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Investigation the Interest Rate of Each Energy Source on Optimal Sizing of Distributed Energy Resources

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Abstract: In this research the effect of variation of interest rate of each energy source on optimal results are investigated. This study 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, 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 genetic algorithm approach is employed to obtain the best cost value of Hybrid Power System construction.

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

INTRODUCTIONS

Some of papers have studied the particular kind of is tribution generation (Amin *et al*., 2007). In other investigation the combination of various energy resources have been considered (Thomas, 2007).every kind of DGs have particular limitations for instance, capacity of the DG sources varies from few kilowatts to 1-2 MW. The resource limitation of fossil fuels and the problems arising from their combustion has led to widespread research on the accessibility of new and renewable energy resources (Lopes *et al*., 2006), so the hybrid model combines several features of the previous two models. Many papers have discussed optimization energy resources in hybrid power market policy. In hybrid power market model, a lot of transactions are expected between buyers and sellers for more flexible and economic market operation (Ault *et al*., 2003; Durga *et al*., 2007). These transactions need to be evaluated ahead of their scheduling time to check their feasibility with respect to system operating conditions. Infeasible transactions can alter the economic schedule, cause congestion and threaten system security and stability of the network. 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) (Amin *et al*., 2010). 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. Hence, in this paper a structure is proposed for HPS based on hybrid renewable energy sources with multiple DG units in distribution system. 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 Interest Rate of each Energy Source on optimal sizing of distributed energy resources or DGs has been investigated and for various of Interest Rate of photovoltaic and fuel cell 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 as results.

PROPOSED STRUCTURE OF POWER SYSTEM BASED ON HYBRID RENEWABLE ENERGY SOURCES

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 supercapacitors 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,

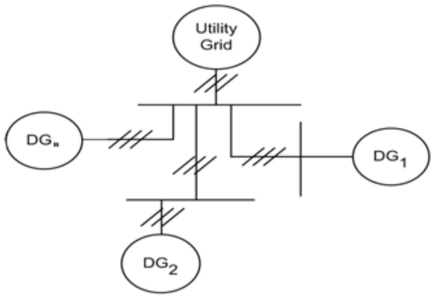

Fig.1: Structure of distribution system with hybrid power system and multiple Distributed Generations (DGs)

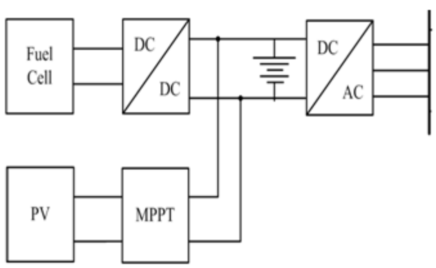

Fig. 2: Hybrid power system based on hybrid renewable energy sources

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.

Photovoltaic (PV) power systems are, however, 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 (Colle *et al*., 2004). In the mean time the fuel cell may be starved of fuel which is not good for the electro catalyst shortening its life. 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. In this study a distributed power generation system based on hybrid PV/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. 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 of the local demand locally, reduce transmission line losses especially for loads very far from the utility grid (Celli *et al*., 2005). 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.

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 (Lasseter, 2000; Ault *et al*., 2003). 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:

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

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

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 (Hatziargyriou and Meliopoulos, 2002).

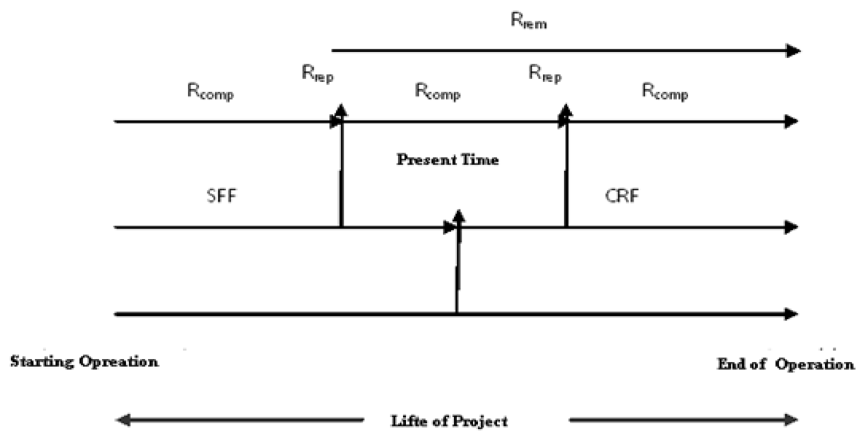

Fig. 3: Economic representation of Capital Recovery Factor and Sinking Fund Factor versus of life time project

For the remote and isolated network areas the best choice to support the network demand is fuel cell. 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 zexible modular structure. Figure 3 shows the power generation versus fuel consumption for the fuel cell.

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 (Lopes *et al.*, 2006). 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 cost (just for Fuel Cell) For this approach all of the factors that will be explained shoul 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:

$$i = (i - f) / (1 + f) \qquad (2)$$

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:

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

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:

Table 1: Specification of distributed generators

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]

$$SFF(i,N) = i/(1+i)^N - 1$$

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:

$$R_{rep} = R_{comp}.INT(R_{proj} / R_{comp})$$

where; R_{comp} = lifetime of the component

Remaining life of the component:

$$R_{ren} = R_{comp} - (R_{proj} - R_{rep})$$

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

$$C_{acap} = C_{cop}.CRF(i, R_{proj})$$

where, C_{cap} is initial capital cost.

Formulation of overall cost function: Figure 3 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:

$$\text{TotalCost}_{\text{DISCO}} = \text{Cost}_{\text{DGs}}$$

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.

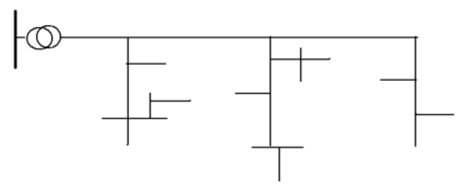

Fig. 4: Study case LV network

Table 2: Parameters of two different cases

	Case I	Case II
Prequest (Kw)	800	800
Eemergency (kWh)	1500	1500
Average of annual radiation (kW/m^2)	0.35	0.25
Fuel price ($/L)	0.2	0.2

Table 3.Simulation results for case (I)

Cost [$]	Nbatt (kA.h)	Ppv (kW)	Pfc (kW)
96420	240.001	8	794.58
202310	240.00	64	778.3
203290	245.00	72	775.59
207040	245.00	0	798.38
215880	245.00	72	773.96

SIMULATION RESULTS

In this part, the simulation results have been presented. A typical study case LV network, shown in Fig. 4, has been proposed in (Bakos and Soursos, 2002). 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 distributed generation applied in 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:

- 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. 5 for case (I).

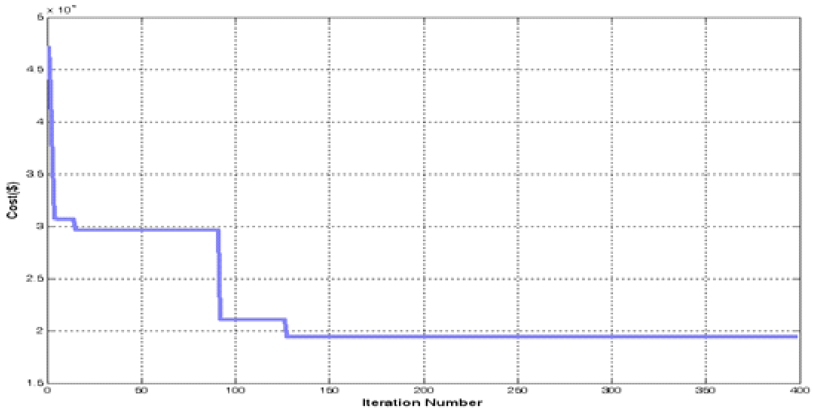

Fig. 5: Best cost value versus iteration number for case (I)

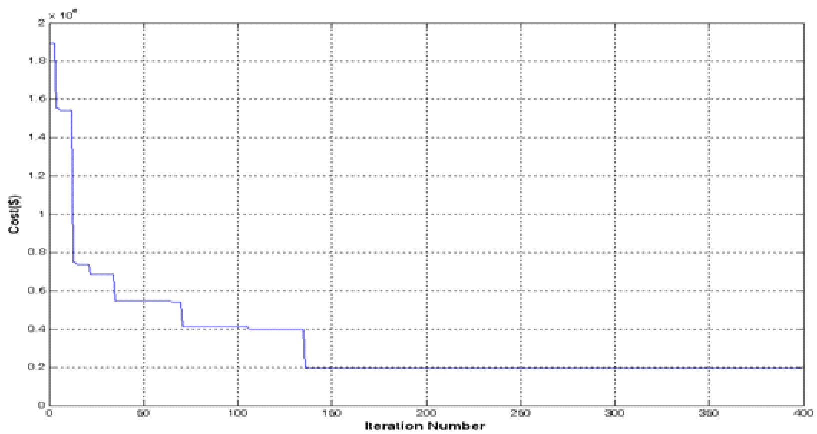

Fig. 6: Best cost value versus iteration number for case (II)

Table 4: Simulation results for case (II)

Cost [$]	Nbatt	Ppv[kW]	Pfc [kW]
199110	250.201	4	782.05
205080	250.201	0	779.01
258740	250.201	64	726.93
326460	250.201	0	665.68
342450	250.201	96	637.93

Table 5: Simulation Results for various interest rates for Photovoltaic arrays

Interest rates	Costs ($)	Nbatt	Ppv (kW)	Pfc (kW)
i_{pv}=0.0790	296140	217	600	0
i_{pv} =0.0795	296610	217	597.97	2.025
i_{pv} =0.0805	296920	217	1.275	594.53
i_{pv}=0.0811	296935	217	0	591.6

Table 6: Simulation Results for various interest rates for Fuel Cell

Interest rates	Costs ($)	Nbatt	(Ppv)kW	Pfc (kW)
i_{fc} = 0.0790	296600	217	0	600
i_{fc} = 0.0795	296770	217	28.05	567.75
i_{fc} = 0.0805	297050	217	196.35	395.25
i_{fc} = 0.0811	297100	217	532.95	50.26

Table 4 shows the simulation results for case (II). The best cost value is shown in Fig. 6 for case (II).
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. In order to investigate the effect of interest rate on optimized results, the various interest rates for Photovoltaic and Fuel cell are analyzed and simulation results are listed in Table 5 for various interest rates of photovoltaic arrays and listed in Table 6 for various interest rates of fuel cell. Simulation results including Cost, number of battery, value of power must be generated with PV and FC.

CONCLUSION

This study 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 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 Hybrid Power System and the distribution network operation are presented and discussed.

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