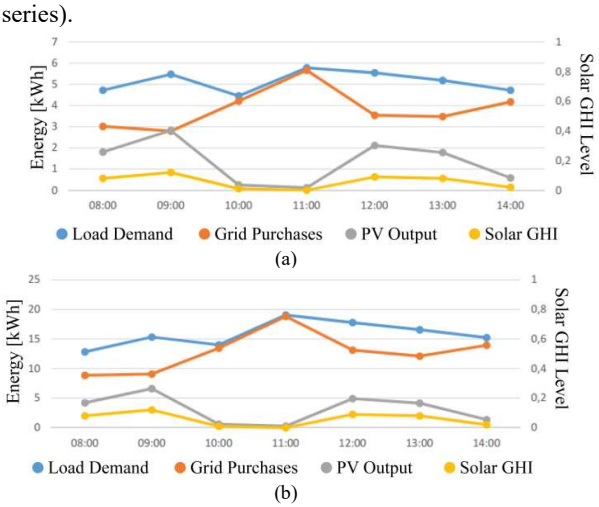

Fig. 10. Performance of designed DG on grid-connected mode and low solar GHI level: a) E6+E8 buildings, b) E11 building

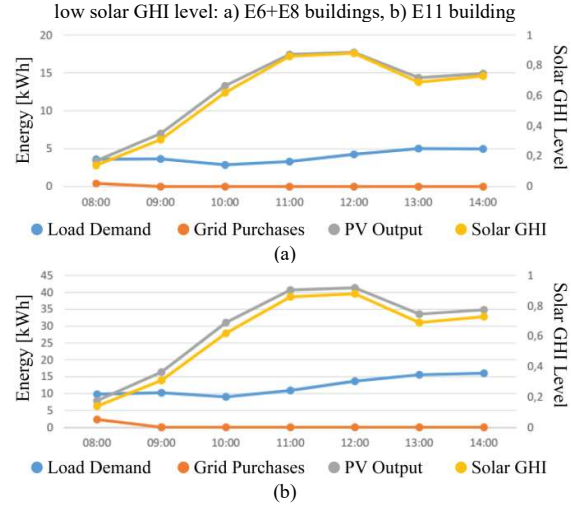

Fig. 11. Performance of designed DG in grid-connected mode and high solar GHI level: a) E6+E8 buildings, b) E11 building

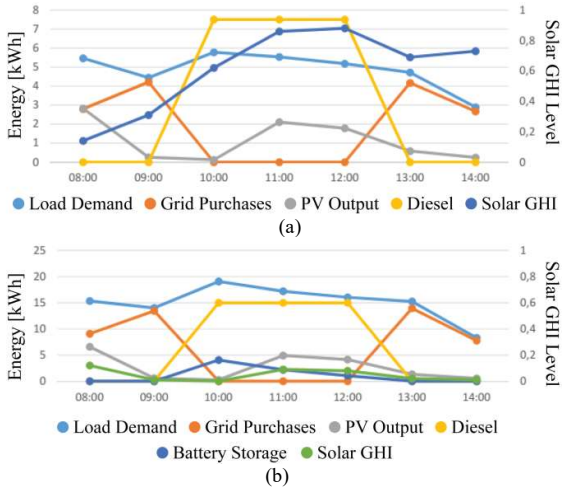

Fig. 12. Performance of designed DG in micro-grid mode and low solar GHI level: a) E6+E8 buildings, b) E11 building

At high solar GHI level, the characteristic of designed DG when operating in a micro-grid mode shows in Fig. 13 almost the same with a grid-connected mode in Fig. 11. The PV system can supply the load demand alone and produce excess energy. Excess energy is also stored in battery storage and inject to the grid.

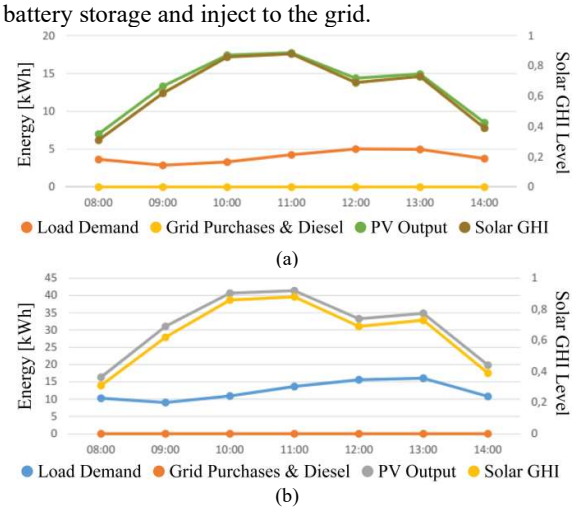

Fig. 13. Performance of designed DG in micro-grid mode and high GHI level: a) E6+E8 buildings, b) E11 building

V.2 Economic Parameter Results

This section discusses about the cost summary of designed DG as presents in Fig. 14. From the cost summary, it can be calculated net present cost (NPC), annualized cost, and cost of energy (COE) of the designed DG system.

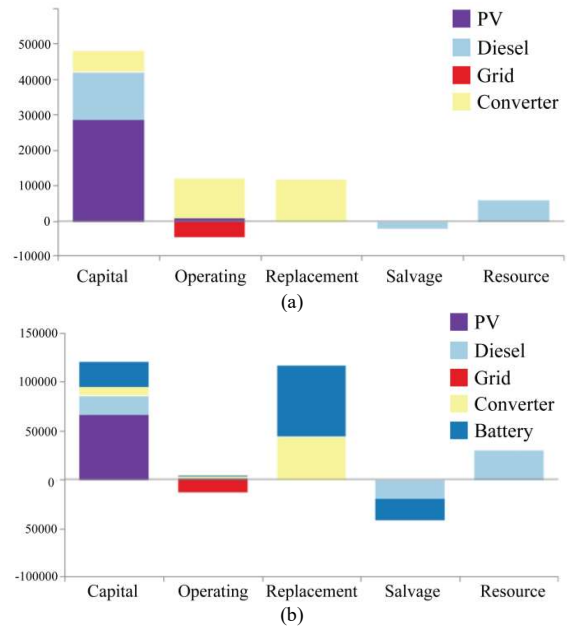

Fig. 14. Cost summary of designed DG: a) E6+E8 buildings, b) E11 building

NPC can be calculated from total present values of all the costs until over its lifetime, minus the present value of all the revenue earned during the lifetime. From Fig. 14 it can be seen that the NPC of the designed DG is $291.073,43.

The annualized cost of each component that equally in each year of the project lifetime, would give the same NPC as the actual cash flow sequence of each component as shown in Fig. 15. From NPC that has been calculated before, affected by a 3,32 % discount rate and a 5,50 % inflation rate, the annual costs for designing the DG system is $12.232.

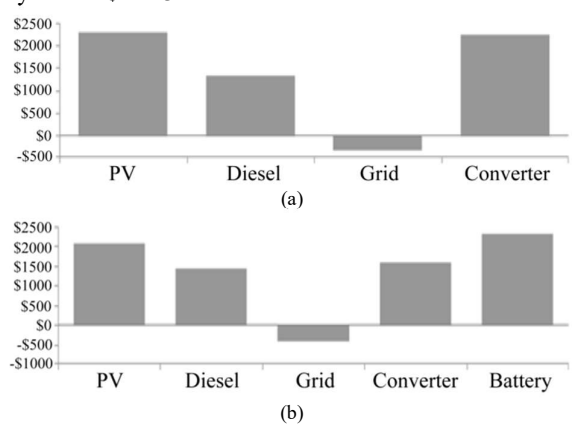

Fig. 15. Annualized cost based on components: a) E6+E8 buildings and b) E11 building

COE of the designed DG system is needed to be compared with the grid tariff from existing regulation. COE can be obtained from the annualized cost of producing energy divided by total load served. The designed DG has COE of 0,12 $/kWh and 0,06 $/kWh for the E6+E8 building system and E11 building system

respectively. COE of the E11 building system is relatively cheaper than the grid tariff. A storage system can reduce high peak demand and improve the quality of the power system [39]. However, the COE of the E6+E8 building system seems more a little expensive than the grid tariff. The DG system has also allowed the excess energy to inject to the grid with a sellback tariff of 0,047 $/kWh. As shown in Fig. 7 and Fig. 8, designed DG system can sell 66.024 kWh/year to the grid. Therefore, the DG system can earn 3.103,12 $/year or 258,59 $/month from energy injected to the grid.

V.3 Pollutants Produced

The two diesel generators used in the designed DG have consumed 81,64 liters/year of fuel for producing 5.040 kWh/year. Most pollutants are sourced from fuel consumption of diesel generators. Table 14 shows the total pollutants produced by the designed DG system.

TABLE XIV
POLLUTANTS PRODUCED BY DESIGNED DG SYSTEM

Pollutant	Quantity (kg/year)
Carbon dioxide	23.856,00
Carbon monoxide	33,30
Unburned hydrocarbon	1,47
Particular matter	0,20
Sulfur dioxide	93,30
Nitrogen oxides	70,60

VI. Conclusion

Intelligence-based design with a new variant modified AHP with fuzzy logic and assessment of PV-battery and diesel generator for DG in the campus area has been carried out in this paper. The DG system that can operate in grid-connected and micro-grid mode in area campus has the mono-crystalline PV alternative design as the most feasible design for implemented in the site project. The designed DG consists of PV system, battery storage, and diesel generator for backup when blackout occurs. From the assessment by HOMER software, the results show the feasibility of the designed DG is competitive and feasible. From the total energy produced in a year, the PV system can produce 128 MW/year or 79% and diesel generator produces 3% from annual energy production. It means that the designed DG only needs about 29 MW/year or about 18% from grid purchases. The DG system is successful in running without relying on energy from the grid. The designed DG can operate on grid-connected and micro-grid mode in low and high solar GHI level properly. The total cost of the 25-years project life is $291.073,43. Then, the cost of energy is $0,12 for E6+E8 buildings and $0,06 for E11 building system. Most of the pollutants are produced from fuel consumption.

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TABLE II
ALTERNATIVES PV DESIGN FOR 30 KWP E6+E8 BUILDINGS INSTALLATION

Alternative	PV type	Amount of PV needed	PV weight	PV price	Covered area	PR	Energy supplied to load		Energy produced in 25 years	Grid feed-in	Initial cost	Life cycle cost	Cost of energy	CO_2 reduction
							PV	Grid						
		unit	kg	$	m^2	%	%		MWh	%	$	$	$	kg/year
I	Poly	124	2.394	243	205,0	71,2	74,8	23,9	942,9	37,9	82.718	114.865	0,10	35,9
II	Mono	90	1.674	320	146,7	75,9	75,9	23,4	1.032,2	37,8	70.168	98.108	0,08	37,4
III	CIS	180	3.600	162	221,1	75,3	75,3	24,3	1.005,1	37,6	101.427	136.095	0,12	36,7
IV	HIT	124	1.890	239	158,9	72,3	74,6	25,1	951,8	37,0	74.172	104.302	0,09	34,9
V	CdTe	75	2.700	445	185,6	74,8	75,5	24,1	982,6	37,4	92.211	125.001	0,11	36,2

TABLE III
ALTERNATIVES PV DESIGN FOR 70 KWP E11 BUILDING INSTALLATION

Alternative	PV type	Amount of PV needed	PV weight	PV price	Covered area	PR	Energy supplied to load			Energy produced in 25 years	Grid feed-in	Initial cost	Life cycle cost	Cost of energy	CO_2 reduction
							PV	Grid	Storage						
		unit	kg	$	m^2	%	%			MWh	%	$	$	$	kg/year
I	Poly	294	5.586	243	53,25	71,1	72,5	12,1	15,4	93.439	42,5	220.341	263.916	0,12	80.552
II	Mono	210	3.906	320	38,03	76,0	74,1	11,2	14,7	100.784	46,2	188.243	231.497	0,09	86.967
III	CIS	420	8.400	162	57,40	74,3	72,7	12,2	15,1	95.745	44,0	261.180	305.163	0,13	82.570
IV	HIT	294	4.410	239	41,16	71,5	71,8	12,8	15,4	92.313	42,3	200.078	243.450	0,11	79.572
V	CdTe	175	6.300	445	48,22	74,2	72,6	12,2	15,1	95.587	43,9	239.677	283.445	0,12	82.433

TABLE IX
TRIANGULAR FUZZY NUMBER FORM OF EXPERT'S ASSESSMENT IN PAIR-WISE COMPARISON MATRIX

Criteria	(C_1)			(C_2)			(C_3)			(C_4)		
	l	*m*	*u*	*L*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*
(C_1)	1.00	1.00	1.00	0.48	0.62	0.82	0.52	0.75	0.99	0.77	0.96	1.19
(C_2)	1.22	1.61	2.08	1.00	1.00	1.00	0.93	1.30	1.72	0.83	1.09	1.46
(C_3)	0.91	1.30	1.69	0.61	0.83	1.19	1.00	1.00	1.00	1.03	1.39	1.79
(C_4)	0.84	1.05	1.31	0.67	0.89	1.15	0.59	0.77	1.07	1.00	1.00	1.00

TABLE XIII
FINAL RANKING OF ALTERNATIVES PV DESIGN

Alternative	Final Score				Ranking
	E6+E8 Buildings		E11 Building		
	Developed algorithm	Conventional AHP	Developed algorithm	Conventional AHP	
II (m-si)	0,226	0,262	0,226	0,263	1st
V (CdTe)	0,203	0,209	0,203	0,206	2nd
III (CIS)	0,195	0,193	0,195	0,194	3rd
IV (HIT)	0,198	0,202	0,189	0,190	4th
I (p-si)	0,178	0,134	0,187	0,148	5th

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