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Investigation the Fuel Price on Optimal Sizing of Distributed Energy Resources

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Abstract: This paper presents an optimized design of Hybrid Power System in a distribution system including sources like, photovoltaic array, fuel cell and battery bank. In this study the effect of Fuel Price on optimal results is investigated.In this research, an algorithm has been developed for evaluation and cost optimization Hybrid Power System. The costs include capital cost, replacement cost, operation and maintenance cost, fuel cost and production cost for Hybrid Power System and DG power during different load profile. Then an objective function with aim to minimizing of total costs has been considered. A Simulated annealing (SA) algorithm is employed to obtain the best cost value of Hybrid Power System construction.

Key words: Hybrid Power System-Power Market- Distributed Generation- Optimization・Renewable Energy

INTRODUCTION

The issue of distributed generator and Hybrid Power System (HPS) optimal sizing in hybrid electricity market model needs to be addressed.HPS systems show great promise for integrating large numbers of distributed energy resource (DER) systems into future power networks [1-3]. The HPS concept has been researched and implemented intensively by many experts with significant research. In fact, interconnection of small, modular generation and energy storage to low or medium voltage distribution systems forms a new type of power system, the HPS. To the utility, a HPS is an electrical load that can be controlled in magnitude. Such controllable load may be constant, may increase during the night and the off-peak loads when electricity is cheaper and it may be held at zero during times of system stress. A HPS may take the form of shopping center, industrial park or college campus. The interest on HPS increases due to its potential benefits to provide reliable, secure, efficient and sustainable electricity from renewable energy sources (RES). Before the HPS concept was introduced, many researches had been conducted on distributed generation (DG) [4, 5]. Researchers soon realized that installing individual DG in power systems may create problems as many as it solves. Hence, HPS concept was proposed to overcome those problems [6]. The Deregulated energy environment, among other effects, has favored the penetration of distributed generation (DG) sources connected near the energy consumers at the medium-voltage or low-voltage (LV) side of the distribution network. In this paper a distributed power generation system based on hybrid PV/WT/Fuel cell/battery that provides part of real and reactive power to load that is connected to local grid is presented. The hybrid power system normally operates under load following mode where only the hybrid power system meets the local demand.

Hybrid Renewable Energy Sources -Photo: Voltaic (PV) power systems are dependent on climatic conditions and their output depends on the time of year, time of day and the amount of clouds. Hybridization of fuel cell with PV will therefore form a very reliable distributed generation where the fuel cell acts as back up during low PV output. The slow dynamics of the fuel cell can be compensated by adding battery energy storage. In the mean time the fuel cell may be starved of fuel which is not good for the electrocatalyst shortening its life [7, 8]. Therefore, the fuel cell should be operated under controlled steady state regime during which the battery is providing the demanded power. In this paper a ramping current reference is generated to avoid starvation of the fuel cell. Addition of the battery energy storage also avoids over sizing of the fuel cell by taking on the remaining peaking power in surplus of the fuel cell maximum power output. For loads beyond the maximum capacity of the hybrid power system and inverter, the grid supplies the rest of the local power demand. This helps to relieve transmission line congestion problem by producing most

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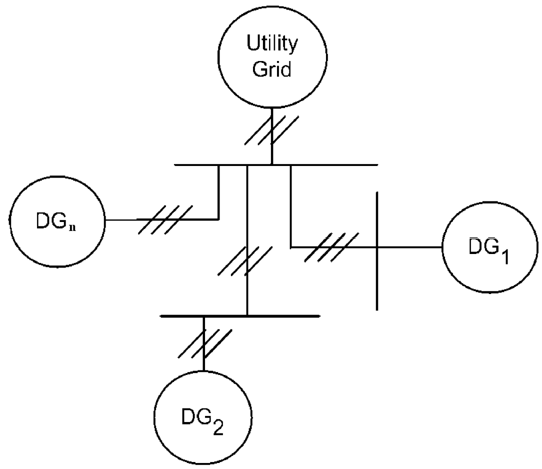

Fig. 1: Structure of Distribution System with Hybrid Power System and Multiple Distributed Generations (DGs)

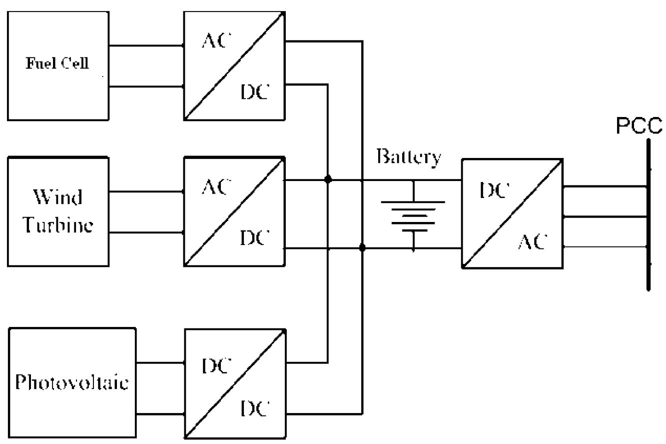

Fig. 2: Hybrid Power System based on Hybrid Renewable Energy Sources

of the local demand locally, reduce transmission line losses especially for loads very far from the utility grid. The hybrid power system can also provide ancillary service to the utility by allowing the grid operates at unity power factor at the point of common coupling.

This section presents a structure for distribution system including Hybrid Power System and multiple DG units, that shown in Fig. 1. The considered structure for Hybrid Power System in this paper is a hybrid renewable energy sources, includes PV, fuel cell and battery bank. Fig. 2 shows the structure of considered Hybrid Power System. Combining fuel cells with energy storages like batteries and super capacitors makes hybrid distributed generation systems (HDGS) could operate properly under transient conditions in demand power. Fuel cells have attracted much attention as an efficient, scalable, low-pollution means of generating electrical power. However, limited by their inherent characteristics such as a long start-up time and poor response to instantaneous power demands, hybrid fuel cell/battery power generation systems have been presented to reach the high power density of batteries with the high energy density of fuel cells. Solar (photovoltaic) energy is a major renewable energy source at the forefront of stand-alone and distributed power systems.

The components of hybrid power system analyzed and explained in detail below.

Photovoltaic Array: The PV power technology uses semiconductor cells (wafers), generally several square centimetres in size. The present PV energy cost is still higher than the price the utility customers. For that reason, the PV applications have been limited to remote locations not connected to the utility lines. Major advantages of the PV power are available.

The solar power generation for any solar radiation can be predicted by using the formula given below [9]:

$$P = Ax^2 + Bx + C \quad (1)$$

Where
x = solar radiation [W/m^2] and P = power generation [W].

A, B and C are constants, which can be derived from measured data. By using the above formula, solar power generation at any solar radiation can be predicted. This is also useful in estimating the suitable solar photovoltaic panels for many required load.

Small Wind Turbine: It is notable that wind energy is one of the most important and promising sources of renewable energy. The main advantage of this energy source is the absence of harmful emissions and its economical efficiency [10]. The wind turbine captures the wind's kinetic energy in rotor consisting of two or more blades mechanically coupled to an electrical generator. The turbine is mounted on tall tower to enhance the energy capture.

Fuel Cell: The certainty of meeting load demands at all times is greatly enhanced by the hybrid system using more than one power source. Most hybrids use fuel cell with PV or wind, since fuel cells provide more predictable power on demand. For the remote and isolated network areas the best choice to support the network demand is fuel cell [11]. Fuel cells are static energy conversion devices that convert the chemical energy of fuel directly into electrical energy. They show great promise to be an important DG source of the future due to their many advantages, such as high efficiency, zero or low emission (of pollutant gases) and flexible modular structure. Fig. 3 shows the power generation versus fuel consumption for the fuel cell.

Battery: The battery stores energy in the electrochemical form and is the most widely used device for energy storage in the variety of applications such as electric and hybrid electric vehicles and hybrid power systems [12]. The PV and wind being intermittent sources of power, cannot meet the load demand all of the time, 24 hours a day and 365 days of the year. The energy storage, therefore, is a desired future to incorporate with renewable power systems, particularly in stand-alone plants. It can significantly improve the load availability, a key requirement for any power system.

Economic Analysis: The economic viability of a proposed plant is influenced by several factors that contribute to the expected profitability. In the economical analysis, all costs such as Capital cost, Replacement cost, Operation and maintenance cost and Fuel cost (just for Fuel Cell) must be considered. For optimal design of a hybrid power system, total annualized costs are defined as follow [13, 14]:

Total annualized cost = Sum of annualized cost of each hybrid system components

Where:
Annualized cost = annual capital cost + annual replacement cost + annual operation and maintenance cost + annual fuel cost (just for Fuel Cell).

For this approach all of the factors that will be explained should be considered:

Interest Rate: The interest rate that one enters for hybrid power system input is the annual real interest rate (also called the real interest rate or just interest rate). It is

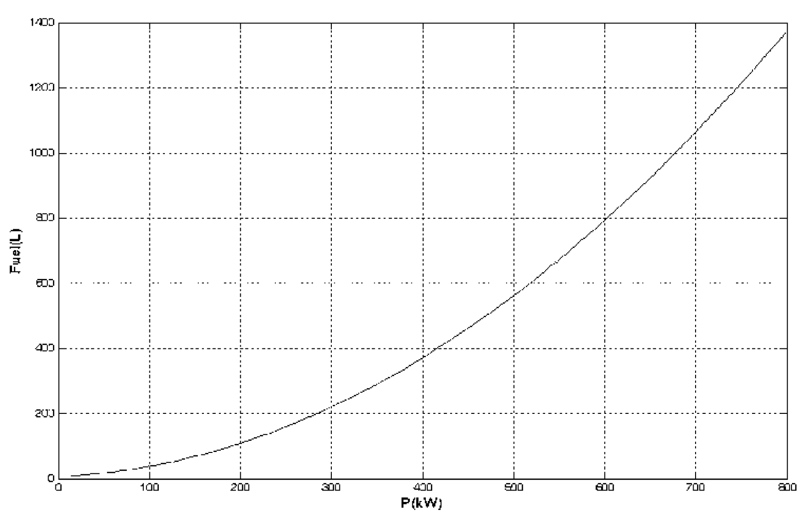

Fig. 3: Fuel-Power curve for the fuel cell

a discount rate used to convert between one-time cost and annualized cost. The annual real interest rate is related to the nominal interest rate by the equation below:

$$i = \frac{(i' - f)}{(1 + f)} \quad (2)$$

Where:

I = Real interest rate.
I' = Nominal interest rate (the rate at which you could get a loan).
F = Annual inflation rate.

Project Lifetime: The project lifetime (R_{proj}) is the length of time over which the costs of the system occur. It uses to calculate the annualized replacement cost and annualized capital cost of each component, as well as the total net present cost.

Capital Recovery Factor: The capital recovery factor is ratio used to calculate the present value of any annuity (a series of equal cash flows). The equation for the capital recovery factor is:

$$CRF(i,N) = \frac{i(1+i)^N}{(1+i)^N - 1} \quad (3)$$

Where, the above equation can be calculated by R_{proj} and R_{rep} instead of N.

The present value is the equivalent value at the present of a set of future sums, taking into account the time value of money.

Sinking Fund Factor: The sinking fund factor is ratio used to calculate the future value of a series of equal cash flows. The equation for the sinking fund factor is:

$$SFF(i,N) = \frac{i}{(1+i)^N - 1} \quad (4)$$

Where, the above equation can be calculated by R_{proj} and R_{comp} instead of N.

The future value is defined as the equivalent at some designated future date of a sequence of cash flows, taking into account the time value of money.

Replacement Cost Duration: The replacement cost duration is given by:

$$R_{rep} = R_{comp}.INT(\frac{R_{proj}}{R_{comp}}) \quad (5)$$

Where:

R_{comp} = Lifetime of the component

Remaining Life of the Component: The remaining life of the component is given by:

$$R_{rem} = R_{comp} - (R_{proj} - R_{rep}) \quad (6)$$

Annualized Capital Cost: The annualized capital cost is given by:

$$C_{acap} = C_{cap}.CRF(i, R_{proj}) \quad (7)$$

Where, C_{cap} is initial capital cost.

Formulation of Overall Cost Function: Figure 4 shows the economic representation of Capital Recovery Factor and Sinking Fund Factor versus of life time project.

According to the proposed structure for distribution system including Hybrid Power System and multiple DG units, the cost function is considered as follow:

$$Total\ Cost = Cost_{DISCO} + COST_{DGs} \quad (8)$$

Which:

Total cost is the cost of the overall system. It includes the costs of distribution company (DISCO) plus the costs of DG unit's. The DISCO provides the necessary power of customers from the Hybrid Power System and DG units. In fact the main purpose is the benefits of DG units, Hybrid Power System and DISCO are maximized.

Simulation Results: In this part, the simulation results have been presented. A typical study case LV network, presented in [15] is shown in Fig. 5, has been proposed in. The network comprises three feeders:

One serving a primarily residential area, one industrial feeder serving a small workshop and one feeder with commercial consumers. The characteristics of the Hybrid Power System have been illustrated in Table 1.

For simulation, the annual peak power has been considered as the main benchmark.

Furthermore than main constraints of the network have been given through (2)-(10), the following constraints must be considered.

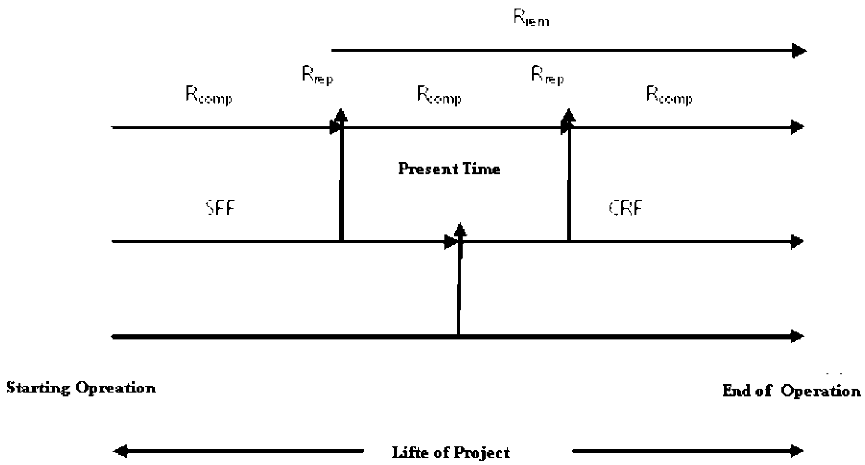

Fig. 4: Economic representation of Capital Recovery Factor and Sinking Fund Factor versus of life time project

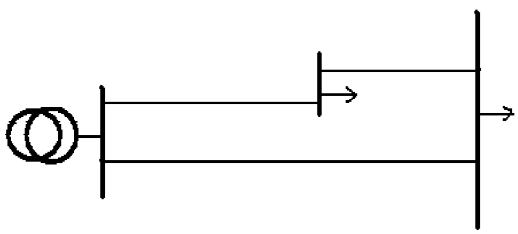

Fig. 5: Test Low Voltage Network.

Table 1: Specification of Network

Source type	Specification	Component Lifetime
Photo Voltaic array	2[kW],DC,i' = 8%, f = 0.035	25[yrs]
Fuel Cell	800[kW], DC,i' = 8%, f = 0.035	15000[hrs]
Battery	1153[Ah],6V,DC,i' = 8%, f = 0.035	12[yrs]
Other DGs	800[kW], AC,i' = 7%, f = 0.03	15000[hrs]

Table 2: Parameters of Two Different Cases

Specifications	CASE I	CASE II
$P_{request}$ [kW]	700	700
$E_{emergency}$ [kWh]	1200	1200
Average of annual radiation [kW/m^2]	0.45	0.35
Fuel price [$/lit]	0.25	0.25

Table 3: Simulation Results for Case (I)

Cost [$]	Nbatt	Ppv[kW]	Pfc [kW]	P_{WT} [kW]
196420	220.00	8	794.58	750
202310	220.00	64	778.30	730
203290	220.00	72	775.59	710
207040	220.00	0	798.38	745
215880	220.00	72	773.96	730

Table 4: Simulation Results for Case (II)

Cost [$]	Nbatt	Ppv[kW]	Pfc [kW]	PDG2 [kW]
199110	220.00	4	782.05	850
205080	220.00	0	779.01	820
258740	220.00	64	726.93	790
326460	220.00	0	665.68	855
342450	220.00	96	637.93	820

Table 5: Parameters of Two Case Studies in Order to Investigate Effect of Fuel Price

Parameters	CASE I	CASE II
Average of wind speed [m/s]	5	5
Average of annual radiation [kW/m2]	0.45	0.45
Fuel price [$/lit]	0.25	0.50

Table 6: Simulation Results with Fuel Price 0.25

Costs [$]	N_{batt}	N_{pv}	N_{wind}	P_{fc} [kW]
184860	217	0	0	800
185530	217	1	0	798.84
186690	217	0	1	798.38

Table 7: Simulation Results with Fuel Price 0.50

Costs [$]	N_{batt}	N_{pv}	N_{wind}	P_{fc} [kW]
186640	217	2	0	796.76
188600	217	3	0	795.14
222720	217	16	0	773.76

- Fuel Cell should generate less than 9 hours a day.
- Delivered and stored energy by battery bank is at most 12 hours a day.
- The PV arrays generation is between 8 am to 6 pm.

In this paper, two different cases have been considered as listed in Table 2.

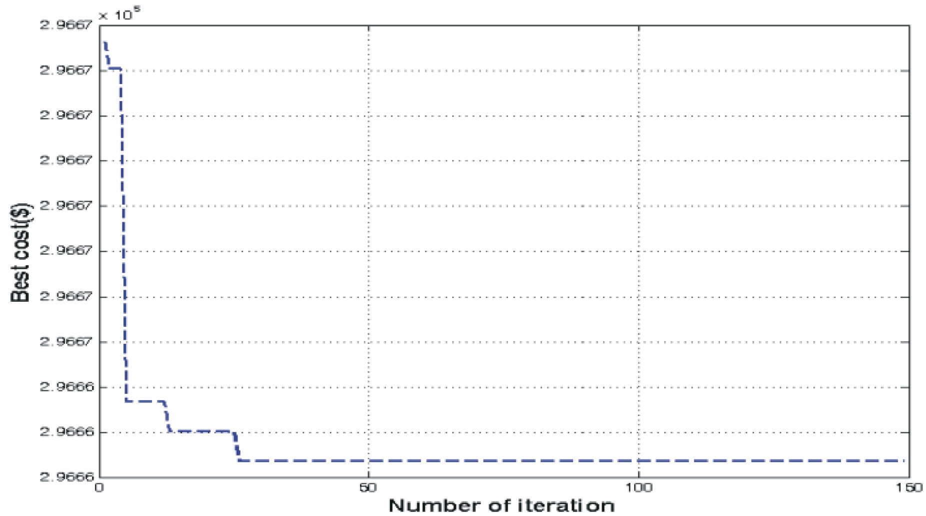

Fig. 6. Best cost value versus iteration number for case (I)

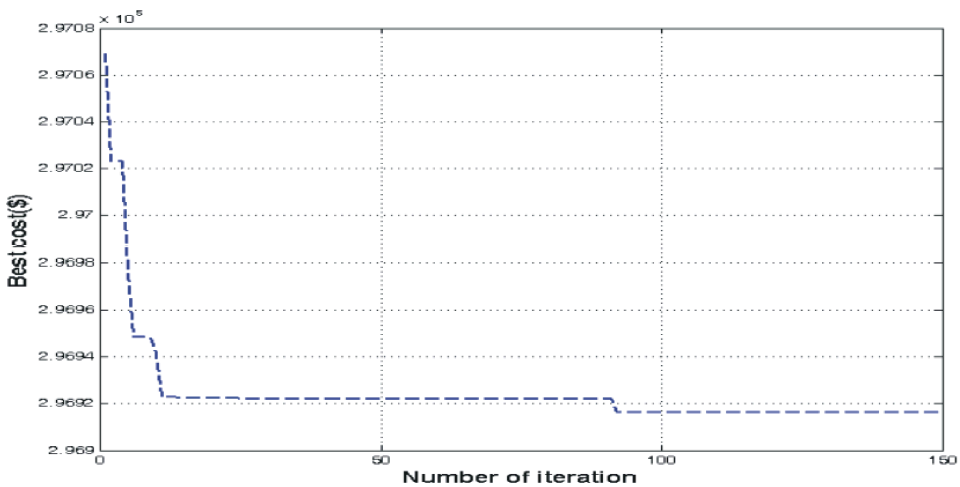

Fig. 7: Best Cost Value Versus Iteration Number for Case (II)

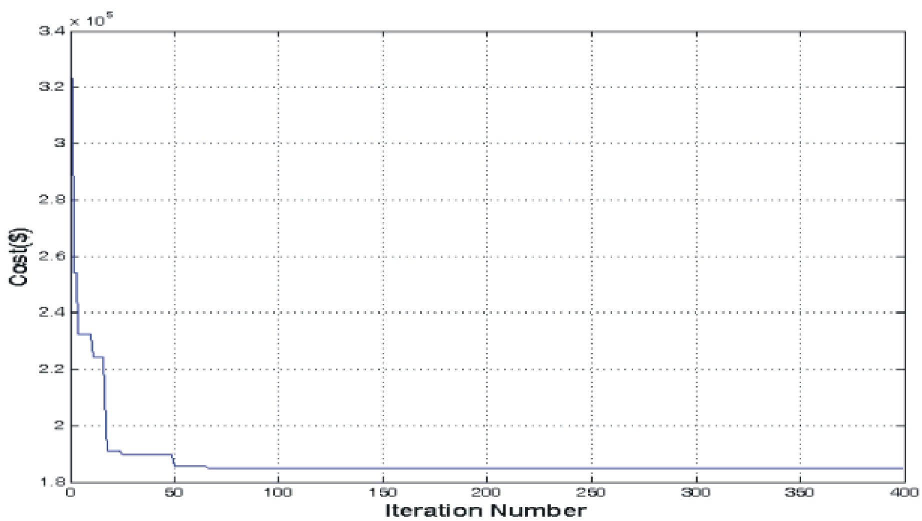

Fig. 8: Best Cost Value versus Iteration Number for Fuel Price 0.25[S/Lit] with Initial Population 200

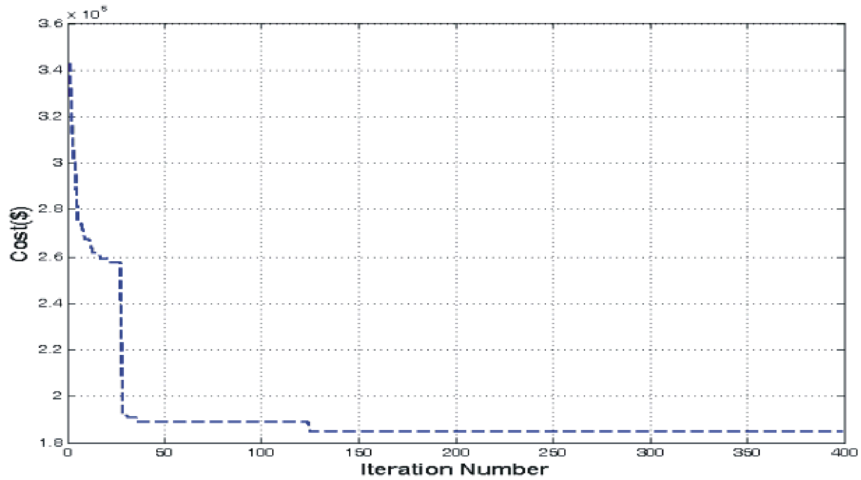

Fig. 9: Best Cost Value versus Iteration Number for Fuel Price 0.25[S/Lit] with Initial Population 100

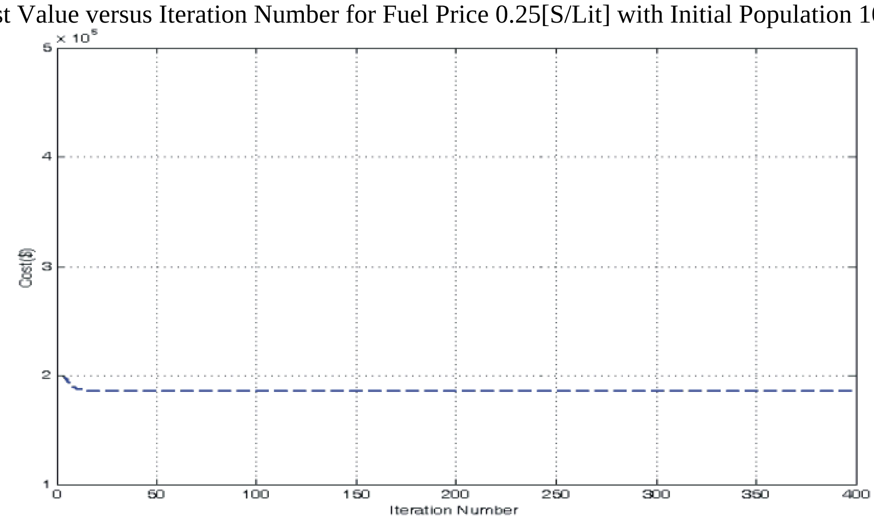

Fig. 10: Best Cost Value versus Iteration Number for Fuel Price 0.5[S/Lit] with Initial Population 200

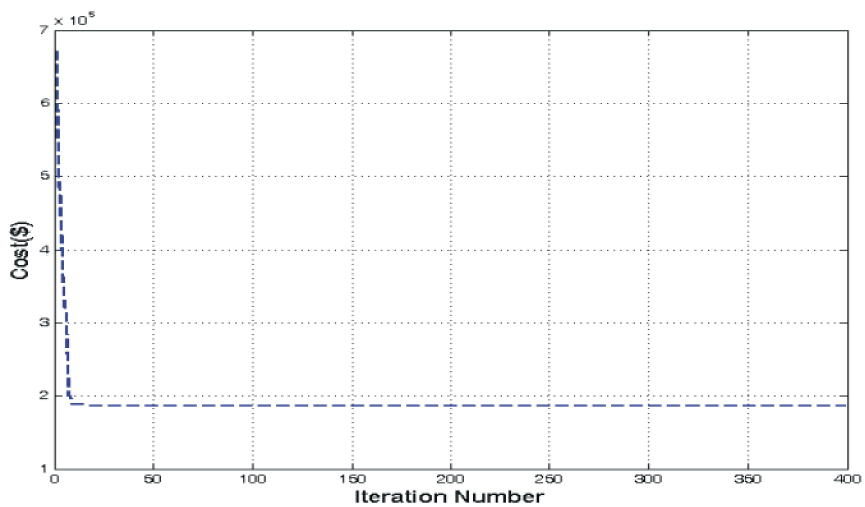

Fig. 11: Best Cost Value versus Iteration Number for Fuel Price 0.5[S/Lit] with Initial Population 100

Table 3 gives the simulation results for case (I). The best cost value is shown in Fig. 6 for this case.

Table 4 gives the simulation results for case (II). The best cost value is shown in Fig. 7 for this case.

By making comparison between Tables (3) and (4), it will be found that by decreasing the annual average radiation, PV array using rate decreased too.

It is noticeable that power production of PV sources depend on the average of annual solar radiation (e.g. for 0.35 kW/m^2 annual radiation a 2 kW PV array can generate 1.1562 kW and for 0.45 kW/m^2, 1.3562kW).

For each case to cover the emergency load energy, a battery bank includes 217 modules must be considered.

In order to investigate the effect of fuel price on optimized results, according Table 5 the two case studies are considered. Table 6 and 7 give the simulation results for case studies with fuel price 0.25 and 0.50 respectively. For these case studies Figs. 8-11 represent the variation of best cost values versus of iteration number with initial population equals to 100 and 200 respectively.

CONCLUSION

This paper deals with the economic evaluation of a typical Hybrid Power System participating in a market following different policies. An optimized design of Hybrid Power System includes sources like, photovoltaic array, fuel cell and battery bank based on an evolutionary algorithm has been presented. For this approach, economic aspects such as interest rate, inflation, capital recovery factor, sinking found factor have been expressed for each power sources and then an objective function with aim to minimizing of all system costs has been clarified. A Simulated annealing (SA) algorithm is employed to obtain the best cost value of hybrid power system construction. The developed optimization algorithms are applied on a typical LV study case network operating under market policies. The effects on the Hybrid Power System and the distribution network operation are presented and discussed. Also in this paper the effect of variation of fuel price on optimum value of each energy sources in distribution network is analyzed.

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