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Research Article

OPTIMIZATION, DEVELOPMENT AND INNOVATION IN MAINTENANCE OF WIND HYBRID TURBINES BASED ON GENETIC ALGORITHM

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ABSTRACT

Given the significant role played by genetic algorithms in different industries, the present study aimed to present an approach to optimize, develop and innovate for maintenance of wind hybrid turbines according to such algorithms. For this purpose, an overview on development and optimization process for turbines maintenance based on genetic algorithm is initially presented. Then, each part of a hybrid wind turbine system, including wind turbine, micro-hydro power, electrolyzer, hydrogen tank, fuel cell and inverter, is described and the corresponding equations are taken into consideration. Finally, our proposed turbines maintenance optimization procedure using genetic algorithm is presented. The simulation results provided an optimum configuration consist of 19.85 Tons of hydrogen tanks, 610kW of micro-hydro unit and 21 units of wind turbine with each capacity is 100kW. The annual cost of system is US$ 2.08 million, while the annual capital cost is US$ 1.35 million. This system concluded to be useful in Manjil and Rudbar Wind Farm.

Keywords: Optimization, Development, Maintenance, Wind Hybrid Turbines, Genetic Algorithm

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INTRODUCTION

In the world of renewable energy production, a novel concept called Genetic Algorithms (GAs) has been evolved. GAs are considered as some randomized-form search algorithms which have been developed for imitation of the natural selection and natural genetics mechanics. GAs operate based on string structures, similar to biological constructs, which timely evolve in accordance with the rule of survival of the fittest parts. This is achieved via a randomized information exchange structure. As a result, at any generation, a new strings set is created through parts of the fittest members of the old strings set (Bozorg-Haddad, Solgi and Loáiciga, 2017).
On the other hand, in this age, renewable energy is being investigated in order to satisfy the load demand. Utilizing renewable energy can lead to assure us from long-term sustainable energy supply, and decrease global and local atmospheric emissions (Atia et al., 2012). In doing so, such technologies as Wind Turbines (WTs) and Micro-hydro (MHyd) are turning into the promising technologies to supply the load demand in remote and even isolated areas. Nevertheless, such systems have plenty of drawbacks including the fact that the weather conditions affect power generated by wind and micro-hydro energy (Lu and Zhu, 2020). The changes of power generated by these sources are likely to be not compatible to the timely demand distribution. Furthermore, the intermittent power generated by wind and micro-hydro power systems are likely to cause serious reliability worries in both design and utilization of micro-hydro and wind turbines system (Gundling, et al., 2015). In order to deal with such reliability problems, over-sizing can be a solution. This is while improper installation of the components will lead to increase overall cost system (Al-Ghussain and Taylan, 2019).
As a matter of fact, several alternative ways exist for prevention of the shortage power from these power systems. A back-up unit can be taken into consideration as a power supply in case of insufficient power. For example, an alternative back-up power may be diesel generator. Nevertheless, the utilization cost of diesel generator is very high and it is not a good option because of the environmental concerns (Movahediyan and Askarzadeh, 2019). Besides, battery storage also can be considered for the back-up unit. However, the operational and maintenance procedures of battery are complicated. The last back-up unit goes to utilization of fuel cell equipped with electrolyzer and hydrogen tank (Rahimi and Ghadiriyan, 2019).
According to what mentioned above, the most important challenge in design of such systems is reliable supply of demand under varying weather conditions, considering operation and investment costs of the components. Therefore, the researchers look for an optimal design of a hybrid-power generation system in a reliable and economical supply of the load (Suryoatmojo et al., 2009). To this end, several methods solutions have been reported for the optimal design of hybrid wind turbine and photo-voltaic generating systems (Bhaskar and Maheswarapu, 2011; Tatsuta and Nishikata, 2014; Chen et al., 2020). Among these solutions, GAs have found optimal sizes of the hybrid system components and power flow (Dufo Lopez and Bernal-Agustin, 2005). Assuming continuous and reliable supply of the load, PSO has been successfully implemented for optimal sizing of hybrid stand-alone power system in some studies (Kashefi Kaviani et al., 2009). Nevertheless, none of the mentioned solutions have considered the microhydro power system.
For this reason ad given the great proven potentials of genetic algorithms, present study proposes a GA-based method for optimal maintenance of hybrid wind-microhydro turbines. Our proposed model is composed of micro-hydro, wind turbine and fuel-cell. To this end, we look for the optimal size of components according to the minimum total Annual Cost System (ACS). In doing so,
GA has been employed to minimize cost of the maintenance over 20 years. Wind speed and stream flow data are available for Manjil and Rudbar Wind Farm in Guilan Province of Iran and system costs include Annual Capital Cost (ACC) and also costumers dissatisfaction cost. Accordingly, we first provide an overview of development and optimization process for turbines maintenance based on GAs.

The development and optimization process for turbines maintenance based on genetic algorithm

Initially, it should be mentioned that GA is considered as a type of stochastic/randomized algorithm in accordance with the theory of probability. In practice, when this method is applied to a stage-wise superstructure model, the search process will be specified by stochastic strategy. The global optimal solution for the optimal maintenance of turbines can be provided at certain probability. This search process starts at a complex of basic stochastic solutions called "population". Also, a solution in this process is entitled "chromosome," which is composed of "gene," (Bozorg-Haddad, Solgi and Loáiciga, 2017) which in turn is applied for the optimal variables of turbines maintenance, for example, wind turbine, inverter and micro-hydro power system.

Two types of calculation operation exist in GAs as follows: genetic operation and evolution operation. The former adheres the transferring principle of probability, chooses suitable chromosomes to be expressed with certain probability, and allows other inferior chromosomes to pass away; As a result, the search direction will be conducted to the most promising area. With such a stochastic search technique, different regions of the search space can be explored simultaneously and consequently they will be less subject to terminate in local minimum. The strength of the genetic algorithm is the exploration of diverse areas of the search space in relatively short computation time. In addition, multiple and complex objectives can easily be taken into account. However, only a general framework is provided by GA for solving complex optimization problem. The genetic operators are often problem-dependent and are critically important for successful use in practical issues. In particular, to the optimal maintenance of turbines, an approach for minimum total Annual Cost System should be provided. Another difficulty for GA application will be the treatment of constraints. During the genetic evolution, a member of the population is likely to turn into infeasible solution after being manipulated by genetic operators, which will result in failure to find a feasible solution during evolution, especially for the optimization problem with strict constraints. Hence, some strategy should be contrived for constraints guarantee in genetic computation (Bozorg-Haddad, Solgi and Loáiciga, 2017).

To this end, the main features of a GA must be as follows:

1. The GA should work with a coding of the parameter set, not the parameters themselves.
2. The GA should initiate its search from a population of points, not a single point.
3. The GA should use payoff information, not derivatives.
4. The GA should use probabilistic transition rules, not deterministic ones.

Hence, the coding to be used must firstly be defined. Next, by a random process, an initial population of strings should be created. Then, a set of operators should be employed to take this initial population generating successive populations, which will be improved with time.

Besides, the main operators of the GAs are as follows: reproduction, crossover, and mutation.

Reproduction is a process which is in accordance with the objective function of each string. This function specifies how "good" a string is. As a result, strings having higher fitness value will have higher likelihood of contributing offsprings to the next generation.

Furthermore, crossover is considered as a process where members of the last population are mated randomly in the corresponding pool. As a result, a pair of offsprings will be created, by mixing the elements from two parents (members), which have improved fitness values. Mutation is the occasional (with low likelihood) random alteration of the value of a string position. Actually, mutation is a process of random walk through the coded parameter space in order to ensure that important information contained within strings may not be lost prematurely (Zheng et al., 2017).

REPRESENTATION OF WIND HYBRID TURBINE

In this section, for the simplicity of understanding the optimization for maintenance, the wind hybrid turbine components are represented.

Block diagram of a hybrid wind turbine system is shown in Figure 1 and the specifications are presented in Table 1. This hybrid system composed of 3 power generation types including wind turbines unit, Microhydro and Fuel-cell unit which are linked to the load system via the inverter. The storage system is composed of electrolyzer, hydrogen storage tank and fuel-cell needed to store all excess power. The components to be considered are wind turbine, micro-hydro, electrolyzer, hydrogen tank, fuel-cell and inverter. Each component is discussed in the following.

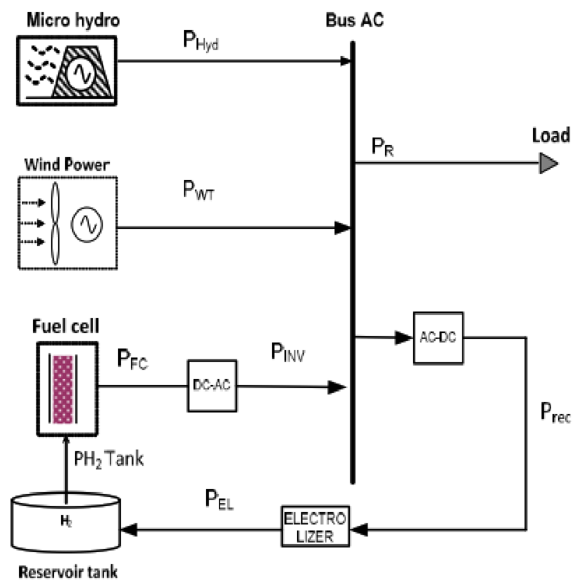

Figure 1. Configuration of hybrid wind turbine system

Table 1. Specifications of hybrid wind turbine system

Rated power (kW)	100
Cut-in (m/s)	3.5
Cut-out (m/s)	25
Rated (m/s)	12
Swept area of rotor (m^2)	314.16
Efficiency	30

Wind turbine

The output power of each wind turbine unit is based on the rated capacity and the specification given by the manufacturer. Here, a 100kW wind turbine is taken into consideration as a power generator. It has a rated capacity of 100 kW and provides alternating current (AC) at the output side. The output power of wind turbines can be calculated by equation (1) (Soedibyo et al., 2012):

$$P_W(t) = \begin{cases} 0 & if\ V_t(t) < V_C \\ \frac{1}{2}.\rho.A.V^3(t).\eta\ wt & if\ V_C \le V_t \le V_r \\ P_{rated} & if\ V_r \le V_t \le V_f \\ 0 & if\ V_t > V_f \end{cases}$$
(1)

where ρ depicts air density in the unit kg/m^3, *A* presents swept area of rotor in m^2, *t* is wind speed in m/s, η_{wt} is efficiency of wind turbines, V_c shows cut-in speed, v_r presents the rated speed, v_f shows furling speed and finally, P_{rated} is rated power of wind turbines.

Micro-hydro power

The electrical power generated by the hydro turbine can be determined using the equation (2) (Kashefi Kaviani et al., 2009):

$$P_{hvd} = \eta_{hvd}.\rho_{hvd}.g.H_{net}.Q_t$$
(2)

Where H_{net} depicts the effective head, the actual vertical drop minus this head loss. It can be calculated using the equation (3) (Soedibyo et al., 2012):

$$H_{net} = H(1 - f_h)$$
(3)

Furthermore, in equation (1), Q_t provides the hydro turbine flow rate, namely, the amount of water flowing through the hydro turbine, which may be computed using the equation (4) (Soedibyo et al., 2012):

$$Q_t(t) = \begin{cases} 0 & if\ Q_{AV}(t) < Q_{min} \\ Q_{AV}(t) & if\ Q_{min} < Q_{AV}(t) < Q_{max} \\ Q_{max} & if\ Q_{AV}(t) > Q_{max} \end{cases}$$
(4)

Where Q_{AV} showsthe flow rate available to the hydro turbine (m^3/s), Q_{min} is the minimum flow rate of the hydro turbine (m^3/s), Q_{max} is the maximum flow rate of the turbine (m^3/s)., assuming that that the hydro turbine can be operated only if the available stream flow is equal to or exceeds this minimum value. The Q_{min} can be calculated using the equation (5):

$$Q_{min}(t) = W_{min}.QD$$
(5)

Where Q_{max} is the maximum acceptable flow rate through the hydro turbine, which is expressed as a percentage of the turbine's design flow rate (Soedibyo et al., 2012). This simulation uses this input to calculate the maximum flow rate trough the hydro turbine, and hence the actual flow rate through the hydro turbine. The Q_{max} can be calculated using the equation (6):

$$Q_{max}(t) = W_{max}.QD$$
(6)

Electrolyzer

Primarily, electrolyzers operate according to the water electrolysis. A direct current is passed between two electrodes then it is submerged in water and decomposes into hydrogen and oxygen. Next, the amount of hydrogen can be collected from the anode side. Usually, the hydrogen is produced by the electrolyzers at a pressure around 30 bars. Also, the reactant pressures within a Proton Exchange Membrane Fuel Cell (PEMFC) are around 1.2bar. It is assumed that the electrolyzer is directly linked to the hydrogen tank. Transferred power from electrolyzer to hydrogen tank can be calucuated using the equation (7) (Kashefi Kaviani et al., 2009):

$$P_{EL-\tan k} = P_{EL}.\eta_{el}$$
(7)

Where η_{el} is the efficiency of electrolyzer.

Hydrogen Tank

The basic principle of energy stored in the hydrogen tanks is the same as in the battery banks. Every hour energy stored in the hydrogen tanks can be calculated using the equation (8) (Kashefi Kaviani et al., 2009):

$$E_{\tan k}(t) = E_{\tan k}(t-1) + \left[P_{EL-\tan k} - \frac{P_{HT}(t)}{\eta\ storage}\right]$$
(8)

where P_{HT} is the power transferred to the fuel cell. In this study, the hydrogen tanks efficiency is assumed to be 98%. Meanwhile, the mass of stored hydrogen, at any time step *t*, is calculated using the equation (9) (Kashefi Kaviani et al., 2009):

$$m_{\tan k}(t) = \left[\frac{E_{\tan k}(t)}{HHV_{H_2}}\right]$$
(9)

Where, the Higher Heating Value (HHV) of hydrogen is equal to 39.7kWh/kg. The energy stored in the hydrogen tanks cannot exceed the constraint according to the equation (10) (Kashefi Kaviani et al., 2009):

$$E_{\tan k,min} \leq E_{\tan k}(t) \leq E_{\tan k,max} \quad (10)$$

Fuel-Cell

Fuel-cells are here considered as electrochemical devices to convert the chemical energy of a reaction directly in to electrical energy. The output power produced by fuel-cell can be determined by multiplying its input power and efficiency (η_{FC}). In this case, the efficiency of fuel-cell is assumed to be 50% (Kashefi Kaviani et al., 2009) and calculation is undertake according to the equation (11):

$$P_{FC-inv} = P_{\tan k} - FC^{x\eta} FC \quad (11)$$

Inverter

Inverter is considered an electrical device to convert electrical power from DC into AC form at the desired frequency of the load (Hossam-Eldin, et al., 2020) and it can be calculated by the equation (12).

$$P_{INV-L} = (P_{FC} + P_{INV}).\eta_{inv} \quad (12)$$

where η_{inv} is inverter efficiency.

TURBINES MAINTENANCE OPTIMIZATION PROCEDURE USING GENETIC ALGORITHM

We used simulation methods to utilize GA in order to optimal the optimal sizing of the hybrid system. The concept of genetic algorithm is different from traditional search and optimization method used to solve the engineering problems. The basic idea of this algorithm is taken from genetic process in biology that used artificially to build search algorithms. This technique is introduced to find the optimal solution based on natural selection. Our proposed GA-based optimization procedure is depicted in Figure 2.

Besides, the main objective of the proposed method is to find the optimum size of hydrogen tanks, number of wind turbines and number of micro-hydro. In other words, here, the objective function is the annual cost of system (ACS). This model is suitable to find the best benchmark of cost analysis. Annual cost of system is consisted of the annual capital cost (ACC), annual operation maintenance (AOM), annual replacement cost (ARC) and annual customer damage cost (ADC). Hence, ACS is computed according to equation (13):

$$ACS = ACC + AOM + ARC + ADC \quad (13)$$

Annual capital cost of each unit that does not need replacement during project lifetime is calculated as equation (14):

$$ACS = C_{cap} CRF(i, y) \quad (14)$$

Where C_{cap} is the capital cost of each component in US$, y is the project lifetime in year. CRF is capital recovery factor, a ratio to calculate the present value of a series of equal annual cash flows. This factor is calculated as equation (15):

$$CRF = \frac{i\,(i+1)^{y}}{(1+i)^{y}-1} \quad (15)$$

Where i is the annual real interest rate. The annual real interest rate includes the nominal interest and annual inflation rates. This rate can calculated as the equation (16):

$$i = \frac{(i' - f)}{(1+f)} \quad (16)$$

Where i' is the loan interest and f is the annual inflation rate. The annual operation and maintenance cost of the system (AOM) as a function of capital cost, reliability of components λ and their lifetime can be determined using the following equation:

$$AOM = C_{cap}(1-\lambda)/y \quad (17)$$

ARC is the annual cost value for replacing units during the project lifetime. Economically, annual replacement cost is calculated using the equation (18):

$$ARC = C_{rep} SFF(i, y_{rep}) \quad (18)$$

Where C_{rep} is the replacement cost of fuel cell and electrolyzer in US$, y_{rep} is the lifetime of electrolyzer and fuel cell in year. In this case, the replacement cost of battery banks is similar toits capital cost. SFF is the sinking fund factor, a ratio to calculate the future value of a series of equal annual cash flows. This factor is calculated as equation (19):

$$SFF = \frac{i}{(i+1)^{y}-1} \quad (19)$$

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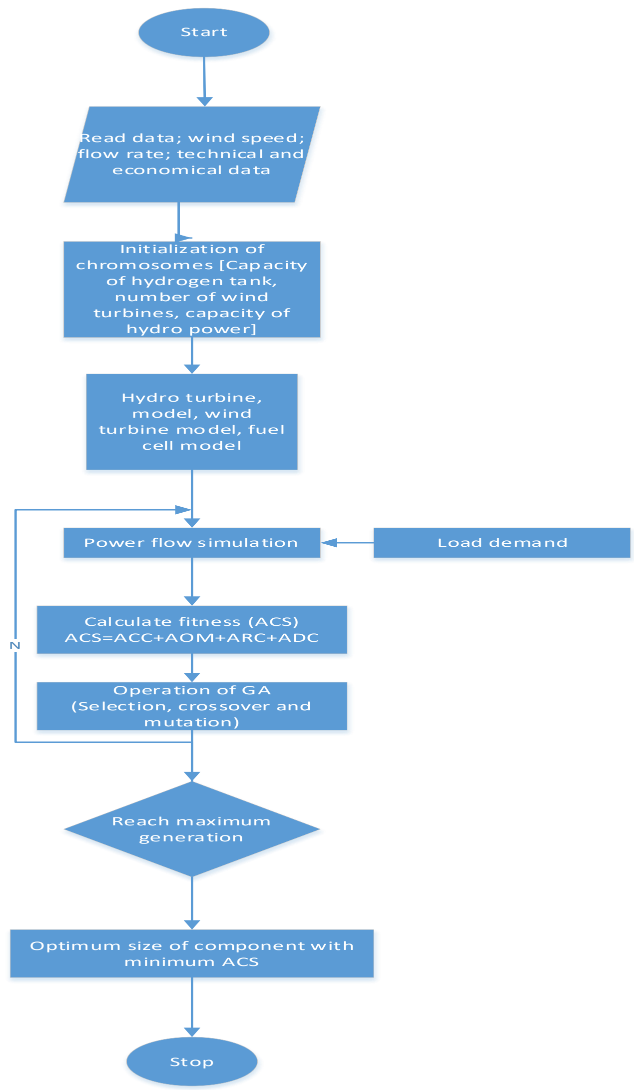

Figure 2. Proposed optimization procedure for turbines maintenance

For the purpose of present study, the annual data of flow rate of river, wind speed and load demand are initially set as the inputs. Then, the size of hydrogen micro-hydro were randomly chosen to become the algorithm's chromosomes. Each chromosome consists of three genes in form of [N_{HyT}, N_{WT}, N_{Hyd}] where N_{HyT} is the number of wind turbines and N_{Hyd} is the number of micro-hydro. After setting the initial population, the annual power supply simulation are performed. The simulations of annual power supply are repeated for each chromosome until it reaches the final generation as defined in the beginning of the simulation process. Each generation of the best chromosome is preserved and compared with the best chromosome obtained from the next generation. The best chromosome in the final generation is considered as the optimum parameter value of the hybrid system. In order to select the chromosomes subjected to the crossover and mutation for processing the next generation population, the roulette wheel method is considered as the selection process. In this simulation, the crossover and mutation probability are assumed as 0.75 and 0.015, respectively.

The convergence curves of the GA for the system under study is shown in Figure 3. It can be seen that the optimal values can be obtained closed to 70 generations. Hence, 100 iterations can be considered as a fair termination criterion.

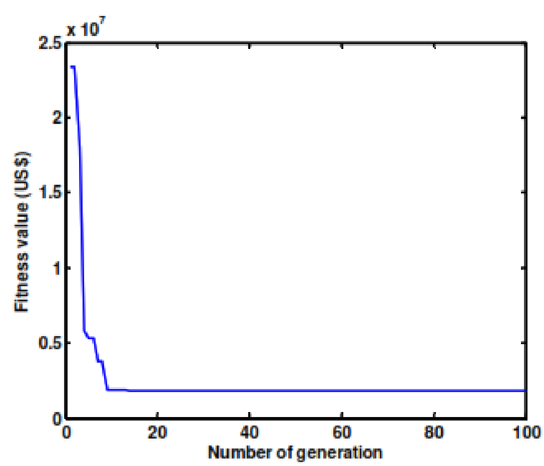

Figure 3. The convergence curves of the genetic algorithm for the system

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Table 3 depicts the capacity of each component that was optimized using GA (method 1) and trial and error (method 2). The optimum system size will be implemented in Leuwijawa hybrid power system, located in Central Java, Indonesia. The cost element of the optimum system using Genetic Algorithm is presented in Figure 7.

Table 3.The main components generating capacity of hybrid turbine

No.	Component	Capacity	
		Method 1 (GA)	Method2 (Trial and Error)
1	Hydrogen Tank	19.85 tones	19.85 tones
2	Wind Power	21 unit*100kW	23 unit*100kW
3	Hydro Power	610 kW	400kW

The optimum capacity of the components are, hydrogen tank of 19.85 tones, 21 wind turbine generator units each100kW and micro-hydro power of 610kW. In this case, overall cost to develop such a system is US$1.83 million. This cost composed of ACC of US$ 1.35 million, AOM of US$ 0.14 million and ARC is US$0.3 million and requires no annual cost for ADC. In other words, the percentage of the cost of each part of the cost is annual capital cost=75%, annual operation and maintenance= 8 %, annual replacement cost=17% and annual customer damage cost=0% interruption the value is zero. It can be concluded that the proposed configuration has 100% reliability.

Figure 4 illustrates the optimum condition provided by genetic algorithm that the Micro- hydro size is 610 kW. Other components are 21 units of wind turbine with each capacity is 100 kW,the annual cost of system is US$ 2.08 million. In this condition, the cost for annual customer damage is zero. However, the annual capital cost of method 2 was found as US$ 12.83 million

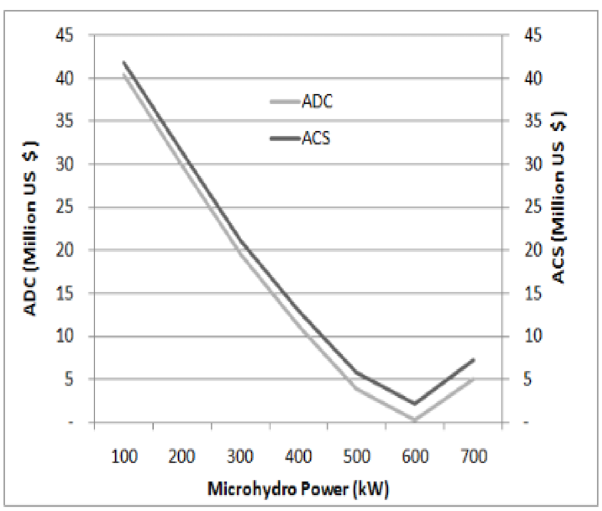

Figure 4. the optimum condition provided by genetic algorithm

Figure 5 demonstrates the daily profile of optimum component sizes to meet the load. The micro-hydro supplies constantly at 610 kW for 24 hour. When the load is lower the micro- hydro power, the remaining energy is for producing hydrogen while the fuel-cell does not supply any power to the load. Then, during the peak load, the fuel-cell contributes power to the load, sharing with the micro-hydro.

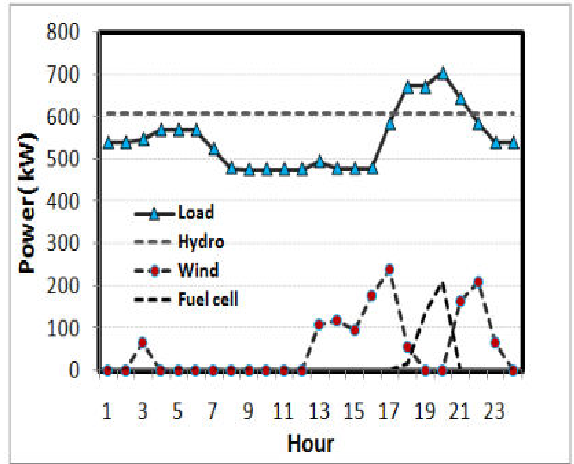

Figure 5. The daily profile of optimum component sizes to meet the load

CONCLUSION

Intelligence method by mean of genetic algorithm has been successfully tested to find the optimization of turbines maintenance. The simulation results provided an optimum configuration consist of 19.85 Tons of hydrogen tanks, 610kW of micro-hydro unit and 21 units of wind turbine with each capacity is 100kW. The annual cost of system is US$ 2.08 million, while the annual capital cost is US$ 1.35 million. This system concluded to be useful in Manjil and Rudbar Wind Farm.

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