Energy Management System for Hospital Building Using Genetic Algorithm

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***Abstract*—Microgrid (MG) as well as energy management system (EMS) is undergoing an immense growth. A cogeneration, as one of MG topologies, needs an efficient controller to manage the supply-demand activity so that both sides can achieve their goals. The EMS plays a role as a supervisory controller to optimally dispatch the energy in order to satisfy the load demand. In this paper, EMS based on optimization approaches to minimize the operating cost of cogeneration system is presented. This study developed a cogeneration system that consists of grid-connected photovoltaic, fuel cell and battery. This system was adopted at hospital building, which was selected as a sample of load profile. An optimization problem was formulated by considering decision variables, input system parameters, objective function and constraints. Furthermore, the problems were solved using Genetic Algorithm. The viability of the optimization approaches was simulated in MATLAB environment.**

***Index Terms*—Cogeneration; Energy Management System; Genetic Algorithm; Hospital; Microgrid.**

I. INTRODUCTION

Recently, development in microgrid (MG) that integrates various renewable energy resources (RERs) has been experiencing an enormous growth. This is due to the progressive needs of energy around the globe and a decrement of the primary energy resource from fossil fuel[1] [2]. Renewable energy resources like wind and photovoltaic are able to generate electricity, environmental-friendly and unlimited. Among all the MG topology, cogeneration is one of the advanced configuration that can produce both electricity and heat energy. During the generation of electrical energy, a waste heat is captured to supply the thermal load[3]. Hence, a cogeneration system can increase the energy efficiency, reduce the operational cost and decrease the greenhouse gas emission compared to the conventional methods of generating electricity and heat separately. However, the integration of MG in terms of cogeneration system with various RERs in the grid requires a well-organized control system to manage the energy flow between generation and demand side.

Basically, an MG control system implementation can be divided into three levels of hierarchy: primary, secondary and tertiary[4]. Energy management system (EMS) located at the tertiary level can control the energy generation, power flow between the MG, grid and the load. EMS designed that can apply optimization technique employed various algorithm to solve various optimization problems. Most of the researchers in the MG optimization field are interested to present a modern, fast and efficient algorithm. The aim of the algorithms is to allow the autonomous grid connected decision making to determine the hourly optimal dispatch of each DG unit in the developed system. In the article [5] and [6], a comprehensive review of the optimization method for renewable resources including wind turbine, solar energy, hydropower, bioenergy, geothermal energy and hybrid system are discussed. Moreover, algorithms like harmony search algorithm (HSA) [7], Colonial Competitive Algorithm (CCA) [8], Particle Swarm Optimization (PSO) [9], [10] [11] has been used to solve the problem of Levelized. Cost of Energy (LCOE) performs an energy management system for long-term operation optimization of a grid-connected hybrid system. Abbas in the article [12] uses ant colony optimization algorithm (ACO) to solve the optimal power flow in his system. M.Rouholamini in the article [13] applies the Interior Search Algorithm to solve the power management system as well as to define the role of the initial state of charge of the storage tank in total cost.

Despite the benefits of using optimization in designing the efficient EMS, a study on the development of EMS for building like airport, shopping complex and residential have been conducted in articles [14], [15] and [16], respectively. However, the EMS design for hospital building that has both electricity and heat energy demand is still limited in publication. Therefore, this article addresses the gap by discussing the EMS design using the optimization approach. In this article, an efficient energy management system (EEMS) based on optimization approach for a cogeneration system is designed, considering a load demand from the public hospital in Malaysia. The cogeneration system contains photovoltaic, fuel cell and battery system and they are assumed to be interconnected to the main utility grid. The integration to the grid allows the cogeneration system purchase some power from the utility grid when the off-peak hours or when the power production in cogeneration system is insufficient to full fill the load demand. Besides, there is a daily income when the generated power exceeds the load demand during peak hours (depending on the system constraints and market parameters). The optimization model is formulated by considering decision variables, input system parameters, objective function and constraints. The information data including an electricity and thermal consumption profile of the hospital is gathered from the engineering department of the selected public hospital in Malaysia. Furthermore, the optimization problems have been solved using GA, which gives the minimum operational cost in 24 hours operation. The simulation is performed in MATLAB environment.

This paper is organized as follows: Section 2 presents the overview of EMS using optimization approach, Section 3 presents a system description followed by Section 4 that discusses the optimization method using Genetic Algorithm (GA). In Section 5, the results of the optimization are presented with the discussion. Finally, the conclusions are outlined in Section 6.

II. ENERGY MANAGEMENT SYSTEM USING OPTIMIZATION

Generally, EMS can be designed based on rule approach and optimization approach. In rule-based approach, the system is managed according to prefixed rules such as simple base rule, multi-agent system and fuzzy logic method. In contrast, an optimization-based approach manages the system using the mathematical concept as well as bring out with objective function and subject to several constraints. Mathematically, the optimization algorithm is a discipline apprehensive with finding inputs of a function that could minimize or maximize the values, which is subjected to the recognized constraints. The optimization algorithm does not only looking for the optimum solution to a problem, but the solution also must be feasible to the characteristic of the desired problems[17]. Figure 1 simplifies the EMS design classification.

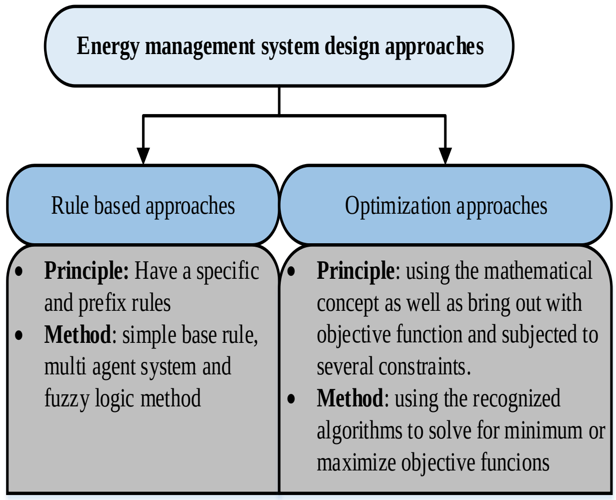

Figure 1: EMS design approaches classifications

In literature, there have been extensive works that use optimization approach to design their EMS. One of them is article [10], where three EMSs based on Particle Swarm Optimization(PSO) are studied. The EMS design are responsible to make the hybrid grid connected to wind turbine (WT) and photovoltaic (PV) panels as primary energy sources, hydrogen system (fuel cell, electrolyzer hydrogen storage tank) and battery as energy storage system (ESS) that produces the demanded power and decides the energy dispatch among the ESS devices. Although this paper provides an explanation of the EMS for the ESS devices, the consideration to full fill the load is beyond the scope of this paper. Moreover, authors in [18] use the GA to optimize their system considering the minimization of total electricity cost. The system contains renewable energy and battery banks apart from the grid to meet the demand. The optimization problem is run for a 24-hour data of renewable input, real-time electricity price and demand from the electric appliances. In an article [19], an optimization approach has been used to search for an optimal operation model for a cogeneration system that consists of wind energy, PV, heat recovery boiler and battery. The study also focuses on the effect of battery and electricity price on system operation cost. An economic dispatch of the smart home using an optimization based on HSA is presented in [7]. In this work, an operating cost of the system is formulated and minimized using HSA as well as the results of this article can be used as a lookup table to generate the electrical and heat power in each time interval to have a daily minimum cost.

From the literature review, it can be said that the optimization method application in energy management system is a popular approach for designing EMS. However, the application of the optimization in a cogeneration system is still limited since there are only a few published papers that discuss on the energy management system design in a building[20][21][22]. In addition, work that discusses the energy management system based optimization method for the hospital building is still limited whereby Mohammad [23] explains the implementation of energy management system optimization that uses PSO for a combined heat and power (CHP) in the hospital building in Northern Iran. The PSO algorithm is used to maximize the Net Present Value (NPV) whereby the integrated EMS strategy is proposed for the planning of an appropriate grid and CHP dispatch for electricity on an hour-by-hour basis.

In Malaysia, works that discuss energy management system for a commercial building like the hospital are mostly focused on how to achieve the energy efficiency. This type of works relates to the consumer responsibility instead of discussing how to manage the energy generation and supply to the customers. Works on how to schedule power generation to fulfil the energy demanded from the load are still limited. This situation exists due to the difficulties to collect technical and economic data information from the hospital personnel in charge since many restrictions from the government need to be fulfilled.

III. SYSTEM DESCRIPTION

Figure 2 shows a design of cogeneration system for the hospital building. The system consists of photovoltaic (PV), fuel cell (FC), battery, thermal and electrical loads. The electrical loads are supplied by the PV, FC, battery and main grid, while the thermal loads can be supplied by natural gas resources for the recovered heat from the FC. The model of energy generation and supply in this cogeneration system is shown in Figure 3. In this model, EMS which functions to minimize the operating cost for supplying the demand of a hospital building in Malaysia is integrated into this model. In order to utilize the available energy resources effectively, the schedule for the system operation has to be worked out in advance for the duration of one day or longer. Hence, an efficient EMS (EEMS) methodology is introduced to send the optimized values of each source to the power converter control circuit that will determine which energy sources will fulfil the demand. The operation decision will be determined by the Genetic Algorithm to serve the optimization problems. In this study, an installation cost of the system components is neglected because it is assumed that all the components have been installed.

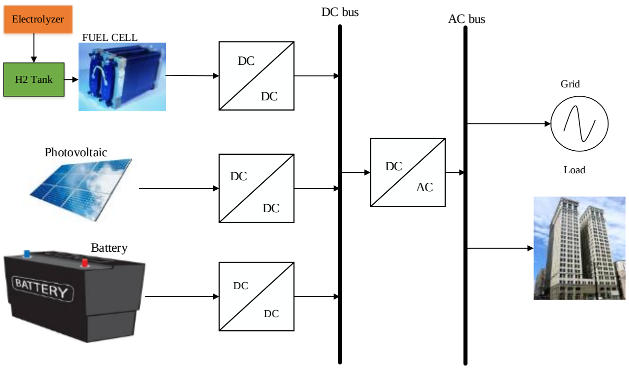

Figure 2: Hybrid cogeneration system for a building

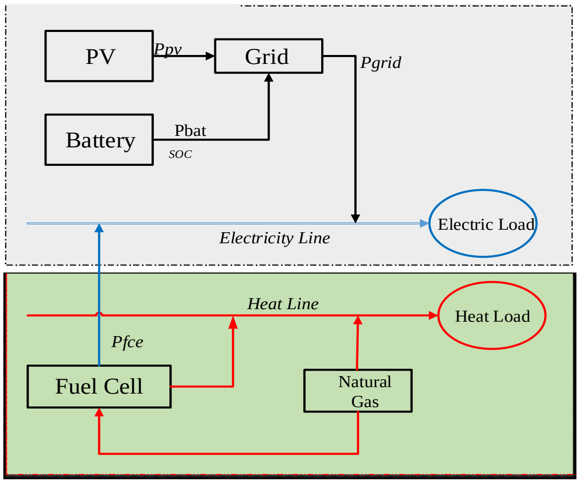

Figure 3: Energy flow model in cogeneration system

IV. Optimization Formulation

In this section, an optimization model of EEMS for the cogeneration is introduced. There are several decision variables including power generation from each energy resources and grid to allocate the optimal power generation set points for each source. A suitable ON and OFF states are used to optimize the total operating cost of the co-generation that satisfies all equality and inequality constraints. The mathematical model of the optimization problems has been formulated. The objective function subjected to a certain constraint is described in the following subsection.

A. *Objective Function*

The following objective function is designed to minimize the operation cost of the system:

$$\min \sum_{i=1}^{i=24} Cot = \left(\sum_{i=1}^{24} C_{PV,i} + \sum_{i=1}^{24} C_{FC,i} + \sum_{i=1}^{24} C_{u,i} + \sum_{i=1}^{24} C_{gas,i} + \sum_{i=1}^{24} C_{B,i} \right) \tag{1}$$

Where;

$$C_{PV,i} = K_{OM,i} * P + K_{rep,i} * P + \frac{A}{P * 8760 * cf} * MU_i \tag{2}$$

$$C_{FC,i} = \begin{cases} T * C_{gas_b} * \frac{P_{efc,i}}{n_{fc,i}} + \alpha_1 & if\ P_{efc,i} > 0, \quad P_{efc,i-1} = 0 \\ \alpha_2 & if\ P_{efc,i-1} > 0, \quad P_{efc,i} = 0 \\ T * C_{gas_b} * \frac{P_{efc,i}}{n_{fc,i}} & else \end{cases} \tag{3}$$

$$C_{gas,i} = T * C_{gas_b} * P_{gas_i} \tag{4}$$

$$C_{u,i} = T * MU_i * C_{UB} * P_{u,i} \tag{5}$$

$$C_{bat,i} = \begin{cases} T * C_{bat_b} * P_{bat,i} & if\ P_{bat,i} \geq 0 \\ -T * C_{bat_b} * P_{bat_i} & if\ P_{bat,i} < 0 \end{cases} \tag{6}$$

B. *Constraints*

The optimization of function in equation (1) is subjected to several constraints including power balance and devices constraint from the fuel cell and battery. The calculation of battery operation cost is conducted by considering the $P_{bat,i}$ is negative in charging mode and positive in discharging mode. Thus, to have a positive battery operating cost in its different operation modes, $C_{bat,i}$ is calculated based on equation (6). MU_i is used in equation (2) and (5).

1) *Constraint of power balance*

In this case, if there is no curtailment from the load, the model should meet the electrical and thermal demands successfully. Mathematically, the electrical power balance and thermal balance are stated in equation (7) and (8), respectively.

$$\textstyle\sum_{i=1}^{N} P_i + P_{u,i} + P_{bat,i} = P_{eload} \tag{7}$$

Where $P_i = P_{pv,i} + P_{fc,i}$ and $P_{bat,i}$ can be either in positive for discharging mode or negative for charging mode.

$$P_{gas,i} + P_{hfc,i} = P_{hLoad} \tag{8}$$

2) *Constraint of fuel cell*

In a fuel cell, the changes rate of output power is limited to upper and lower boundaries[24]. Inequalities equation in (9) and (10) are used in the case of increasing or decreasing FC output power, respectively.

$$P_{efc,i} - P_{efc,i-1} < \Delta P_{FC,U} \tag{9}$$

$$P_{efc,i-1} - P_{efc,i} < \Delta P_{FC,D} \tag{10}$$

On the other hand, the maximum output power of the FC is limited to its nominal capacity. Further, if FC output power becomes less than a lower threshold, the FC will not be able to work properly and it should be turned off. Equation (11) states the inequality constraint of FC generated power.

$$P_{fc,min} < P_{efc,i} < P_{fc,max} \tag{11}$$

Moreover, the efficiency of the FC is related to the part of load ratio (PLR), which is a ration of electrical generation to the maximum FC power rating [24][25]. The efficiency and the ratio of the generated electrical to thermal energy are formulated as equations of PLR, which is:

$$When\ PLR_i < 0.05, n_{fc,i} = 0.2716,\ r_{fc,i} = 0.6816 \tag{12}$$

While $PLR_i \geq 0.05$, the following can be attained:

$$n_{fc,i} = 0.9033PLR_i^5 - 2.9996PLR_i^4 + 3.6503PLR_i^3 - 2.0704PLR_i^2 + 0.4623PLR_i + 0.3747 \tag{13}$$

and

$$r_{fc,i} = 1.0785PLR_i^4 - 1.9739PLR_i^3 + 1.5005PLR_i^2 - 0.2817PLR_i + 0.6838 \tag{14}$$

3) Constraint of battery

The constraint of the battery is referred to the available energy in a battery, which is limited to its capacity. The state of the charged battery is represented as energy, wherein E is stated in the equation (15).

$$E_{min} < E_i < E_{max} \tag{15}$$

Ideally, if the battery is discharged (charge the system) with Pbat, its energy is reduced (increased by the system) by $P_{bat,i}\, X\, \Delta t$. While in real condition, the energy reduction of a battery is discharged with the rate of $P_{bat,i} = \frac{P_{bat,i}\, X\, \Delta t}{n_{dch}}$. These can be simplified for $\Delta t = 1h$ as in the following:

$$E_i = E_{i-1} - \frac{P_{bat,i}}{n_{dch}} \tag{16}$$

Furthermore, a battery is charged by the energy that is less than the energy absorbed from the system. This means that if the battery absorbs $P_{bat,i}$ inΔt, its charging level is increased by $P_{bat,i}\, X\, \Delta t\, X\, n_{ch}$. This can be stated for $\Delta t = 1h$, as in equation (17) below:

$$E_i = E_{i-1} + P_{bat,i} X n_{ch} \tag{17}$$

On the other hand, the available energy in the battery is decreased (increased in the system) by $P_{bat,i} X \Delta t$, which is limited to the maximum value in discharging (charging in the system) mode. Therefore, the following inequalities in equation (18) and (19) represent the limitations of charging and discharging rates for the battery, respectively.

$$\frac{E_i - E_{i-1}}{\Delta t} < P_{bat_{chmax}} \tag{18}$$

$$\frac{E_i - E_{i-1}}{\Delta t} > P_{bat_{dchmax}} \tag{19}$$

C. System Variables

This part presents a full description of the system variables such as load profile, grid tariff, PV power profile in the co-generation system. The data studied in this section is formulated based on the practical knowledge and engineering information from the hospital.

1) Load demand profile

Considering hospital has two loads of electricity and thermal load, Figure 4 shows the load demand profile of the hospital building involved in this study for the year 2014. The graphical information shows that there are high electrical power and thermal consumption from 8 a.m. until 8 p.m. This is due to the fact that most activities in the hospital are performed at that time.

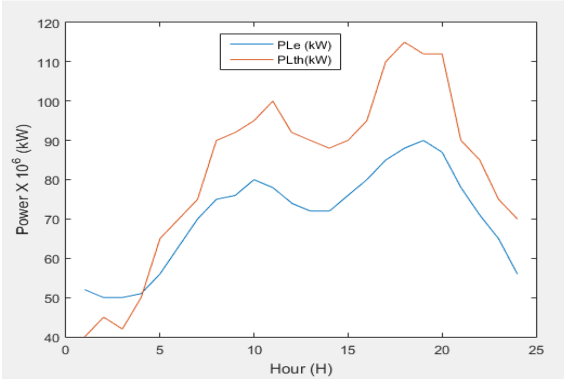

Figure 4: Load profile of hospital building

2) Grid Tariff

In Malaysia, the main utility provider *Tenaga Nasional Berhad* (TNB) has determined the tariff into several categories depending on the type of customers. As the hospital is the commercial client, they fall into the C2 category and they deserve to get some discounts on the tariff. In order to do the analysis for this study, the tariff is assumed to be 0.365 MYR/kWh [26].

3) PV power availability

The availability of PV power during the operating mode depends on the solar irradiation and temperature. Figure 5 shows the hourly PV power profile for the hospital location with the coordinate of 3.4486° N, 102.4163° E, considering the time of day, time of year and climate change.

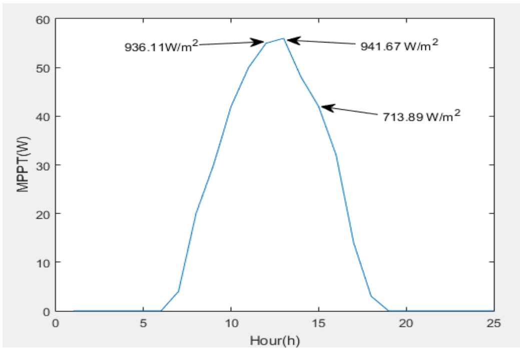

Figure 5: PV Power availability

D. System Parameters

In this analysis, the power limit of each component and operating cost of the system are considered as system parameters. The following sub-sections provide explanations of the system parameters.

1) Power limit of system components

Each component in the system has the maximum limits for the output during the operating mode. This is important to ensure the lifetime of the components can be utilized within an appropriate duration. Table 1 lists the maximum and minimum limits for the output power during the operating mode. In the analysis, it is assumed that the fuel cell is working all the time with a power range between minimum and maximum limits in order to reduce the start-up cost

Table 1
Maximum and Minimum Power Limit for Components in Cogeneration System

Components	$P_{minimum}$ (kW)	$P_{maximum}$ (kW)
Photovoltaic	0	25
Fuel Cell	1	40
Battery	-20	20
Gas	2	55

2) Operation cost of system components

Traditionally, the total cost per produced kWh (unit cost) for DGs unit is calculated by discounting the investment cost and operation and maintenance cost over the lifetime divided by the annual electricity production. In this study, the unit cost of generation is tabulated as shown in Table 2. As shown in Table 2, the value of the unit cost of generation is calculated as an average cost over the lifetime. However, in reality, the actual cost will be lower than the calculated average at the beginning of life because of low O&M costs, and it will increase within the period of the usage of DGs.

Table 2
Unit Cost For Each Element

Component	PV	FC	Battery	Gas	Grid
Unit cost of generation (MYR/kwH)	3.19	1.41	1.59	2.099	0.36

E. Application of Genetic Algorithm

In this section, an optimization method is discussed as well as the optimization problems are solved using GA. Historically, GA known as a heuristic algorithm is a concept introduced by John Holland in the 1970s [27] [28]. It mimics Darwin's evolution theory and uses the concept of survival of fitness [29]. GA has been used in various disciplines including nonlinear, non-convex optimization problem and multi-dimensional cases where GA needs to find a global optimal solution in the constraint solution space. The process flow of GA is shown in Figure 6.

1) Initialization process

In this work, the main aim of GA is to solve the optimization problem where it searches for an optimal (minimum cost) solution in terms of the variables of the problem (Ppv, Pfc, Pbat ,Pgas and Pgrid). Hence, GA started the process of fitting by defining a chromosome (individual) as an array of variable values to be optimized. In this study, the chromosome has Nvar =5.

Chromosome = [Ppv Pfc Pbat Pgas Pgrid]

GA runs based on a number of potential solutions, called as a population, which composes between 30 and 100 chromosomes. The population consists of 1 X Nvar array (chromosomes) is normally presented in a matrix form. In this work, an initial population of Npop chromosomes is represented in full matrix Npop x Nvar random values as below:

$$\begin{bmatrix} Ppv1 & Pfc1 & Pbat1 & Pgas1 & Pgrid1 \\ Ppv2 & Pfc2 & Pbat2 & Pgas2 & Pgrid2 \\ Ppv3 & Pfc3 & Pbat3 & Pgas3 & Pgrid3 \\ & & .. & .. & \\ & & .. & .. & \\ & & PpvNpop & PfcNpop & \end{bmatrix}$$

The cost of each chromosome is determined by evaluating the cost function f at the variables, as shown below:

$$\text{Cost}= f(chromosomes) = (Ppv, Pfc, Pbat, Pgas, Pgrid)$$

2) Selection process

Selection is a process that defines which parents are to be preserved and allowed to reproduce, and which ones deserve to die out while keeping the population size constant. Several different techniques have been used to perform the selection in GA, including roulette selection, tournament selection, rank selection and steady-state selection. In this work, Roulette selection method was adopted due to its advantage to measure and select chromosomes based on some measures of their performances.

3) Crossover process

Crossover is the basic operator for producing new chromosomes in the GA. Using its counterpart in nature, crossover produces new chromosomes that have some parts of both parent's genetic material. The crossover operator is used to create new solutions from the existing solutions available in the mating pool after applying selection operator. Crossover points are randomly selected and applied to selected parents.

4) Mutation process

Similar to the crossover that has the responsibility to search for the best and optimal solution, mutation is also used for the same purpose. Mutation is a random process, in which one allele of a gene is replaced by another to form a new genetic structure. In GAs, mutation is randomly applied to the new offspring with low probability and modifies the elements in the individuals. Overall, mutation process performs the following jobs:

- Choose the mutate rate
- Number of mutation matrix columns can be calculated by multiplying mutation rate*Nvar*(Npop-1)
- Random numbers are chosen to select the row and columns of the variables to be mutated.
- A mutated variable is replaced by a new random variable according to variables limits.

V. RESULT AND DISCUSSION

This section presents the result evaluation of co-generation system using a genetic algorithm optimization. In the analysis, the optimization for the installed capacity of cogeneration is investigated according to 24 hours load demand variations in a hospital building in Malaysia. The optimum allocation co-generations and the main grid that are referred to cost function for a day operation is illustrated in Figure 7. The results show the variation of the power during daily operation, whereby it presents the minimum (optimum) cost = MYR650 with 39 iterations. The convergence curve is shown in Figure 8.

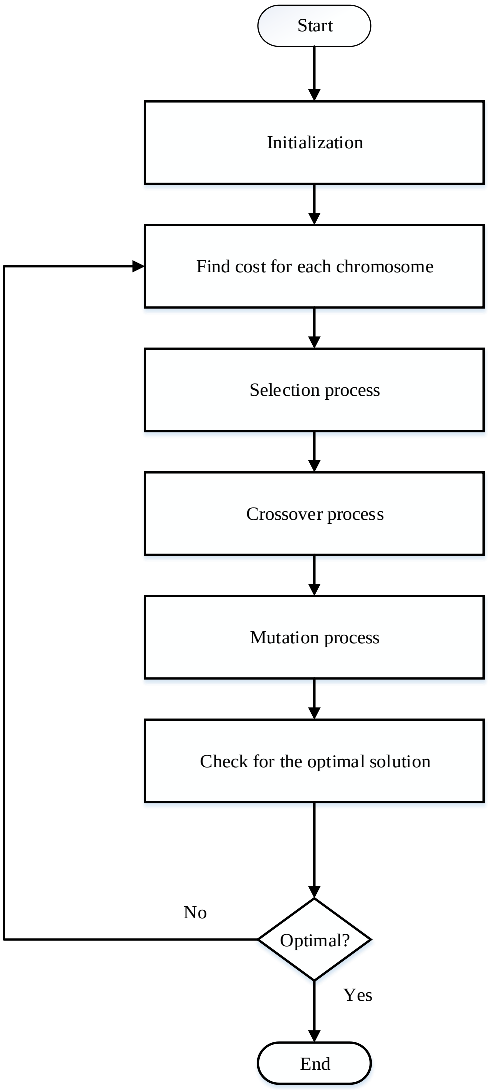

Figure 6: Flowchart of genetic algorithm

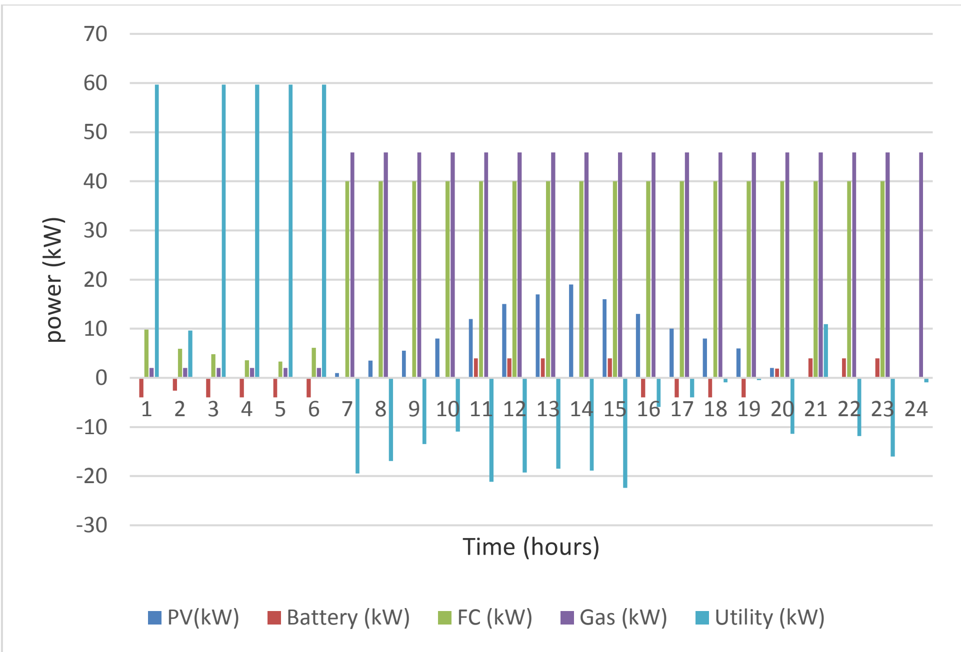

Figure 7: Optimal power generation

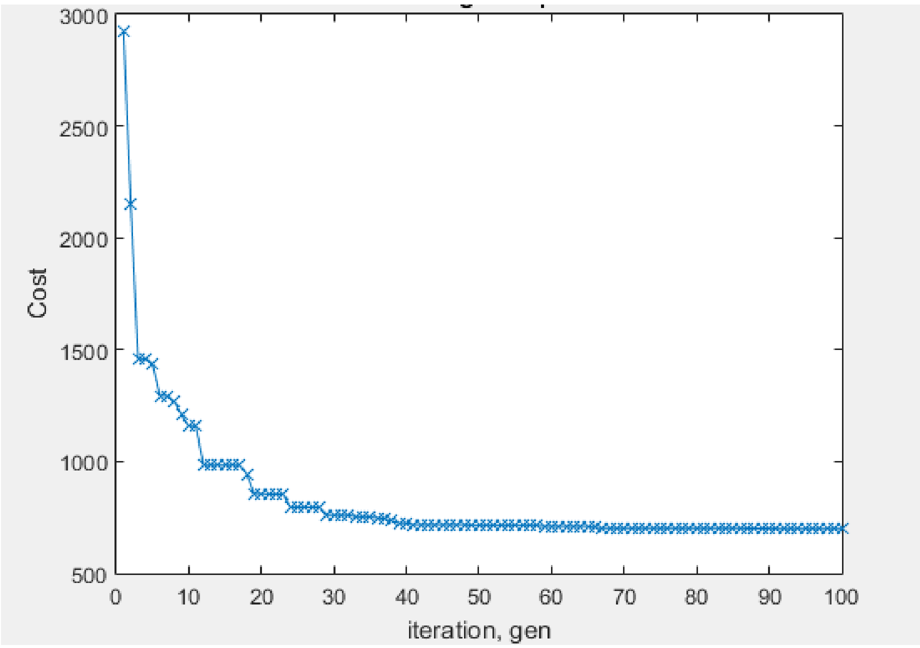

Figure 8: convergence curve

VI. Conclusion

In this paper, an energy management system for a cogeneration system consists of photovoltaic, fuel cell and the battery has been developed. An energy management system is developed based on optimization approach, whereby the fitness function is solved throughout the Genetic Algorithm. The optimization model is to investigate the optimal power allocating as several variables and parameters are considered in the analysis. The optimization model that employed GA gives the minimum (optimum) cost = MYR650 with 39 iterations. The result shows that the sufficient energy management design for the hospital building will benefit the hospital building owner.

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