PAPER • OPEN ACCESS

An energy management system employing Direct Supply Strategy for the hybrid cogeneration application

To cite this article: Normazlina Mat Isa *et al* 2021 *J. Phys.: Conf. Ser.* **1878** 012029

View the article online for updates and enhancements.

An energy management system employing Direct Supply Strategy for the hybrid cogeneration application

Normazlina Mat Isa[1], Shafura Shariff[2], Tan Chee Wei[3]

[1]Politeknik Tun Syed Nasir, Hab Pendidikan Tinggi Pagoh, KM1 Jalan Panchor, 84600 Pagoh, Johor
[2]Politeknik Merliimau, KB 1031, Pejabat Pos Merlimau, 77300 Melaka
[3]School of Electrical Engineering, Faculti of Engineering, Universiti Teknologi Malaysia, 81310 Skudai, Johor

Email: mzzlina@gmail.com

Abstract. Cogeneration needs an efficient energy management system to ensure their components able to work with minimum cost and at the same time have the maximum efficient. Due to that, the planning on the energy operation is important part whereas the study on energy management system has been discussed widely. Hence, this article presents the Direct Supply Strategy (DiSS) with the application of Harmony Search Algorithms (HSA) to cater the energy management system optimization issue for hybrid FC-PV cogeneration. The component of hybrid FC-PV is including PEMFC, photovoltaic integrated with battery storage to meet a demand from the medical block in Hospital Temerloh. The recognized input parameters needed in the simulation is solved in MATLAB environment whereby the finding from the HSA is then benchmarked with the Genetic Algorithms in order to observe the efficiency of proposed HSA to solve the DiSS. In addition, the proposed operation mode of DiSS also presented. As a results, the total profits obtained from this strategy were estimated to be RM167 per day or RM6095.50 per year.

Keywords: Direct Supply Strategy, cogeneration, fuel cell, photovoltaic, optimization

1. Introduction

Nowadays, microgrid can be formed in several types either in grid connected or isolated[1]. Cogeneration with the combination of conventional fuel cell and renewable energy seems to be the famous topology which can results better efficiency to the community [2]. However, the developed cogeneration in the microgrid should have a good energy management system that can ensure the successfulness of the energy flow in the cogeneration. Energy Management System (EMS) is a computer-aided tool integrated with electrical grids that functioning to monitor, control and optimize the performance of the generation, transmission and distribution[3]. It is usually located at the tertiary level and plays a role as a supervisor to control the microgrid operation based on the outlined criteria. The EMS is comprised of several elements such as forecasting unit, optimization, data interface and human-machine interface whereas the EMS can be implemented in both centralized and decentralized control system. In centralized control, the management of the microgrid is performed by a central controller located at the global control level, known as Microgrid Central Control (MGCC). Normally, MGCC is ready in the microgrid to interface with the Distributed Management System (DMS), therefore the definition of centralization or decentralization is based on the location of the MGCC[4][5]. The decentralized control is ideal for implementation in a microgrid with different

suppliers, as there are needs to make a separate decision regarding the individual situation, besides requiring some microgrids to function as an intelligent control unit. Detail discussions of both control types can be found in [4], while works related to both centralized and decentralized control system can be found in [6]–[8]. Several operation strategies have proposed in many study in order to execute the best profitable microgrid as well as to reduce the lack of system efficiency. Due to this situation, this current paper presents the Direct Supply Strategy (DiSS) as an energy management system for the hybrid FC-PV cogeneration system. This study that obtain the meaningful findings in the simulation result is believed can reduce the energy bill of the selected building in the case study. The presented paper is structured into five section which is started with introduction followed by the system description in section 2. Then, a proposed operation strategy is presented in Section 3 while their results discussion and conclusion were described in Section 4 and 5, respectively.

2. System description

Figure 1 shows proposed system which consists of the hybrid FC-PV cogeneration with a battery to satisfy the load demand from a medical block at Hospital Temerloh. The chosen fuel cell in this study was a Proton Exchange Membrane Fuel Cell (PEMFC) type with a rated capacity of 10 kW, as it was supposed to meet both electricity and heat demands throughout the day. In order to obtain the benefits of solar technology, the PV generator has been combined into the system. As the output power from the PV generator fluctuates in nature, energy storage is needed to support during low power generation. The mathematical modelling for each component in the system is presented in the following section.
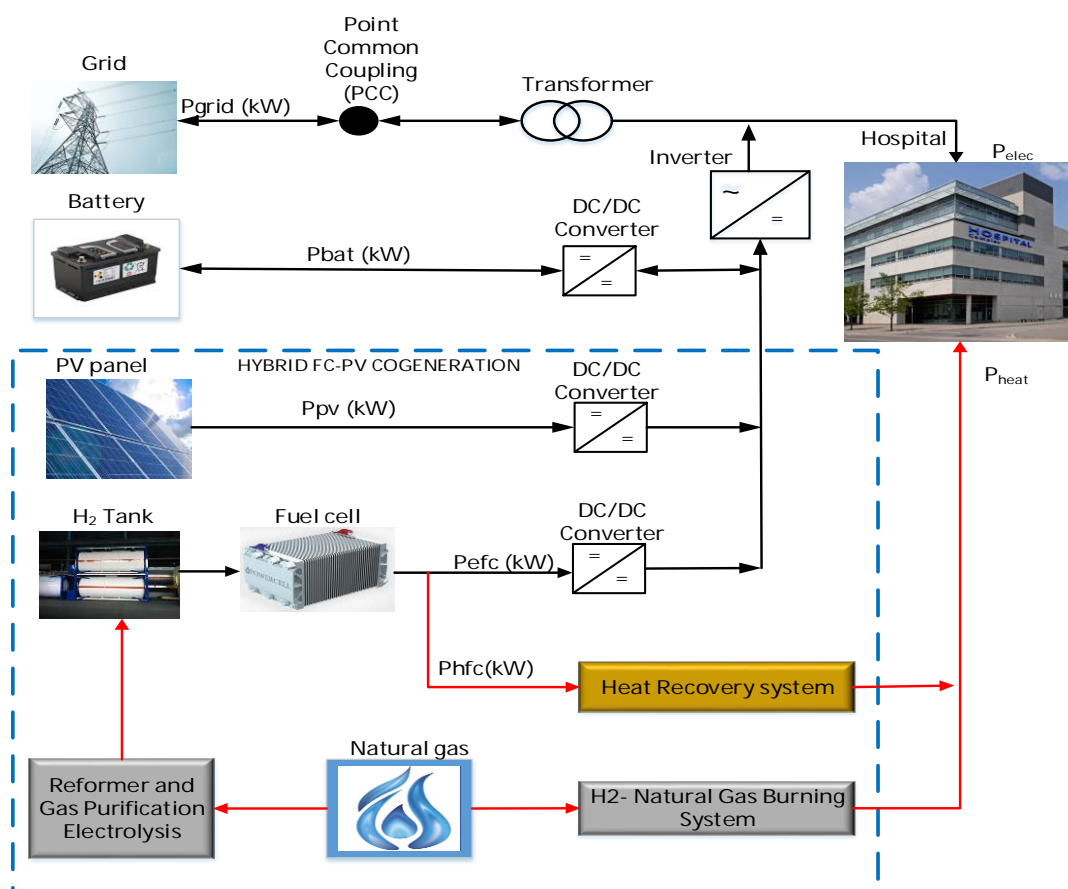
Figure 1. A model of hybrid cogeneration system

2.1 Mathematical modelling of hybrid cogeneration components

i. Photovoltaic System

Photovoltaic panel is used to transform the solar energy into an electric power. A photovoltaic generator typically consists of an array of semiconductor p-n junctions, which are connected in series or parallel to generate a certain amount of current and voltage. The PV system performance generally depends on the irradiance and temperature. For this purpose, the PV system's mathematical model is necessary to obtain power from the PV system. In this study, the PV generated power were determined from equation (1).

$$P_{PV}(t) = A_{PV} * R(t) * \eta_{pv}$$

$$(1)$$

Where A_{pv} is an area of PV panel, R is solar radiation at time t and η_{pv} is efficiency of PV panel. The PV panel efficiency (η_{pv}) was obtained from the PV panel specification provided by the manufacturer. The power generated from the PV module was considered as being injected into the main grid. The patterns of solar irradiance observed at the chosen locations were almost identical. One-day data were, therefore, known to have a constant 24-hour of solar data radiation. The tilt angle of the installation of the PV panel was believed to be constant for the whole year. This study utilize MLE280HD2 PV solar panel module by Mitsubishi to develop an array of PV systems. The panel is made of 120 monocrystalline-silicon cells connected with a peak power of 280 (Wp) in series. The electrical and mechanical specifications of this PV panel, were listed in Table 1.

Table 1   Electrical and mechanical specifications of MLE280HD2 solar panel

Electrical Specification	Rating	Unit
Maximum power rating,(P_{max})	280	W
Number of cells	120	Pcs
Maximum power voltage (V_{mp})	32.4	V
Maximum power current (I_{mp})	8.68	A
Short circuit current (I_{sc})	9.37	A
Open circuit voltage (V_{oc})	38.6	V
Module efficiency	16.9	%
Mechanical Specification		
Dimension	1,625 mm $\times$ 1,019 mm $\times$ 46 mm	(mm)^2
Weight	20	kg

ii. Proton Exchange Membrane Fuel Cell System

In this study, the Ballard Mark V PEMFC stack was selected as their dynamic model is referred to the article [9]. This type of fuel cell consists of 35 cells stacked together; at 960 mA / cm2, it achieves 5 kW of power. The PEMFC dynamic model was built in MATLAB software, and the well-known Nernst equation was used to calculate the output voltage produced from the stack of fuel cells. Calculation of the power generated from the fuel cell was using equation (2), in which P_{FC} is power generated by the FC, I_{FC} represents a fuel cell current and V_{FC} specifies FC voltage. The parameters used in the mathematical model of the FC were tabulated in Table 2 [9]. The output power of the modelled PEMFC system was 100 kW, the nominal voltage at the fuel stack terminal was 333,8 V and the current demand was 300 A.

$$P_{FC} = I_{FC} \times V_{FC}$$

$$(2)$$

Table 2 Parameters used for PEMFC model in simulation [9]

Parameter	Value	Unit
Number of the series–wound fuel cells in the stack, N	35	
Temperature, T	343	K
Cell active area, A_{FC}	50.6	cm^2
Membrane thickness, tm	178	µm
Gas constant, G	831,447	(I/kmol/K)
Faraday's constant, F	964,645	(C/mol)
Limiting current, I_{LM}	1.5	A/cm^2

iii. Battery Energy Storage System

The selected lead-acid model in this study was RM12-75DC, following the manufacturer's technical specification as specified in [10]. The nominal voltage and capacity values of the battery were 12 V and 75 Ah (20 hours), respectively. The battery's modelling is done based on the Shepherd Model [11]. The battery source terminal, as in equation (3) [12][13] was obtained from the Peukert's equation:

$$V_T = V_{OC} - R_i - \left(K_i \times \frac{1}{SOC_i - DOD} \right) \tag{3}$$

where V_{OC} is battery open circuit voltage, R_i is an internal resistance in ohm, K_i denotes polarization coefficient, SOC_i indicates initial state of charge, and DOD represents depth of discharge which calculated using equation (4):

$$DOD = \frac{1}{Q_{max}} \int i\, dt \tag{4}$$

where Q_{max} is the maximum available capacity of the battery storage.

2.2 A development of energy management system module

The block diagram shows in Figure 2 depicted the methodology, which began with gathering input data such as selected building load profile, location solar radiation, and electricity prices. All the data required were obtained from the responsible party including the Hospital Temerloh Engineering Department and Tenaga Nasional Berhad (TNB) to ensure data validity. The proposed EMS was conceived using an optimization approach to solve the operation issues in the hybrid FC-PV cogeneration. Harmony Search Algorithm (HSA) is used to solve the optimization problems in the EMS.
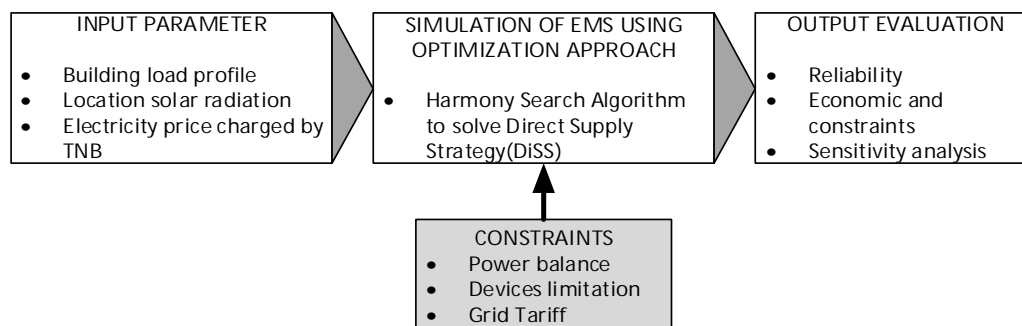
Figure 2. Overview of the EMS development framework

## 2.3 Input parameters for Energy Management System Module

In this study, the input parameters were the load profile of selected buildings, solar radiation and electricity prices were described.

i. Hospital load profile

Hospital Temerloh which located at the longitude of 102°45' East and latitude of 3°45' North was chosen as a case study. The hospital has the medical blocks comprise of 24 wards, with 650 beds in total. In addition, the hospital has a kitchen, canteen, and public area. For the purposes of simulation and analysis, the medical block's average data of one-day load consumption were collected whereas the Hospital Temerloh's thermal and electricity data for year 2012, 2013 and 2014 is shown in Figure 3. According to Figure 3, from year 2012 to 2014, the hospital's total electricity consumption was projected to be between 18 MW and 20 MW, while heat energy was expected to be around 17 MW to 23 MW. Furthermore, the power consumption was calculated using equation (5).

$$P_{Le}(t) = I(t)V(t)\cos\theta \qquad (5)$$

where P_{Le} is electrical power, $I(t)$ is current data for 24 hours (provided by TNB), $V(t)$ is equal to 415V and $\cos\theta$ is 0.8.
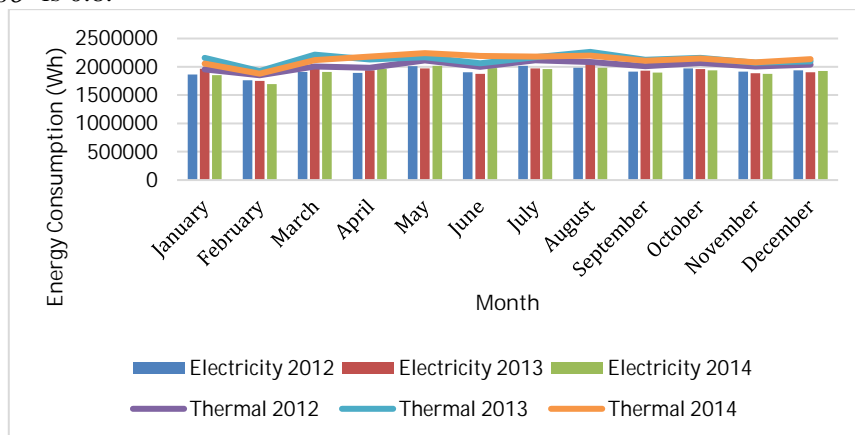

Figure 3. Hospital's monthly energy and heat consumption pattern in three years time

The average energy profile for medical block's one-day consumption is shown in Figure 4, where it shows that the hospital's thermal consumption was more than the usage of electricity, attributed to HVAC load operation. The electricity consumption (PL$_{elect}$) from 8 a.m. to 8 p.m. ranged from 0.7 MW to 0.9 MW, while the thermal consumption (PL$_{therm}$) ranged from 0.8 MW to 1.15 MW from 6 a.m. to 8 p.m., respectively. This indicates a steady increase in energy consumption from 8 a.m. to 8 P.M. because during this time frame, important activities were carried out. Moreover, the Hospital Temerloh's energy bill was shown in Figure 5, where the electricity charge was at a cost of RM 0.312 per kWh in year 2012 and 2013. In year 2012 and 2013, the overall amount of energy bills was RM 9,000,923, and RM 8,387,773, respectively. In the year 2014, the energy bill rose to RM 9,766,380 due to the increase in electricity charge to RM 0,365 per kWh. The energy bill is expected to rise annually due to increased fuel costs and lack of subsidies in Malaysia. Therefore, the proposed EMS in the current study is believed can support the reduction of energy bill of the Hospital Temerloh.
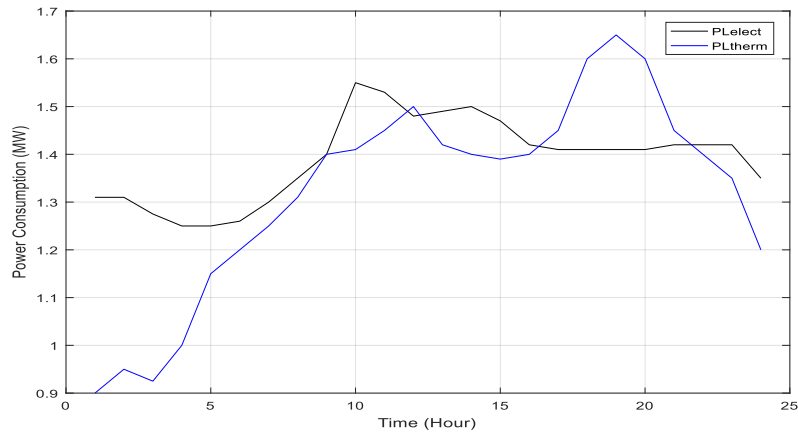
Figure 4. Medical block's hourly electricity and heat load consumption patterns
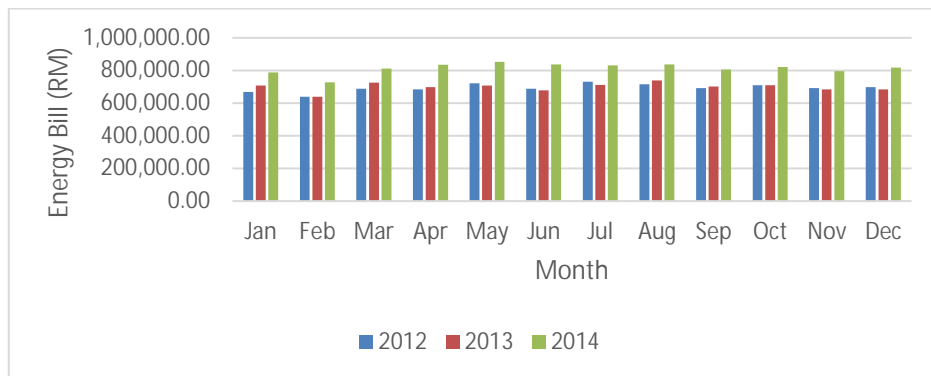

Figure 5. Energy Consumption and Energy Bill of Hospital Temerloh

ii. Solar radiation and temperature at hospital location

In this study, solar radiation and temperature data for the location of Hospital Temerloh was obtained from the website of NASA Surface Meteorology [14]. NASA has created a longitude grid map. Solar radiation data were collected from terrestrial cloud-cover's satellite-based scans. It should be noted that NASA data were available on a monthly-mean basis. As for this study, the available data were on average for each hour in each month of 2014 to 2016. The data were collected in a location at 3°45' North latitude (boundary between -2° and 3°) and 102°45' East longitude (boundary between 102° and 103°). Figure 6 (a) and (b) show the solar radiation pattern at the hospital location.
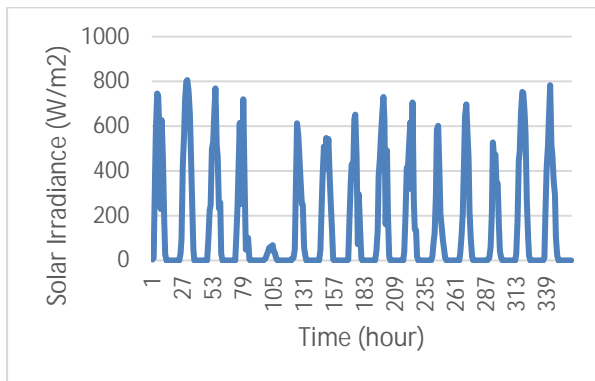
(a)
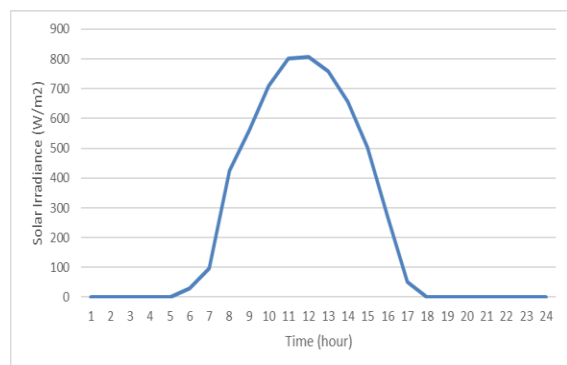
(b)

Figure 6.Solar irradiance profile for Hospital Temerloh location (a) Solar radiation data for 6 June 2014 to 20 June 2014 at the hospital location (b) Pattern of average solar radiance for 24 hours

iii. Electricity tariff

The electricity tariff used in this study complied with the tariff schedule established by TNB as the foremost authority. The hospital is charged RM 0.36 per kWh for a tariff rate of C2.

3.Proposed Operation Strategy

Figure 7 displays the proposed Energy Flow Model (EFM), which reflects a hybrid cogeneration system's operational strategy. The goal of the EFM is to meet the demand for loads at all times as well as to minimize the cost for electricity and maximize the benefit from hybrid cogeneration. In this case, Direct Supply Strategy (DiSS) has been proposed to cater the energy flow in the hybrid cogeneration system. The description of DiSS will be described in the following section.
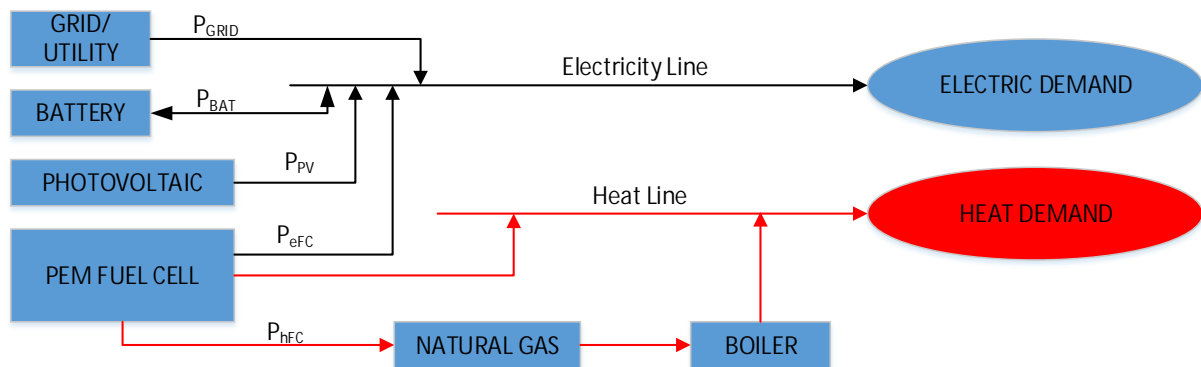

Figure 7. Proposed energy model for hybrid cogeneration operation

3.1 Direct Supply Strategy (DiSS)

Direct Supply Strategy (DiSS) is inspired by research in [15], which the strategy employed determination rule to operate the microgrid. In this strategy, only at night will the battery be charged by the grid. The plan sought to generate the maximum energy production from the PEMFC and PV, and will at the same time reduce the hospital's energy bill. This can be achieved as the load was completely dependent on the component of the hybrid cogeneration, thus, energy purchases from TNB can be minimized. This technique could, therefore, help to reduce the building's energy bill. Figure 8 displays the activity of the proposed strategy. There are two proposed operation mode, namely Night Mode (NM) and Day Mode (DM). In this strategy, the mode operation is classified according to the solar availability. DM is running from 7 a.m. until 7.00 p.m. followed by NM operation from 7.00 p.m. until 7.00 a.m on the next day. It will guarantee zero grid power supply. The battery will be discharged during the operation of DM if there is a lack of power during the day, while the fuel cell is operated in NM mode to supply the charge. The battery is charged by the grid in NM. In this respect, as they can sell more excess power to the grid, the maximum power generation from the PV panel will give the building owners more financial gains. Tilt angle and orientation of the PV panel has a crucial role to play in optimizing the PV panel's harvested solar radiation. Therefore, maximizing the radiation would boost the power generation. Using equation (6), the amount of excess energy when the PV power is higher than the power load level can be estimated:

$$P_{exx} = P_{PV}(t) - P_{load}(t) \qquad\qquad (6)$$

Where P_{exx} is excess power generated by a PV panel. The profit from the selling power to the grid can be calculated from equation (7):

$$B_{profit} = EP(t + nk) \times P_{exx}$$

(7)

However, if the power of the PV is less than the power load, the requirement will be met by the fuel cell or battery. The battery is also used as a substitute if the system loses power. In this case, the discharge of battery power is measured according to $SOC(t) \geq SOC_{max}$. The benefits derived from power trading can be analyzed on the basis of this proposed strategy.

3.2 *Harmony Search Algorithm*

In the proposed strategy DiSS, the objective function outlined is to optimize the extracted solar radiation in order to increase the production of PV. Hence, the objective function is described as in equation (8):

$$\max \sum Rad(\beta_a, \gamma_a)$$

(8)

Where Rad is solar radiation, β_a is tilt angles and γ_a is azimuth angle. The constraints that should be taken into account are written in equations (9) and (10):

$$\beta_{a\min} \leq \beta_a \leq \beta_{a\max}$$

(9)

$$\gamma_{a\min} \leq \gamma_a \leq \gamma_{a\max}$$

(10)

In this problem, the values of $\beta_{a_{min}}$, $\beta_{a_{max}}$, $\gamma_{a_{min}}$ and $\gamma_{a_{max}}$ are set to 0º, 90º, 0º and 360º, respectively. This optimization problem is solved using HSA which the HSA algorithm parameters that required in the simulation were set as listed in the following points:

- harmony memory size (number of solution vectors in harmony memory, HMS) = 6,
- harmony memory considering rate (HMCR) = 0.9,
- pitch adjusting rate (PAR) = (0.4, 0.9),
- termination criterion (maximum number of searches) = 2000.
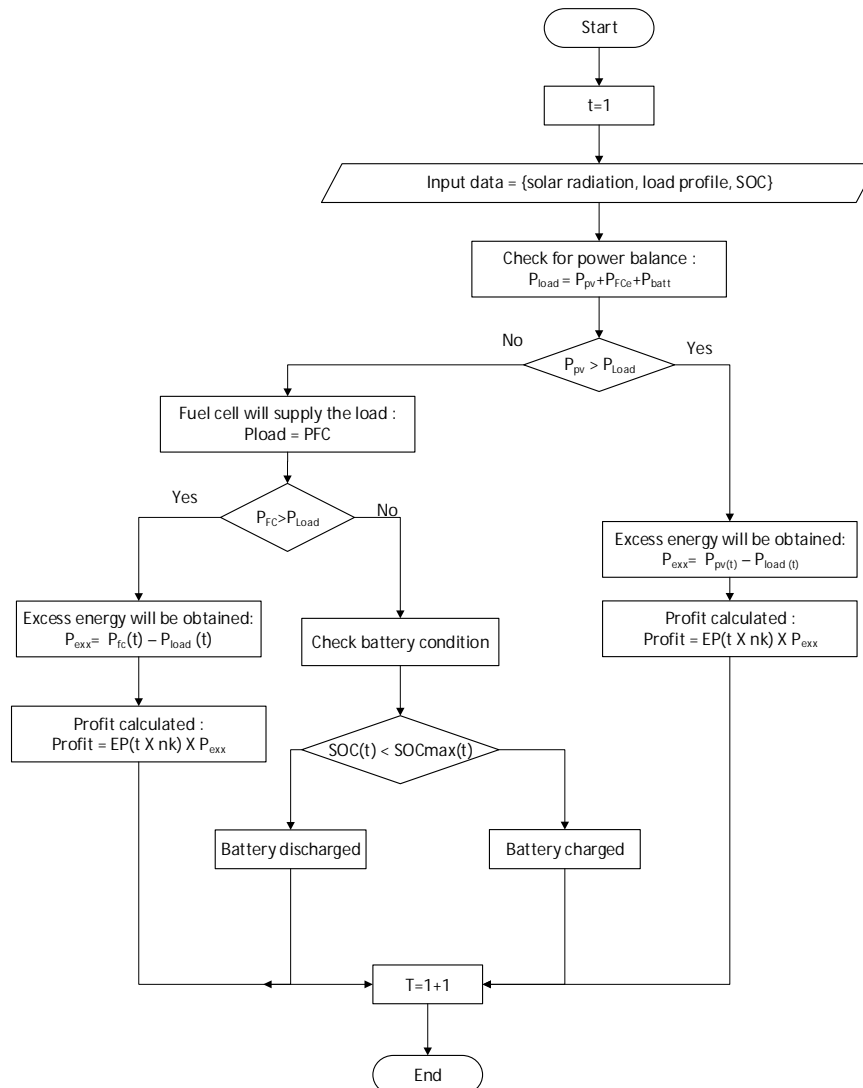
Figure 8. Operation mode of the proposed Direct Supply Strategy

4. Results and discussions

In this problem, the values of β_{min}, β_{max}, $\gamma_{1_{min}}$ and $\gamma_{1_{max}}$ were set to 0º, 90º, 0º and 360º, respectively. The optimization problem was solved using HSA whereas the optimal tilt angle given by the optimization simulation process was 5.15º, and the convergence of the HSA was obtained at 90th iteration compared to GA at 168th iteration. As shown in Figure 9, it was proven that the optimization simulation using HSA have faster convergence compared to GA. In addition, the power generated from the optimized tilt angle and the setting value had also been compared. The tilt angle was set to be 10º and 15º, at facing south direction. The radiation data for the optimized tilt angle and the set tilt angle were obtained from the *Meteornorm 7.11* software. Furthermore, the solar irradiance obtained from the optimized values of tilt angles had been plotted, as shown in Figure 10. In addition, the optimized and maximum irradiance gain maximum power from the PV panel which results to increment in the profits generated from the excess PV power.
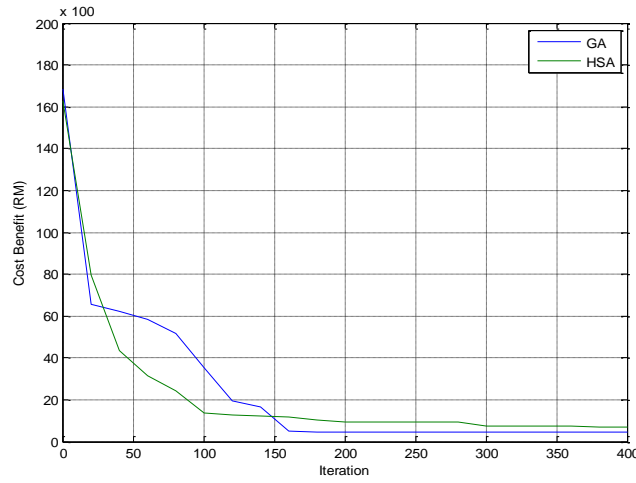
Figure 9. Simulation results for comparison of HSA and GA
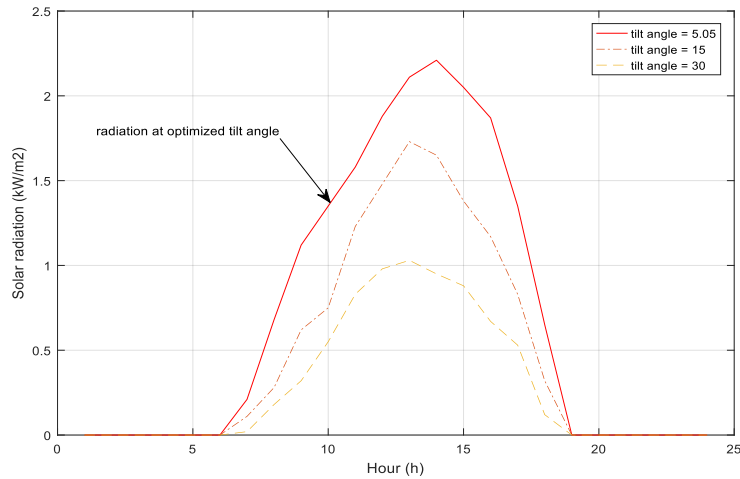
Figure 10. Solar radiation of optimal tilt angle compared to other tilt angle
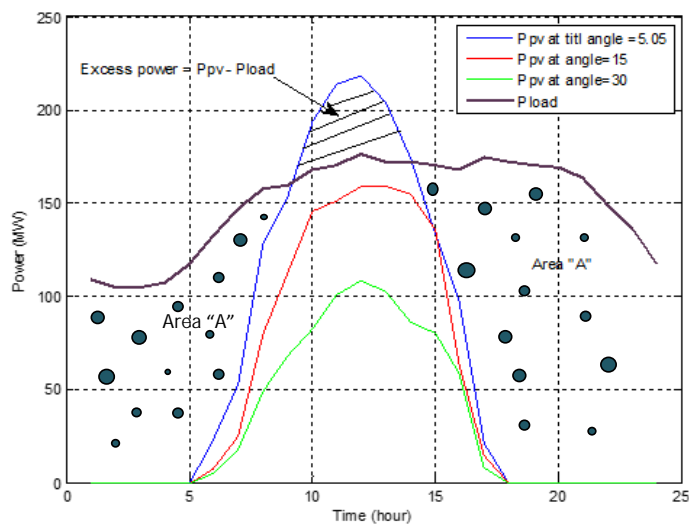
Figure 11. PV power generated at the optimal tilt angle

According to Figure 11, there was excess power from PV generation at the time of 9 a.m to 13 p.m, as the PV panel generated excess load demand, at an optimum title angle of 5.05 degrees. The demand in area "A" was catered by the fuel cell at its constant output. According to the operation strategy, discussed in Section 3.1, there were two modes of operation, namely Night Mode (NM) and Day Mode (DM), which operation mode was classified based on solar availability. DM operation started from 7.00 a.m. until 7.00 pm while NM operation started from 7.00 p. m until 7.00 a.m. Area "A" represented the operation of PEMFC to supply the load at night, while the battery was charged at this time. The tilt angle and orientation of the PV panel played an essential role in order to maximize the solar radiation collected by the PV panel. In this strategy, the optimized tilt angle will provide maximum power generation from the PV panel, and this situation will give more financial profits to the building owner as they can sell more excess power to the grid. Hence, during the hours of excess energy at 9 to 13, there were profits obtained from the PV generation. The profits (R_{profit}) from the PV excess power can be calculated using equation (11) [16]:

$$R_{profit} = (P_{pv}(i) - P_{le}(i)) \times S_p \qquad (11)$$

Where S_p is a selling price, which is equal to RM 0.40 / kWh. Since solar radiation was assumed to be constant for the entire year, the total profits obtained from this strategy were estimated to be RM167 per day or RM6095.50 per year.

Conclusion

As a conclusion, the proposed DiSS has contributed to reduction in Hospital Temerloh's energy bill. Two mode of operations were proposed namely Night Mode (NM) and Day Mode (DM). The modes were classified based on solar availability where DM operation started from 7.00 a.m. until 7.00 pm while NM operation started from 7.00 p.m. until 7.00 a.m. Using the proposed HSA to optimize the solar panel tilt angle, , the obtained power generation from solar panel also increased. Hence, the profit gained from this strategy were estimated to be RM167 per day or RM6095.50 per year.

References

[1]   N. M. Isa, C. W. Tan, and A. H. M. Yatim, "Smart Grid Technology : Communications , Power Electronics and Control System," in *2015 International Conference on Sustainable Enegy Engineering and Application(ICSEEA)*, 2015, pp. 10–14.

[2]   N. M. Isa, C. W. Tan, and A. H. M. Yatim, "A comprehensive review of cogeneration system in a microgrid : A perspective from architecture and operating system," *Renew. Sustain. Energy Rev.*, no. February 2016, pp. 1–28, 2017.

[3]   P. Siano, "Demand response and smart grids—A survey," *Renew. Sustain. Energy Rev.*, vol. 30, pp. 461–478, Feb. 2014.

[4]   Q. Fu, A. Nasiri, A. Solanki, A. Bani-Ahmed, L. Weber, and V. Bhavaraju, "Microgrids: Architectures, Controls, Protection, and Demonstration," *Electr. Power Components Syst.*, vol. 43, no. 12, pp. 1453–1465, 2015.

[5]   R. Zamora and A. K. Srivastava, "Controls for microgrids with storage: Review, challenges, and research needs," *Renew. Sustain. Energy Rev.*, vol. 14, no. 7, pp. 2009–2018, Sep. 2010.

[6]   T. Ersal, M. Brudnak, A. Salvi, Y. Kim, J. B. Siegel, and J. L. Stein, "An Iterative Learning Control Approach to Improving Fidelity in Internet-Distributed Hardware-in-the-Loop Simulation," *J. Dyn. Syst. Meas. Control*, vol. 136, no. 6, p. 061012, Aug. 2014.

[7]   F. O. Resende, J. A. P. Lopes, and S. Member, "Management and Control Systems for Large Scale Integration of Renewable Energy Sources into the Electrical Networks," pp. 1–6.

[8]   A. Urtasun, P. Sanchis, D. Barricarte, and L. Marroyo, "Energy management strategy for a battery-diesel stand-alone system with distributed PV generation based on grid frequency modulation," *Renew. Energy*, vol. 66, pp. 325–336, Jun. 2014.

[9]   N. Bigdeli, "Optimal management of hybrid PV / fuel cell / battery power system : A comparison

of optimal hybrid approaches," *Renew. Sustain. Energy Rev.*, vol. 42, pp. 377–393, 2015.

[10]   REMCO Ltd, *12V battery module (RM12-75DC)*. 2012.

[11]   A. Jossen, J. Garche, H. Doering, M. Goetz, W. Knaupp, and L. Joerissen, "Hybrid systems with lead – acid battery and proton-exchange membrane fuel cell," *J. Power Sources*, vol. 144, pp. 395–401, 2005.

[12]   M. Ceraolo, "New dynamical models of lead-acid batteries," *IEEE Trans. Power Syst.*, vol. 15, no. 4, pp. 1184–1190, 2000.

[13]   S. Sukumar, "Energy Management System for Optimal Operation of Microgrid Consisting of Pv, Fuel Cell and Battery," 2017.

[14]   "Nasa surface meteorology and solar energy data set. http://eosweb.larc.nasa. gov/sse," 2014.

[15]   T. Kamal and S. Z. Hassan, "Energy Management and Simulation of Photovoltaic / Hydrogen / Battery Hybrid Power System," *Adv. Sci. Technol. Eng. Syst. J.*, vol. 1, no. 2, pp. 11–18, 2016.

[16]   K. Hasim, M. K. Almsafir, and V. Kumaran, "An Economic Evaluation of Grid- Connected Photovoltaic Generation System for Residential House in Malaysia," *J. Adv. Sci. Eng. Res.*, vol. 4, no. 1, pp. 47–60, 2014.