Australian Journal of Basic and Applied Sciences, 5(8): 889-898, 2011
ISSN 1991-8178

Economic Analysis of Optimal Planning of Distribution System in Presence of DGs with Considering Power Quality Indices with Fuzzy Logic Algorithm (FLA)

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Abstract: One of the remarkable phenomena in power systems is the appearance of Distributed Generation (DGs). DGs can improve losses and voltage profile of system. In this paper Fuzzy Logic Algorithm is used to obtain optimal number, capacity and location of DGs for radial distribution networks. First of all FLA is used for optimal placement and capacity of DGs in the network. A composition of power quality index such as voltage profile improvement with economic indices is defined as the objective function in the optimization procedure. This method was carried out on a 33-feeder distribution network. Simulation results validate the effectiveness of the proposed method.

Keywords: Index Terms-fuzzy logic algorithm, distributed generation, optimization, economic analysis, power quality indices, voltage profile.

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 (G.W.Ault and *et al*, 2003). 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. 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 (Amin Hajizadeh and Masoud Aliakbar Golkar, 2007). Solar, wind, hydro sources, and biogas are among these renewable energy resources. Solar and wind energy are non-depletable, site-dependent, non-polluting, and potential sources of alternative energy (Thomas Ackermann, 2007). However, common drawback with solar and wind energy is their unpredictable nature. 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. This subject was considered in some researches (Durga Gautam and Nadarajah Mithulananthan, 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) (S.Colle and *et al*. 2004). 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 paper a structure is proposed for HPS based on hybrid renewable energy sources with multiple DG units in distribution system.

In this paper a multi objective function including economic indices and voltage profile improvement are considered and optimized with fuzzy logic algorithm.

1-Proposed Structure of Power System based HPS:

In this paper 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 paper is a hybrid renewable energy sources, includes PV, fuel cell and battery bank. Various distributed generations applied in this investigation are presented as bellow:

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. In the mean time the fuel cell

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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 (Carlson and D. E. 1995, F. Katiraei, *et al.* 206). 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 paper 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 (J. A. P. Lopes and *et al*, 2006). 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. 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 supercapacitors makes hybrid distributed generation systems (HDGS) could operate properly under transient conditions in demand power.

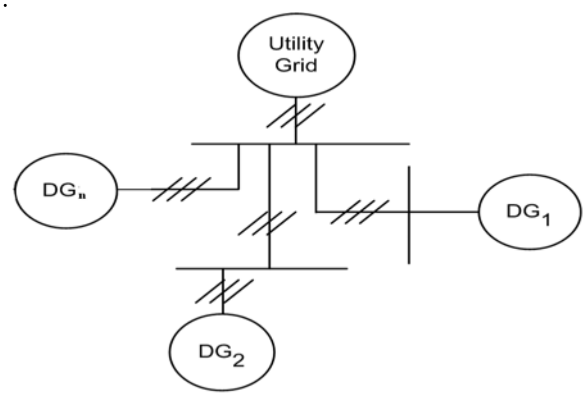

Fig. 1: Structure of Distribution System with HPS and Multiple Distributed Generations (DGs The omponents of hybrid power system analyzed and explained in detail below.

2.1. 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:

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

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 2 shows the V-I characteristics of PV.

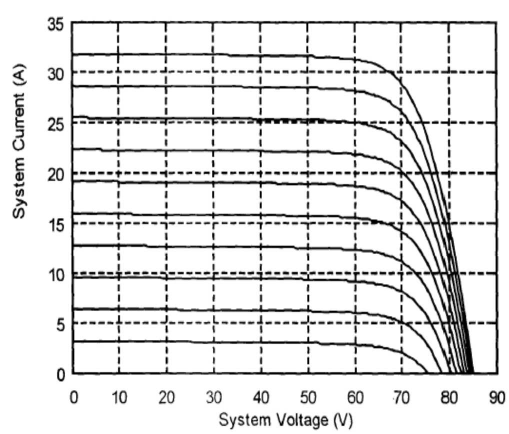

Fig. 2: Voltage-Current characterization of a Photovoltaic array.

2.2. 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 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.

2.3. 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 (S. Diaf and *et al*, 2007). 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 flexible modular structure.

1. Economic Analysis:

The economic viability of a proposed plant is influenced by several factors that contribute to the expected profitability (Lasseter B, 200). 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:

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:

3.1. 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

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

where:
i = real interest rate
i' = nominal interest rate (the rate at which you could get a loan)
f = annual inflation rate

3.2. 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.

3.3. 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:

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

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.

3.4. 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:

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

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.

3.4. Replacement Cost Duration:

The replacement cost duration is given by:

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

where:
R_{comp} = lifetime of the component

3.5. Remaining life of the component:

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

3.6. Annualized Capital Cost

The annualized capital cost is given by:

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

where, C_{cap} is initial capital cost.

3.8 Formulation of Overall Cost Function:

Figure 3 shows the economic representation of Capital Recovery Factor and Sinking Fund Factor versus of life time project.

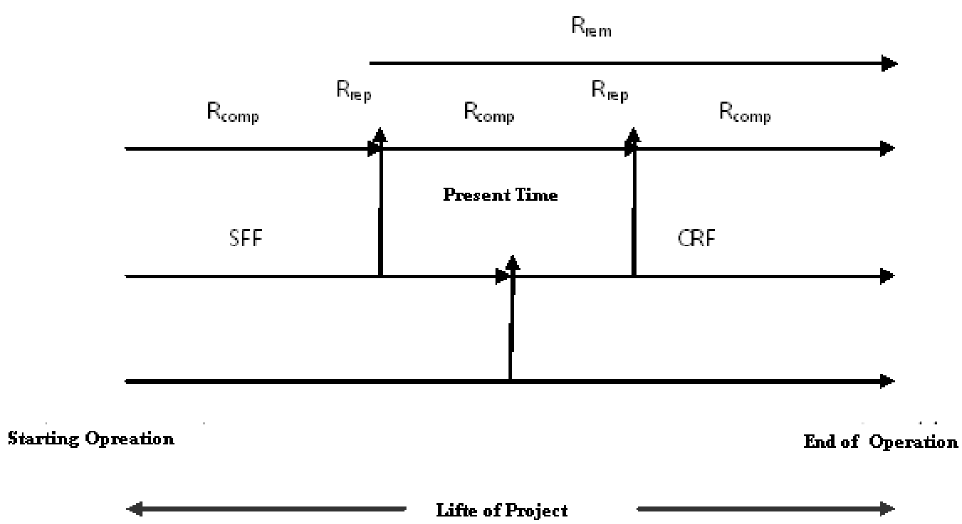

Fig. 3: Economic representation of Capital Recovery Factor and Sinking Fund Factor versus of life time project.

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

$$F=k1*(T_1)+k2*(T_2)$$
$$k1+k2=1$$

Which:

$$T_1 = \sum_{i=1}^{l} (|V_b - V_i|^2)$$

V_i Voltage at ith load point,

V_b Base voltage that is equal one per unit,

$$T_2 = (h_1 * NPW_{DG} + h_2 * NPW_{DISCO})$$

$$h1 + h2 = 1$$

NPW is the Net Present Worth of the overall system. It includes the net present worth of distribution company (DISCO) plus the net present worth of DG units. The DISCO provides the necessary power of customers from DG units. In fact the main purpose is maximizing the benefits of DG units, MG and DISCO. For this purpose FLA has been employed for optimization procedure.

1.Fuzzy Logic Algorithm (FLA):

In this paper Fuzzy Logic Algorithm (FLA) is used for selection among candidate distributed generators. Fuzzy logic is a practical alternative for a variety of challenging decision making applications since it provides a convenient method for constructing nonlinear relationship via the use of heuristic information (Carlson and D. E. 1995, F. Katiraei, *et al.*, 206). A fuzzy logic algorithm used in this research consists of the rule base, fuzzification, inference engine, and defuzzification. The rule base collects the control rules which describe experts' knowledge and experience in the fuzzy set. In the fuzzification process, the numerical inputs are converted into linguistic fuzzy values. Then, from the fuzzy values and the already established rule base, linguistic control values are generated in the inference engine. Because these linguistic inference results cannot be used in the actuator directly, they should be converted into numerical output again in the defuzzification process. MAX-MIN composition and the centre of gravity method are used in the inference engine and defuzzification of this fuzzy logic, respectively. Here, FLA is a method to find optimum answer in problems in which there are several criteria that should be considered.

In the proposed model, in order to achieve the optimum answer, two criteria are considered. They are: voltage profile and profit function. Final weights of criteria are shown in Table 1.

Table 1: Final weight of criteria.

Criterion	Voltage deviation	Profit Fun.
Weight	0.115	0.077

Membership functions for each choice are: very good (VG), good (G), medium (M), bad (B) and very bad (VB). These functions are illustrated in Fig.4.

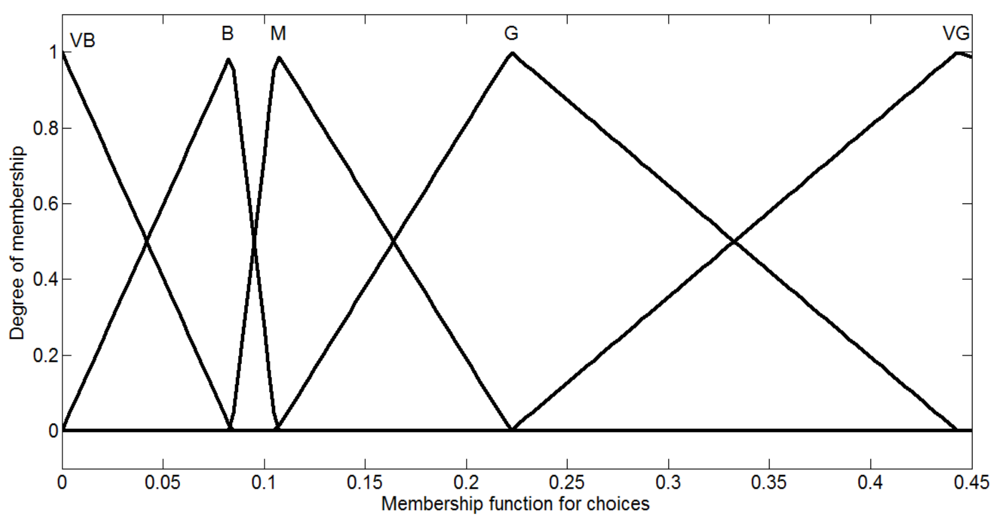

Fig. 4: Functional membership of fuzzy logic algorithm.

The way of allocating value levels for each choice into each criterion is explained.

After determining the value levels for each choice into each criterion, final weight of each choice is calculated using equation .

$$W_k = \sum_i C_i \times LV_{i,k}$$

In this equation, C_i is the weight of ith criterion, W_k is defined as the final weight of kth choice and $LV_{i,k}$ is weighting values. Fig.5. shows the flowchart of optimization procedure with FLA.

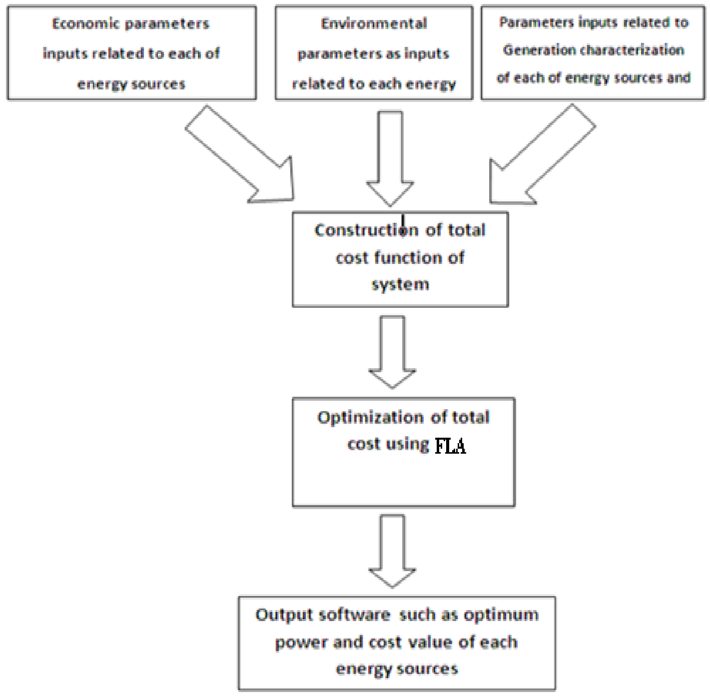

Fig. 5: Flowchart of optimization procedure with FLA.

1.Simulation Results:

The proposed method is applied to the modified 33-feeder IEEE distribution network as shown in Fig.6. Network data is given in Table 2. Network specification before implementing the algorithm is given in Table 3. The proper tuning of FLA parameters and weighting coefficients in the objective function depend on the achievement of an effective The network comprises three feeders: one serving a primarily residential area, one industrial feeder serving a small workshop, and one feeder with commercial consumers.

Table 2: Customer Data.

Bus No	Number of Customer	Q (kVAr)	P (kW)	Bus No	Number of Customer	Q (kVAr)	P (kW)
1	6	14	28	**18**	0	0	0
2	0	0	0	**19**	10	23	52
3	13	41	67	**20**	1	2	4
4	16	43	82	**21**	8	20	40
5	41	121	206	**22**	1	2	5
6	17	393	83	**23**	27	70	135
7	9	23	45	**24**	7	17	34
8	83	20	414	**25**	0	0	0
9	0	0	0	**26**	0	0	0
10	6	17	32	**27**	0	0	0
11	1	1	2	**28**	0	0	0
12	3	7	15	**29**	0	0	0
13	90	225	450	**30**	3	8	16
14	0	0	0	**31**	0	0	0
15	0	0	0	**32**	11	29	55
16	0	0	0	**33**	0	0	0
17	1	2	4	**34**	0	0	0

Table 3: Line Data.

Line No	Era Bus	Dest. Bus	R (p.u)	X (p.u.)	B (p.u.)	r (f/year)	Time (h)	u (h/year)
1	1	2	0.00285	0.00211	0.006478	1.85	0.15	0.27
2	2	4	0.00017	0.00012	0.000438	0.106	0.01	0.0001
3	3	4	0.00051	0.00037	0.001345	0.328	0.03	0.01
4	4	5	0.00158	0.00116	0.004192	1.021	0.08	0.08
5	5	10	0.00119	0.00087	0.00316	0.77	0.06	0.05
6	6	7	0.00031	0.00023	0.000829	0.202	0.02	0.0004
7	7	8	0.00215	0.001569	0.005694	1.387	0.11	0.15
8	8	9	0.0008	0.00058	0.002112	0.512	0.04	0.02
9	9	10	0.00077	0.00012	0.000438	0.107	0.01	0.0001
10	10	12	0.00344	0.00251	0.00912	2.221	0.18	0.39
11	11	12	0.00139	0.00074	0.002091	0.617	0.05	0.03
12	12	15	0.00289	0.00211	0.007665	1.867	0.15	0.28
13	13	14	0.15447	0.15418	0.616451	4.024	0.32	0.3
14	14	15	0.00307	0.00658	0.008	1.98	0.16	0.31
15	15	16	0.00005	0.00004	0.00015	0.04	0.01	0.0004
16	16	18	0.02171	0.01588	0.057611	14.035	1.12	15.76
17	17	18	0.01995	0.01059	0.030111	8.891	0.71	6.32
18	18	19	0.00031	0.00022	0.000813	0.198	0.02	0.0004
19	19	20	0.01205	0.00881	0.031973	7.789	0.62	4.85
20	20	22	0.0005	0.00036	0.001314	0.32	0.03	0.01
21	21	22	0.00259	0.00138	0.003911	1.154	0.09	0.11
22	22	26	0.00602	0.0044	0.015971	3.891	0.31	1.21
23	23	24	0.01175	0.00624	0.017734	5.236	0.42	2.19
24	24	25	0.04118	0.02185	0.062145	18.349	1.47	26.94
25	25	26	0.00146	0.00078	0.002207	0.651	0.05	0.03
26	26	27	0.00018	0.00013	0.000485	0.118	0.01	0.0001
27	27	28	0.00006	0.00004	0.00015	0.04	0.01	0.0004
28	28	29	0.01214	0.01212	0.048451	11.33	0.91	10.27
29	29	31	0.01531	0.01529	0.06114	14.291	1.14	16.34
30	30	31	0.00496	0.00263	0.007491	2.212	0.18	0.39
31	31	32	0.01316	0.01314	0.052525	12.282	0.98	12.07
32	32	33	0.00071	0.00071	0.002819	0.65	0.05	0.03
33	33	34	0.00105	0.00105	0.004205	0.983	0.08	0.08

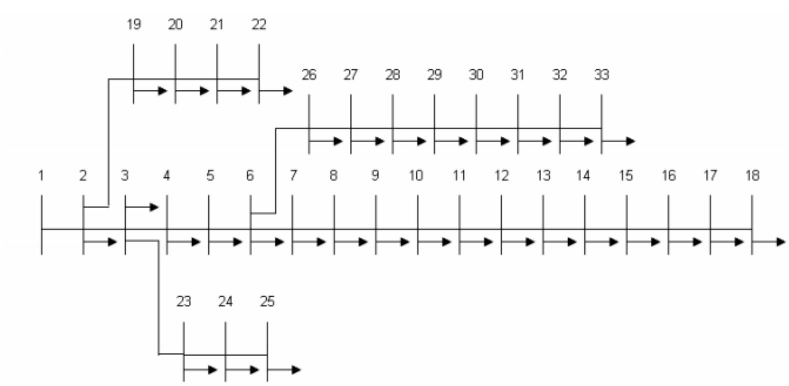

Fig. 6: Study case LV network.

Economic parameters of each kind of distributed generations that applied in this paper are listed as Table 3.

Table 3: Specification of network.

Source type	Economic parameters	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]

The variation of the cost value versus the iteration number is shown in Fig.7.

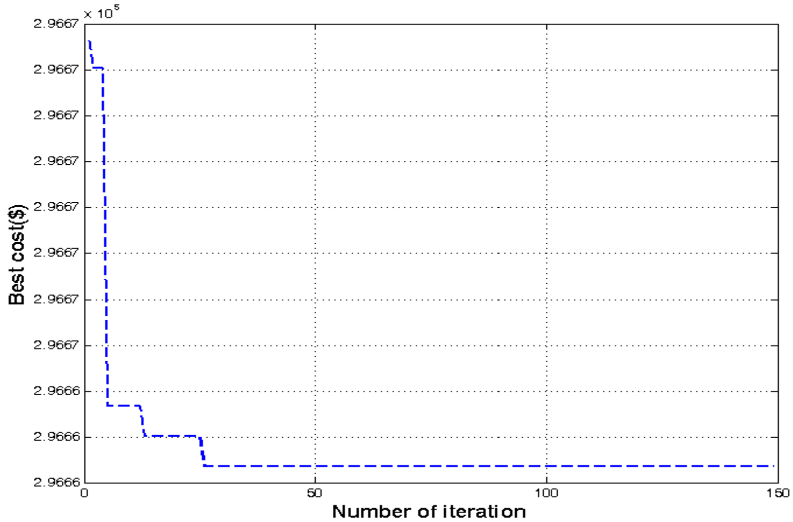

Fig. 7: Best cost value versus iteration number.

Results of FLA method in proposed algorithm are presented in Table 4. According to value level and final weight of each simulation in this table, answer set is achieved. Regarding to simulations of 15th to 18th, 20th and 21st, optimum number of DGs are achieved.

Table 4: Result of FLA.

Simulation Num.	Num. of DGs	Bus Number for DGs Installation						DGs Capacity According to Their Placement						Objective Function
1	1	13						600						2.9102
2	1	13						600						2.6905
3	1	13						600						2.6839
4	1	13						600						2.671
5	1	13						600						2.6627
6	1	13						600						2.6334
7	2	13	9					520	600					1.4961
8	2	7	13					600	590					1.2245
9	2	6	13					600	530					1.0828
10	2	13	7					520	600					1.0491
11	2	13	8					510	600					1.03
12	2	13	8					520	590					1.0299
13	3	13	8	12				420	470	540				0.9535
14	3	9	14	13				560	430	440				0.91
15	3	13	14	10				420	470	560				0.8695
16	3	13	5	7				470	520	440				0.8309
17	3	13	8	12				460	540	440				0.8139
18	3	13	12	8				460	490	490				0.8027
19	4	13	8	6	15			410	160	270	600			0.9243
20	4	12	7	13	5			390	190	420	430			0.9061
21	4	4	6	13	14			410	230	440	350			0.8555
22	4	13	4	14	7			440	310	340	340			0.8041
23	4	9	14	2	13			550	220	190	470			0.7986
24	4	13	6	14	4			460	240	350	380			0.7914
25	5	6	13	5	14	13		260	270	380	370	150		0.926
26	5	7	10	13	12	14		360	170	410	170	320		0.8795
27	5	7	8	14	13	25		460	100	160	470	210		0.864
28	5	2	6	15	13	13		380	230	350	300	170		0.8105
29	5	13	13	6	4	15		380	100	290	410	250		0.8034
30	5	2	4	14	7	13		350	170	430	100	390		0.7818
31	6	4	13	13	6	14	2	170	180	250	230	300	300	0.9167
32	6	13	6	6	14	15	10	450	200	260	110	280	130	0.8685
33	6	11	13	7	4	13	2	300	130	290	180	300	230	0.836
34	6	3	13	4	7	13	14	200	280	170	340	130	310	0.7908
35	6	14	13	4	10	6	13	250	190	210	270	240	270	0.7897
36	6	6	13	14	13	8	2	130	360	360	100	270	210	0.7813

Fig. 8: Shows that variation of power losses and the best variation in losses of network is obtained by allocation of first DG.

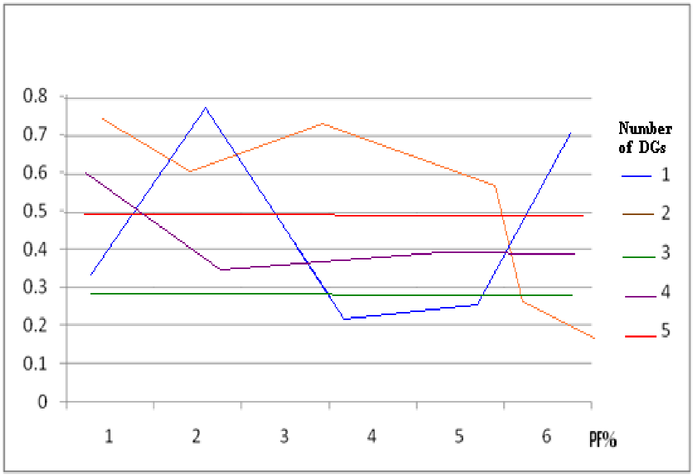

Fig. 8: Variation in voltage deviation with optimum number of DGs and Penetrated Factor (PF%).

1.Conclusion:

This paper 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 FLA 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. The simulation results validate the effectiveness of the proposed methods. Using of this algorithm, DGs are installed close to the load centers to decrease losses, improve voltage profile.

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