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Minimum Cost Design of Distributed Energy Resources with Studying the Effect of Capital Cost and Replacement Cost

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Abstract: This study presents an optimized design of HPS in a distribution system including sources like, photovoltaic array, Diesel generator and battery bank.In this research, an algorithm has been developed for evaluation and cost optimization HPS. The costs include capital cost, replacement cost, operation and maintenance cost, fuel cost and production cost for HPS and DG power during different load profile. Then an objective function with aim to minimizing of total costs has been considered. A genetic algorithm approach is employed to obtain the best cost value of HPS construction. This study tested on case study network on Mardasht city in Iran.

Key words: Distributed generation, economic analysis, hybrid power system, optimization, power market

INTRODUCTION

In restructured power market environment, under competition and open access, the different transactions can be take place between buyers and sellers directly; these transactions are bilateral, multilateral and ancillary services transactions (Amin and Masoud, 2007). The most important character of HPSs is that the power generators are distributed and located in close proximity to the energy users (Lopes *et al*., 2006). The HPS can supply electricity and heat together. It can interconnect to the larger electricity network, or can operate independently in a deliberate and controlled away. Recently many investigations have been done on the operation, control and management of HPSs. In most researches such as (Colle *et al*., 2004) the economical studies of each power sources inside HPS have not been considered properly and a complete study about the different costs for HPS and distribution system has not been presented (Durga and Nadarajah, 2007). 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 Hybrid Power System (HPS). To the utility, a HPS is an electrical load that can be controlled in magnitude (Bakos and Soursos, 2002; Celli *et al*., 2005). 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. In this research, an algorithm has been developed for evaluation and cost optimization HPS. The costs include capital cost, replacement cost, operation and maintenance cost, fuel cost and production cost for HPS and DG power during different load profile. Then an objective function with aim to minimizing of total costs has been considered. Also in this paper the effect of the initial capital cost and initial replacement cost of each energy source on optimal sizing of distributed energy resources or DGs has been investigated and for various of initial capital cost and initial replacement cost of each energy source, the simulation results including total costs, optimal number of batteries and optimal value of generated power with photovoltaic arrays and fuel cell are obtained and listed.

POWER SYSTEM IN PRESENCE OF MULTIPLE DISTRIBUTED GENERATORS (DG)

The hybrid power system normally operates under load following mode where only the hybrid power system meets the local demand .This section presents a structure for distribution system including HPS and multiple DG units, that shown in Fig. 1. The considered structure for HPS in this paper is a hybrid renewable energy sources, includes PV, fuel cell and battery bank. Figure 2 shows the structure of considered HPS. 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 (Colle *et al*., 2004). However,

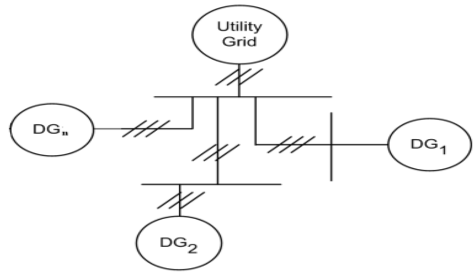

Fig. 1: Structure of distribution system with HPS and multiple Distributed Generations (DGs)

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 (Lopes *et al*., 2006). 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:

$$P = Ax^2 + Bx + C \tag{1}$$

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.

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 (Ault *et al*., 2003). The PV and wind being intermittent sources of power, cannot meet the load demand all of the time, 24 h 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.

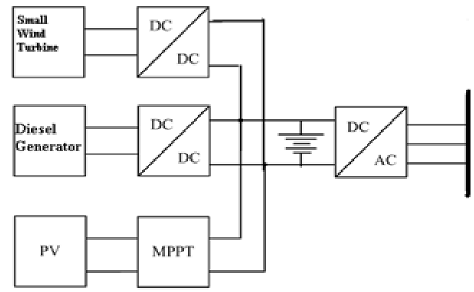

Fig. 2: HPS based on hybrid renewable energy sources

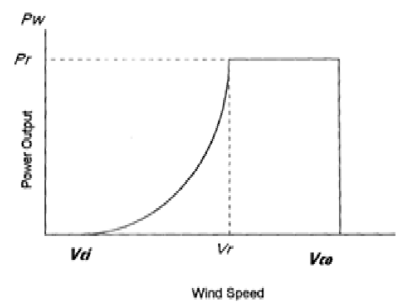

Fig. 3: Generation characterization of a wind turbine

It can significantly improve the load availability, a key requirement for any power system.

Small Wind Turbines (WTs): Wind turbines have improved in technology in recent years so that their efficiency has increased from 15% up to 50%.

The rotor of turbine is connected to induction generator. This connection is done from gearbox for adapting the speed of rotation of rotor (Diaf *et al*., 2007). The output power of wind turbines is follow as:

$$\begin{cases} P_w = 0 & v \langle v_{CI} \\ P_w = a\,v^3 - b\,P_r & v_{CI} \langle v \langle v_r \\ P_w = P_r & v_r \langle v \langle v_{CO} \\ P_w = 0 & v \rangle v_{CO} \end{cases} \tag{2}$$

That the parameters “a” and “b” calculated as:

$$a = p_r / (v_r^3 - v_{CI}^3) \tag{3}$$

$$b = v_{CI}^3 / (v_r^3 - v_{CI}^3) \tag{4}$$

In these equations:
P_w is the measurement power at the turbine
P_r is the nominal power of turbine
V_r is the speed related to nominal power
V is the speed of wind
V_{CI} is the low cut speed
V_{CO} is the up cut speed

Figure 3 shows the output power of wind turbine versus of its speed.

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. 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. The turbine power versus wind speed curve for Generic 10 kW is plotted in Fig. 4.

Diesel generator: The certainty of meeting load demands at all times is greatly enhanced by the hybrid system using more than one power source (Carlson, 1995; Katiraei *et al*., 2005). Most hybrids use diesel generator with PV or wind, since diesel generator provide more predictable power on demand. For the remote and isolated network areas the best choice to support the network demand is diesel generator. They 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.

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 must be considered (Carlson, 1995; Katiraei *et al*., 2005). For optimal design of a hybrid power system, total annualized costs are defined as follow:

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 costs

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 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:

$$i = \frac{(i' - f)}{(1 + f)} \tag{5}$$

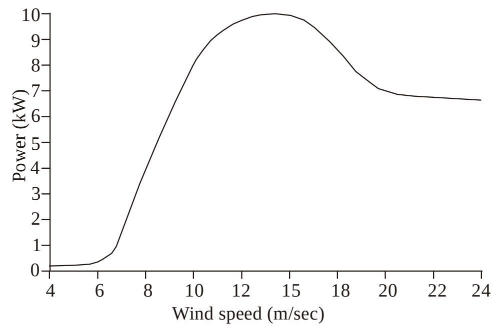

Fig. 4: 10 kW generic wind turbine power generation curve

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 (Rproj) 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:

$$CRF\ (i, N) = \frac{i(1+i)^N}{(1+i)^N - 1} \tag{6}$$

where, the above equation can be calculated by Rproj and Rrep 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:

$$SFF\ (i, N) = \frac{i}{(1+i)^N - 1} \tag{7}$$

where, the above equation can be calculated by Rproj and Rcomp 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:

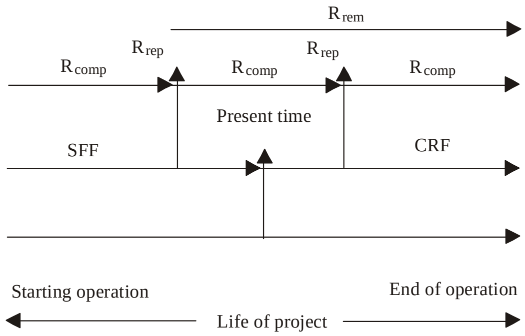

Fig. 5: Economic representation of capital recovery factor and sinking fund factor versus of life time project

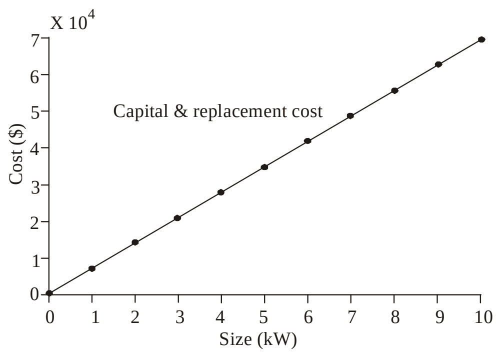

Fig. 6:Cost characteristic of PV

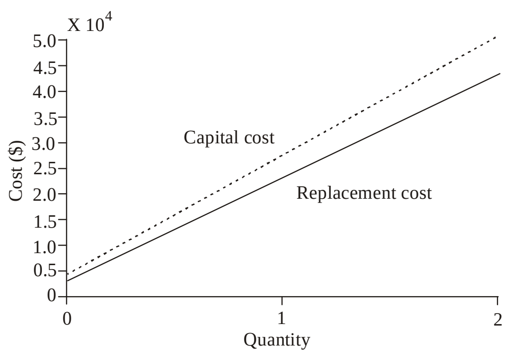

Fig. 7: Cost characteristic of WT

$$R_{rep} = R_{comp} \, .INT\left(\frac{R_{proj}}{R_{comp}}\right) \tag{8}$$

where, Rcomp = life time of the component.

Remaining life of the component:

$$R_{rem} = R_{comp} - (R_{proj} - R_{rep}) \tag{9}$$

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

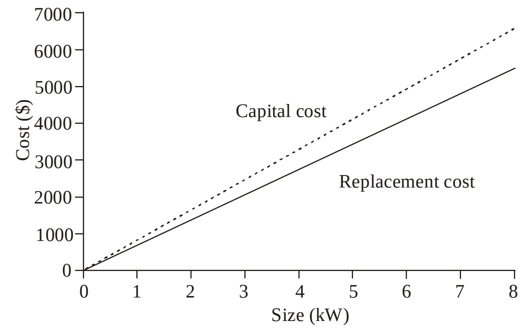

Fig. 8: Cost characteristic of diesel generator

$$C_{acap} = C_{cap} \, .CRF\,(i, R_{proj}) \tag{10}$$

where, Ccap is initial capital cost.

Formulation of overall cost function: Figure 5 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 HPS and multiple DG units, the cost function is considered as follow:

$$Cost = \sum_{i} (C_{acapi} + C_{arepi} + C_{0\&mi} + Ca_{fueldg}) \tag{11}$$

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 HPS and DG units. In fact the main purpose is the benefits of DG units, HPS and DISCO are maximized

Figure 6, 7 and 8 show the Cost characteristic of PV, WT and Diesel Generators (Diaf *et al*., 2007).

SIMULATION RESULTS

In this part, the simulation results have been presented. A typical study case LV network, shown in Fig. 9, 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 HPS have been illustrated in Table 1.

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 [h]
Battery	1153 [Ah], 6V, DC I' = 8%, f = 0.035	12 [yrs]
Other DGs	800 [kW], AC I' = 7%, f = 0.03O	15000 [h]

Table 2: Parameters of two different cases

	Case I	Case II
$P_{request}$ [kW]	800	800
$E_{emergency}$ [kWh]	1500	1500
Average of annual Radiation [kW/m^2]	0.35	0.25
Fuel price [$/L]	0.20	0.20

Table 3: Simulation results for case (I)

Cost [$]	Nbatt	Ppv[kW]	P_{Disg} [kW]	P_{WT} [kW]
196420	250.201	8	794.58	730
202310	250.201	64	778.30	710
203290	250.201	72	775.59	700
207040	250.201	0	798.38	720
215880	250.201	72	773.96	690

Table 4: Simulation results for case (II)

Cost [$]	Nbatt	Ppv[kW]	P_{Disg} [kW]	P_{WT} [kW]
199110	250.201	4	782.05	750
205080	250.201	0	779.01	730
258740	250.201	64	726.93	710
326460	250.201	0	665.68	745
342450	250.201	96	637.93	730

Table 5: Various coefficients of production characteristics for energy sources

	A_{cap} [$/kw]	B_{cap} [$]	A_{rep}[$/kW]	B_{rap}[$]	A_{osm} (%)
WT	365	40	300	30	0.1
PV	2000	0	2000	0	0.0
FC	812.5	0	587.5	0	1.0
Battery bank	1200	0	1100	1	0.1

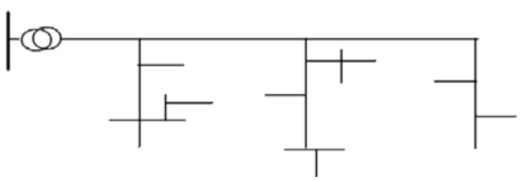

Fig. 9: Study case LV network

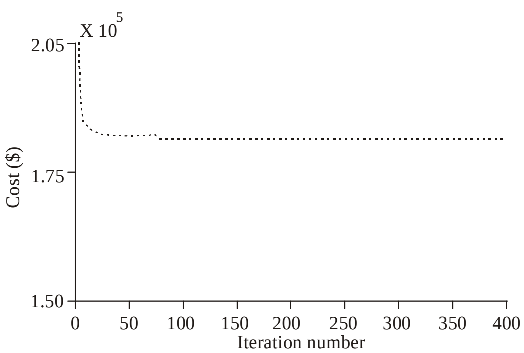

Fig. 10: Best cost value versus iteration number for case (I)

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.

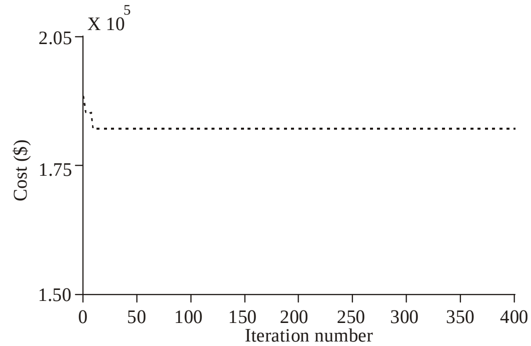

Fig. 11: Best cost value versus iteration number for case (II)

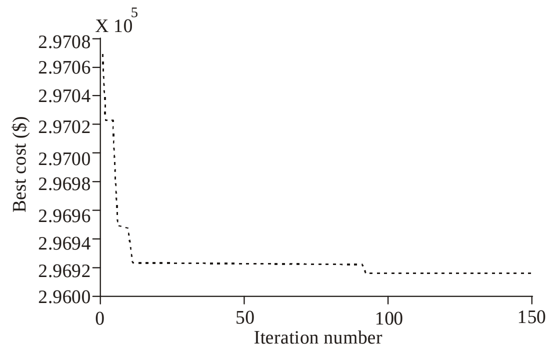

Fig. 12: Best cost value versus iteration number for various coefficients of production characteristics of WT

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

In this study, two different cases have been considered as shown in Table 2.

Table 3 shows the simulation results for case (I). The best cost value is shown in Fig. 10 for case (I).

Table 4 shows the simulation results for case (II). The best cost value is shown in Fig. 11 for case (II).

Table 6 gives the simulation results for various coefficients of production characteristics of WT. Table 7 gives the simulation results for various coefficients of production characteristics of PV. Table 8 gives the simulation results for various coefficients of production characteristics of FC. Table 9 gives the simulation results for various coefficients of production characteristics of Battery.

Figure 12 shows the best cost value versus iteration number for various coefficients of production characteristics of WT. Figure 13 shows the best cost value versus iteration number for various coefficients of production characteristics of PV. Figure 14 shows the best cost value versus iteration number for various coefficients

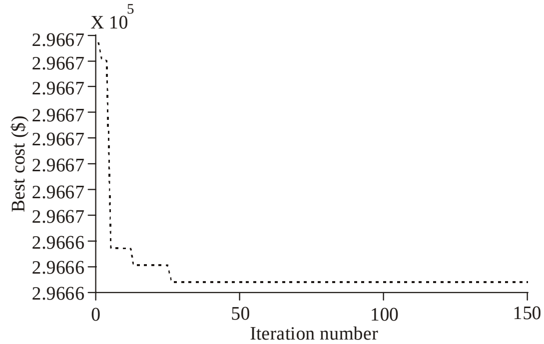

Fig. 13: Best cost value versus iteration number for various coefficients of production characteristics of PV

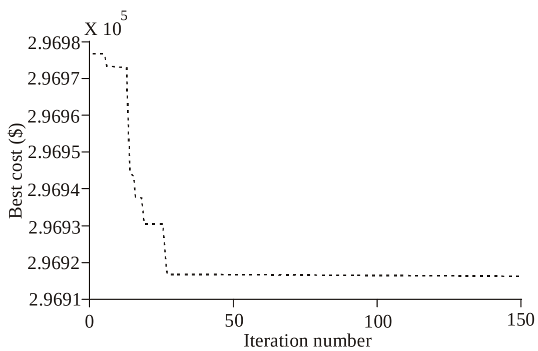

Fig. 14: Best cost value versus iteration number for various coefficients of production characteristics of FC

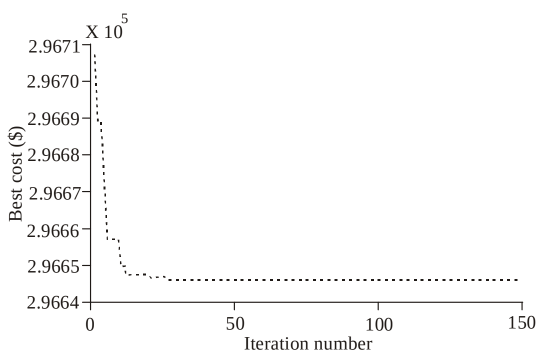

Fig. 15: Best cost value versus iteration number for various coefficients of production characteristics of battery

of production characteristics of FC. Figure 15 shows the best cost value versus iteration number for various coefficients of production characteristics of Battery.

By making comparison between Table 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 0.25 kW/m^2 annual radiation a 2 kW PV array can generate 1.1562 kW and for 0.35 kW/m^2, 1.3562 kW).

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

Table 6: Simulation results for various coefficients of production characteristics of WT

Costs [$]	N_{batt}	P_{pv}[kW]	P_{wind}[kW]	P_{Disg} [kW]
296690	217	28.05	537.29	34.662
296730	217	2.55	369.39	228.06
296760	217	85.425	369.39	145.19

Table 7: Simulation results for various coefficients of production characteristics PV

Costs [$]	N_{batt}	P_{pv} [kW]	P_{wind} [kW]	P_{Disg} [kW]
296920	217	81.6	0	518.4
296930	217	40.8	4.1976	555.0
296930	217	0	4.1976	595.8

Table 8: Simulation results for various coefficients of production characteristics FC

Costs [$]	N_{batta}	P_{pv} [kW]	P_{wind} [kW]	P_{Disg} [kW]
296680	217	0	470.13	129.87
296770	217	36.975	264.45	298.58
296840	217	25.5	130.12	444.38

Table 9: Simulation results for various coefficients of production characteristics battery

Costs [$]	N_{batta}	P_{pv} [kW]	P_{wind} [kW]	P_{Disg} [kW]
296950	217	8.925	0	591.08
296960	217	45.9	8.3951	545.70
296980	217	6.375	16.79	576.83

In order to investigate the effect of the Initial Capital Cost and Initial Replacement Cost of on optimized results, the various coefficients of production characteristics for Photovoltaic, Wind Turbine and Diesel generator are analyzed. In order to studying the effect of capita cost and replacement cost, various coefficient of capital cost and replacement cost of each energy source are considered as Table 5.

In this studying, for investigating the effect of economic parameters of each energy source on optimal results, four simulations have been considered and in each simulation the effect of economic of each energy source have been analyzed. Table 6 gives the simulation results for various coefficients of production characteristics of WT. Table 7 gives the simulation results for various coefficients of production characteristics of PV. Table 8 gives the simulation results for various coefficients of production characteristics of FC. Table 9 gives the simulation results for various coefficients of production characteristics of Battery. Figure 12 shows the best cost value versus iteration number for various coefficients of production characteristics of WT. Figure 13 shows the best cost value versus iteration number for various coefficients of production characteristics of PV. Figure 14 shows the best cost value versus iteration number for various coefficients of production characteristics of FC. Figure 15 shows the best cost value versus iteration number for various coefficients of production characteristics of Battery.

CONCLUSION

This study deals with the economic evaluation of a typical HPS participating in a market following different policies. An optimized design of HPS 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 genetic algorithm approach 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 HPS and the distribution network operation are presented and discussed. Investigation the Initial Capital Cost and Initial Replacement Cost of each Energy Source on Optimal Sizing of Distributed Energy Resources are analyzed in this study.

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