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

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Abstract: This study presents an investigation of Inflation Rate of each Energy Source on the optimized design of Hybrid Power System (HPS) in a distribution system including sources like, photovoltaic array, fuel cell 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.

Key words: Annual inflation rate, distributed generation, hybrid power system, optimization, power market, renewable energy

INTRODUCTION

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. These sources comprise several technologies, such as diesel Engines, Micro Turbines (MTs), and fuel cells either in Combined Heat and Power (CHP) operation or purely for electricity production, Photovoltaic (PV), small Wind Turbines (WTs), hydro turbines, etc.

Some of papers have studied the particular kind of istribution generation (Amin *et al*., 2007).in other investigation the combination of various energy resources have been considerd (Thomas, 2007). Every kind of DGs have particular limitations. for instance, The 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). Solar, wind, hydro sources, and biogas are among these renewable energy resources (Ault *et al*., 2003).

Solar and wind energy are non-depletable, site-dependent, non-polluting, and potential sources of alternative energy. However, common drawback with solar and wind energy is their unpredictable nature, so for overcome this problem the idea of combination of solar energies with other distributed energies such as wind turbine are presented (Durga and Mithulananthan, 2007). Standalone Photovoltaic (PV), do not produce usable energy for considerable portion of time during the year. This is mainly due to dependence on sunshine hours, which are variable. In general, the variations of solar and wind energy do not match with the time distribution of demand.

The independent use of both the systems results in considerable over-sizing for system reliability, which in turn makes the design costly. In fact, interconnection of small, modular generation and energy storage to low or medium voltage distribution systems forms a new type of power system, named the Hybrid Power System (HPS) (Amin *et al*., 2010). The most important character of HPSs is that the power generators are distributed and located in close proximity to the energy users. The HPS supplies electricity and heat together. It can interconnect to the larger electricity network, or can operate independently in a deliberate and controlled way.

Hence, in this study 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 study the effect of Annual Inflation Rate of each Energy Source on optimal sizing of distributed energy resources or DGs has been investigated and for various Annual Inflation 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.

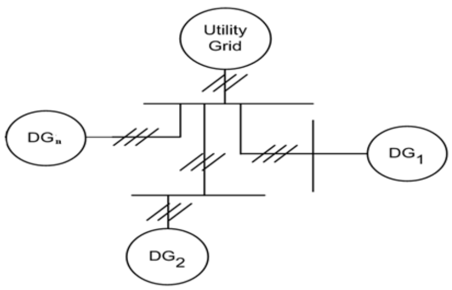

Fig. 1: Structure of distribution system with HPS and multiple Distributed Generations (DGs)

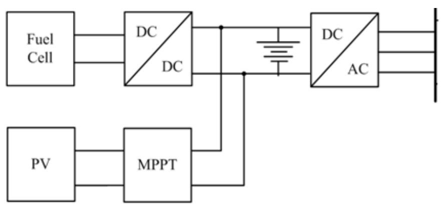

Fig. 2: HPS based on hybrid renewable energy sources

PROPOSED STRUCTURE OF POWER SYSTEM BASED HPS

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. 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 study is a hybrid renewable energy sources, includes PV, fuel cell and battery bank. Figure 2 shows the structure of considered HPS.

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 study 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

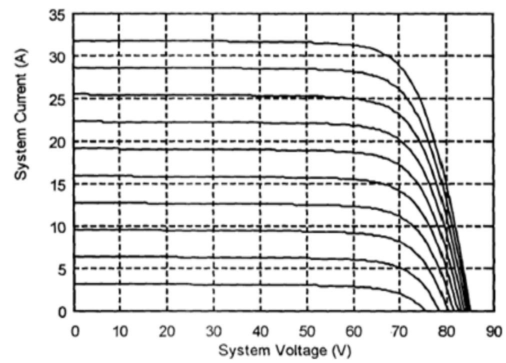

Fig. 3: Voltage-current characterization of a photovoltaic array

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 (Celli *et al*., 2005.). 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. 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.

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 (Carlson, 1995; Katiraei *et al*., 2005). 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 centimeters in size. The present PV energy cost is still higher than the price the utility customers (Lasseter, 2000). 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:

$$P = Ax^2+Bx+C$$

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. Figure 3 shows the V-I characteristics of PV.

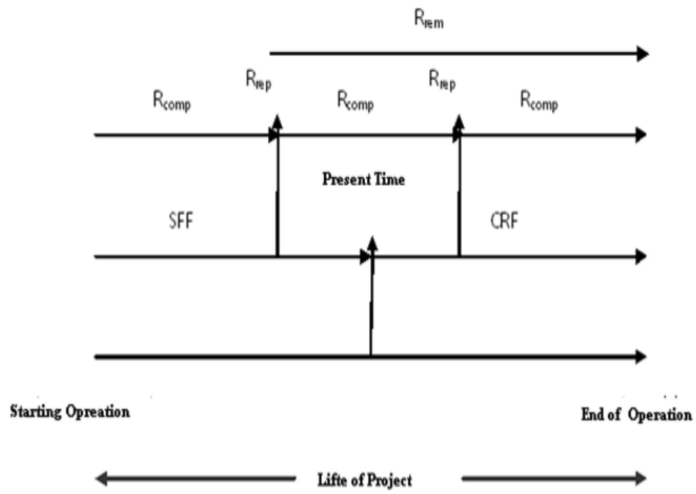

Fig. 4: Economic representation of Capital Recovery Factor and Sinking Fund Factor versus of life time project

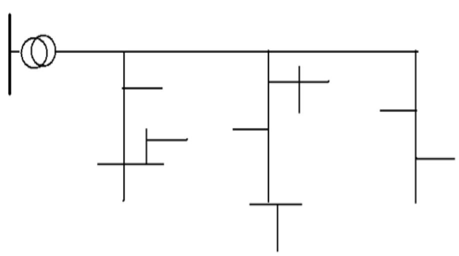

Fig. 5: Study case LV network

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. 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 (Diaf *et al.*, 2007). 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 (just for Fuel Cell) must be considered (Hatziargyriou *et al.*, 2007; Hatziargyriou and Meliopoulos, 2002). 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 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:

$$I = (i' - f)/(1+f)$$

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:

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

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:

$$SFF(i,N) = \frac{i}{(1+i)^N - 1} \quad (2)$$

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:

$$R_{rep} = R_{comp}.INT\left(\frac{R_{proj}}{R_{comp}}\right) \quad (3)$$

where; R_{comp} = lifetime of the component

Remaining life of the component:

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

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

$$C_{acap} = C_{cap}.\ CRF(i, R_{porj})$$

where, C_{cap} is initial capital cost.

Figure 4 shows the economic representation of Capital Recovery Factor and Sinking Fund Factor versus of life time project.

Formulation of overall cost function: According to the proposed structure for distribution system including HPS and multiple DG units, the cost function is considered as follow:

$$\text{Total cost} = \text{Cost}_{DISCO} + \text{Cost}_{DGS}$$

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

SIMULATION RESULTS

In this part, the simulation results have been presented. A typical study case LV network as considered in (Bakos and Soursos, 2002), 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 HPS 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. 6 for case (I).

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

Table 1: Specification of energy resources

Source type	Specification	Component lifetime
Photo voltaic array	2[kW],DC, i' = 8%, f = 0.035	(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 = 0.03	15000 (h)

Table 2: Parameters of two different cases

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

Table 3: Simulation results for case (I)

Cost ($)	Nbatt	Ppv (kW)	Pfc (kW)
196420	250.201	8	94.58
202310	250.201	64	778.30
203290	250.201	72	775.59
207040	250.201	0	798.38
215880	250.201	72	773.96

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
342450	250.201	96	637.93

Table 5: Simulation Results for various Annual Inflation rates for Photovoltaic arrays

Pfc(kW)	Ppv (kW)	Nbatt	Costs ($)	Inflation rate
591.6	0	217	296920	$f_{pv} = 0.030$
598.73	1.275	217	296915	$f_{pv} = 0.033$
56.85	543.15	217	296600	$f_{pv} = 0.035$
0	600	217	295130	$f_{pv} = 0.037$

Table 6: Simulation Results for various Annual Inflation rates for Fuel Cell

Pfc (kW)	Ppv (kW)	Nbatt	Costs ($)	Inflation rate
167.4	428.40	217	297070	$f_{fc} = 0.0343$
303.83	291.97	217	297050	$f_{fc} = 0.0345$
570.3	25.50	217	296830	$f_{fc} = 0.0353$
597.45	2.55	217	296590	$f_{fc} = 0.0355$

each case to cover the emergency load energy, a battery bank includes 217 modules must be considered. In order to investigate the effect of annual inflation 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 Annual Inflation rates of photovoltaic arrays and listed in Table 6 for various Annual Inflation 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 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.

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