Optimal Placement of Fuel Cell DG and Solar PV in Distribution System using Particle Swarm Optimization

Athira Jayavarma, Tibin Joseph, Sasidharan Sreedharan

Abstract— Distributed generation (DG) sources are becoming more prominent in distribution systems due to the incremental demands for electrical energy and to reduce the power disruption in the power system network. Due to the installation of DGs in the system, the total power loss can be reduced and voltage profile of the buses can be improved. This paper presents a new methodology to determine the optimal location of fuel cell DG and Solar PV in distributed system. The proposed algorithm Particle Swarm Optimization (PSO) identifies the optimal location of fuel cell DG and Solar PV with minimum active power losses. The proposed method is tested on IEEE 14-Bus test model. The results show a considerable reduction in the total power loss in the system and improved voltage profiles of the buses within the frame-work of system operation and security constraints in radial distribution systems.

Index Terms— Constraints; Distribution Systems; Distributed Generators (DG); Fuel Cell ; Optimal Location; Particle Swarm Optimisation(PSO); Solar Photo Voltaic Cell (PV);

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1 INTRODUCTION

Distribution systems are usually radial in nature for the operational simplicity. Radial distribution systems (RDSs) are fed at only one point which is the substation. The substation receives power from centralized generating stations through the interconnected transmission network. Hence, high R/X ratios in distribution lines result in large voltage drops, low voltage stabilities and high power losses.

Recently, several solutions have been suggested for complementing the passiveness of RDS by embedding electrical sources with small capacities to improve system reliability and voltage regulation. Such embedded generations in a distribution system are called dispersed generations or distributed generations (DG) [1].

DG technologies can be categorized into renewable and non-renewable energy resources. The DG technologies that based on renewable are solar, wind, small-hydro, biomass, geothermal etc. whereas the DG technologies that based on non-renewable are combustion turbines, steam turbines, micro turbines, reciprocating engines etc. Fuel cells can be categorized into renewable (using hydrogen) and non-renewable (using natural gas or petrol) [2] [3].

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The advantages of the implementation of DG are as follows [2] [4]:

1. Line loss reduction
2. Voltage profile improvements
3. Power quality improvements
4. Low cost
5. Reduction of peak power requirements
6. Increased electric system reliability
7. Increased efficiency levels
8. Reduced environmental impacts

Photovoltaics(PV) is a method of generating electrical power by converting solar radiation into direct current electricity using semiconductors that exhibit the photovoltaic effect. Solar photovoltaics is now, after hydro and wind turbine, the third most important renewable energy source in terms of globally installed capacity.

Integrating PV in the distribution system has positive as well as negative effects. The positive impacts are Solar energy is supplied by nature thus it is abundant, it can be made available almost anywhere there is sunlight, ease of operation and negligible operating cost, pollution free [5]. The negative impacts of PV are, solar energy has intermittency issues; not shining at night but also during daytime there may be cloudy or rainy weather, less reliable, fragile and can be damaged relatively easily. Therefore, for a continuous supply of electric power, especially for on-grid connections, Photovoltaic panels require storage cells.

The evolution of distributed generation, providing an advanced management system that has the capability to balance electrical loads from diverse, and often intermittent, alternative generation sources. Prior to the integration of renewable energy source like solar to the electrical grid, the task of load-balancing was simpler, with conventional centralized power plants producing a predictable amount of energy on demand. Renewable energy sources, however, are subject to the natural conditions they encounter. Solar energy may only produce power during certain times, often not timed to match peak energy demand. A key component of the grid is the capacity to store electrical energy and to draw upon it when needed. Fuel cells coupled with electrolysers can offer a cost competitive grid scale energy storage solution.

Fuel cell is an electrochemical device that converts the chemical energy of a fuel directly into electrical energy. Intermediate conversions of the fuel to thermal and mechanical energy are not required [6]. The advantages of Fuel cell DGs comparing to other DGs are high efficiency, Low chemical and thermal emissions, Fuel flexibility, can be place at any site in a distribution system, without geographic limitations.

DG allocation in the distribution system that minimizes the active power losses is a popular issue that attracts many researchers recently. Some novel optimization techniques have been used to solve this problem such as evolutionary programming (EP) [7], genetic algorithm (GA) [8], and others.

Comparing to another algorithms, Particle Swarm Optimization [9] has the flexibility to control the balance in the search space and PSO overcomes the premature convergence problem and enhances the search capability. Here the solution quality doesn't rely on the initial population.

In this paper, an algorithm is developed to find the optimal location of Fuel Cell DG and Solar PV in the distribution system. The problem is formulated as a single objective function of minimizing the system active power losses considering the constraints on active power generation and voltage limits. This optimization problem is solved using Particle Swarm Optimization (PSO) algorithm. At each step, Fuel Cell DG and Solar PV are placed at a bus and the power flow analysis is carried out by Newton-Raphson method to evaluate the variation in power losses of the system considering the constraints.

This paper is organized as follows: Proposed methodology and modelling of the power system and Fuel Cell DG and Solar PV are described in section II. Problem formulation for the optimal placement of Fuel Cell DG and Solar PV and the PSO algorithm are presented in section III. The results and discussions are described in section IV. Finally a brief conclusion is deduced in section V.

2 PROPOSED METHODOLOGY & MODELING

The proposed methodology consisted of finding the best suitable bus for connecting the Fuel Cell DG and Solar PV as shown in Figure 1. The development of the algorithm required problem formulation with modeling of the Fuel Cell, modeling of Solar PV and the dynamic model of IEEE 14-bus system.

2.1 Modeling of Power System Components

The IEEE 14-bus system with Solid Oxide Fuel Cell DG has been modeled in this paper for the analysis. The dynamic model of IEEE 14-bus system has been analyzed and the power flow results are verified with the standard values.

The Fuel Cell model has been explained in the next section.

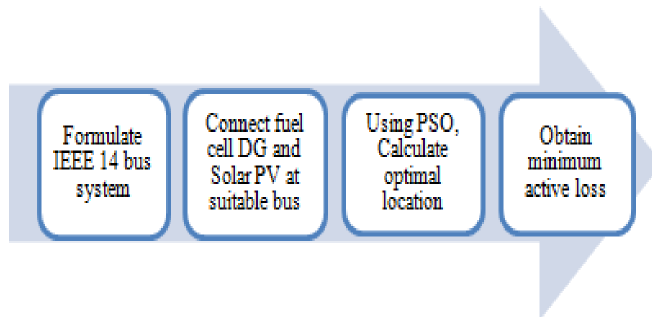

Fig1. Proposed Methodology

2.2 Modeling of Fuel Cell DG

Fuel cells have the potential to provide distributed power generation. Solid Oxide Fuel Cells employ a solid state electrolyte and operate at the highest temperature of around 1000°C/1800°F of all fuel cell types. Figure 2 shows a SOFC connected to AC grid. The Fuel Cell DG details are given in Table II. The voltage E is developed over a single cell is ideally described by the Nernst equation [10] [14].

$$E = N[E^0 + (\frac{RT}{2F})\ln[\frac{pH_2 pO_2^{1/2}}{pH_2O}]] \qquad (1)$$

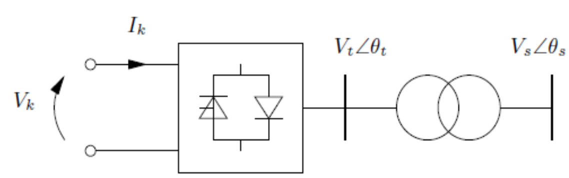

Fig. 2 SOFC connected to AC grid

TABLE1. FUEL CELL DG MODEL DETAILS

Electrical response time	0.8 s
Fuel processor response time	5 s
No. of cells	384
Ideal Standard Potential	1.18

2.3 Modeling of Solar PV

PV is the most versatile, simplest to install and cheapest to maintain, and provides a highly valued product –electricity- generally at or close to the point of use, avoiding the cost and risk of failure of infrastructure[17]. A storage system is in general absent in large grid-connected SPVG installations, except for small critical loads of the plant such as start-up controls. However, there are some instances in which considerable storage has been integrated into large scale SPVGs [11].

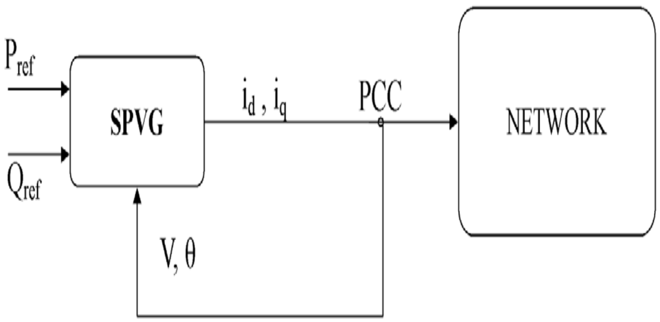

Fig.3 SPVG Model 1

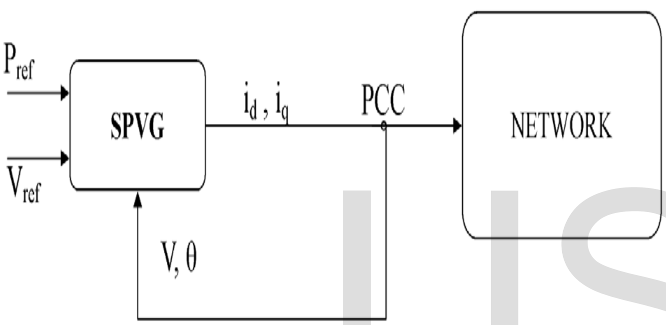

Fig.4 SPVG Model 2

In the current paper, the following models are considered for the SPVG :

- Model 1: Constant P and constant Q control.
- Model 2: Constant P and constant V control.

3 Problem Formulation

3.1 Objective Function & Constraints

A general constrained single-objective optimization problem considering active power loss of all the transmission lines in the system has been formulated to find the optimal location of the Fuel Cell DG. Accordingly, the objective function has been formulated for any time (t) as:

Minimize,

$$\mathbf{F} = \sum_{k=1}^{ntl} \mathbf{P}_{LK} \qquad (2)$$

Subjected to the following equality constraints

$$\left.\begin{aligned} P_i &= P_{Gi} - P_{Di} - \sum_{j=1}^{N_b} V_i V_j Y_{ij} Cos(\delta_i - \delta_j - \theta_{ij}) \\ Q_i &= Q_{Gi} - Q_{Di} - \sum_{j=1}^{N_b} V_i V_j Y_{ij} Sin(\delta_i - \delta_j - \theta_{ij}) \end{aligned}\right\} \qquad (3)$$

And the following inequality constraints

$$\left.\begin{aligned} Q_{Gi_{min}} \le Q_{Gi} \le Q_{Gi_{max}} \quad & i=1, \ldots\ldots\ldots, N_G \\ V_{i_{min}} \le V \le V_{i_{max}} \quad & i=1, \ldots\ldots\ldots, N_b \end{aligned}\right\} \qquad (4)$$

Where

F is the objective function.
PLK is the active power loss in the Kth line.
ntl is the number of lines in the system
Nb is the set of buses indices
NG is the set of generation bus indices
Yij and θij are the magnitude and phase angle of element in admittance matrix
Pgi and Qgi are the active and reactive power generation at bus i
Pdi and Qdi are the active and reactive power load at bus i
Vi is the voltage magnitude at bus i.

3.2 Particle Swarm Optimization (PSO)

PSO is a robust stochastic optimization technique based on the movement and intelligence of swarms. PSO applies the concept of social interaction to problem solving. It was developed in 1995 by James Kennedy (social-psychologist) and Russell Eberhart (electrical engineer). It uses a number of agents (particles) that constitute a swarm moving around in the search space looking for the best solution. Each particle treated as a point in a N-dimensional space which adjusts its "flying" according to its own flying experience as well as the flying experience of other particles. Each particle keeps track of its coordinates in the solution space which are associated with the best solution (fitness) that has achieved so far by that particle. This value is called personal best, P_{best} . Another best value that is tracked by the PSO is the best value obtained so far by any particle in the neighbourhood of that particle. This value is called G_{best}. The basic concept of PSO lies in accelerating each particle toward its P_{best} and the G_{best} locations, with a random weighted acceleration at each time step.

Each particle tries to modify its position using the following information: the current positions, the current velocities, the distance between the current position and P_{best}, the distance between the current position and the G_{best}. The modification of the particle's position can be mathematically modeled according the following equation:

$$V_i^{k+1} = \omega^k V_i^k + a_1 rand_1 * (P_{best\,i}^k - X_i^k) + a_2 rand_2 * (G_{best}^k - X_i^k) \qquad (6)$$

$$X_i^{k+1} = X_i^k + V_i^{k+1} \qquad (7)$$

In the updating, a new velocity for each particle based on its previous velocity V_i^k is determined. The particle's location at which the best fitness ($P_{best\,i}^k$) and the best particle among G_{best}^k

the neighbours (   ) have been achieved.
The learning factors, *a*1 and *a*2, are the acceleration constants which change the velocity of a particle towards P_{best} and G_{best}. The random numbers, $rand_1$ and $rand_2$, are uniformly distributed numbers in range [0, 1]. Finally, each particle's position X_i^k is updated by (7).

3.3 PSO Algorithm

Step 1: Input line data, bus data, fuel cell data, voltage limits, line limits and PSO settings
Step 2: Identify the best location for fuel cell DG and Solar PV placement by the calculation of total active power loss of the system and connect the Fuel Cell DG and Solar PV to that particular bus.
Step 3: Calculate the base case power flow with the Fuel Cell DG and Solar PV connected at the identified bus.
Step 4: The population of N particles is initialized with random positions, x and the velocity, v of each particle is set to zero. Each particle can have d number of variables.
Step 5: The objective function is evaluated with all particles in order to find the objective value. If the value of a particle and the objective value obtained from that particle are within the limit,, that particle will be accepted. Otherwise, new particle will be generated and this step will be repeated. Then Pbest is set as the current position and Gbest is set as the best initial particle.
Step 6: The new velocity,vi+1 and the new position, xi+1, is calculated using equations (6) and (7) and the values of the current Gbest and Pbest.
Step 7: Evaluate the objective values of all particles using the new position.
Step 8: The objective value of each particle is compared with its previous objective value. If the new value is better than the previous value, then update the Pbest and its objective value with the new position and objective value. If not, maintain the previous values.
Step 9: Determine the best particle of the whole updated population with the Gbest. If the objective value is better than the objective value of Gbest, then update Gbest and its objective value with the position and objective value of the new best particle. If not, maintain the previous Gbest.
Step 10: If the stopping criterion is met, then output Gbest and its objective value; otherwise, repeat step six.
Step 11: Display the optimal solution to the target problem. The best position gives the location for Fuel Cell DG and Solar PV resulting in minimum total active power loss for the system.
Figure 5 gives the flowchart of the Proposed algorithm.

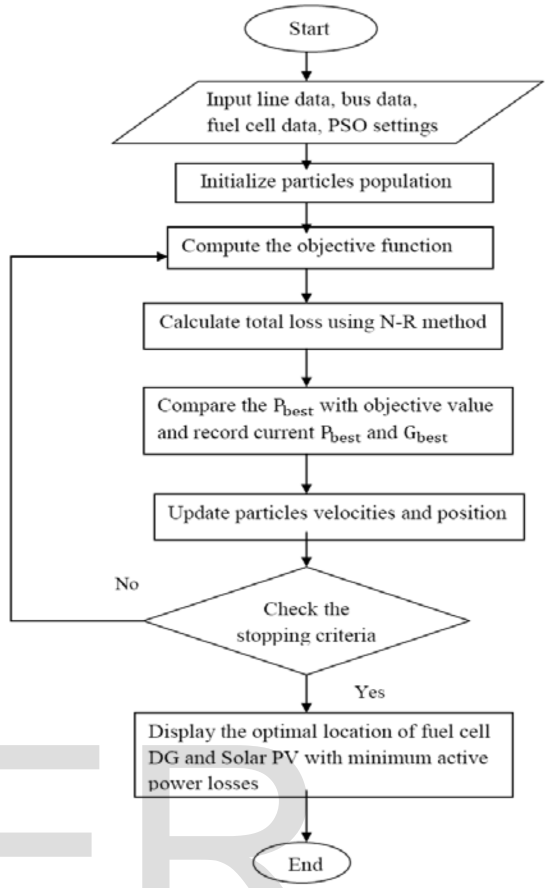

Fig. 5 Flow Chart of PSO Algorithm

4 Result & Discussion

4.1 Specification of Test system

The proposed solution method was tested on an IEEE 14 bus test system, shown in Figure.6. The bus system consists of 6 generators, of which one is slack and there are 20 lines. The results can be divided into two steps. The first step is to access the best location of Fuel Cell DG and Solar PV and the second is the calculation of minimum active power loss. The proposed methodology has been tested on IEEE14-bus system as shown in figure 5. Bus-2, 13 are PV buses and 3, 6 and 8 are synchronous compensator buses.

Fuel Cell DG and Solar PV have been connected to different bus and loads were modeled as constant power loads and were solved by using Newton Raphson Power flow method. The program was coded in MATLAB software.

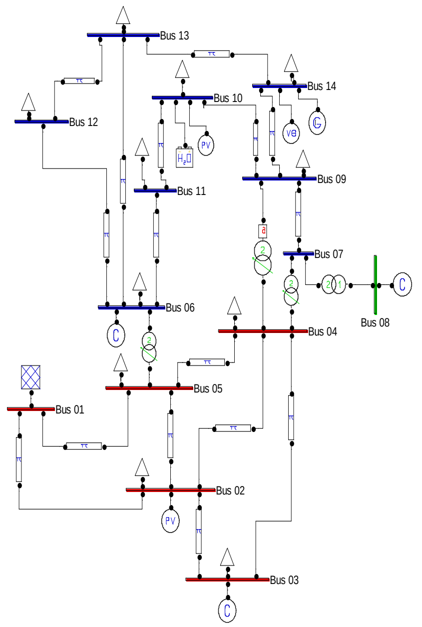

Fig. 6 IEEE- 14 Bus system with Fuel Cell DG and Solar PV

In fig. 7, the model of IEEE 14 bus system without Fuel cell DG and Solar PV bus voltage level is compared against the base model with Fuel cell DG and Solar PV voltage limit. The figure clearly shows that by placement of fuel cell DG and Solar PV, the voltages are within the limit.

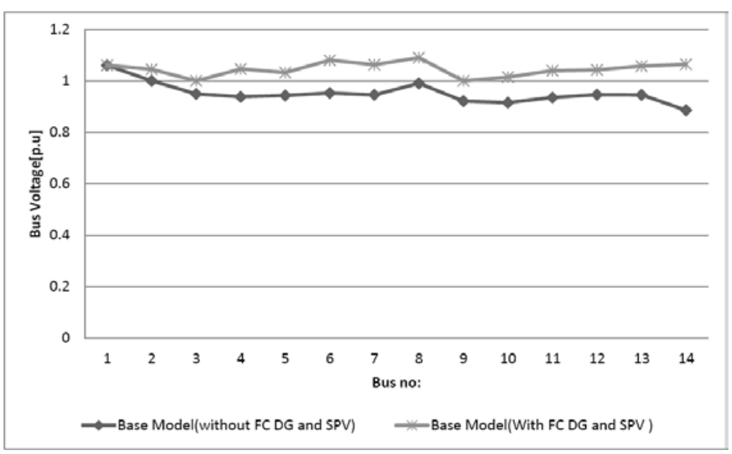

Fig. 7 Voltage levels with and without FC DG and SPV

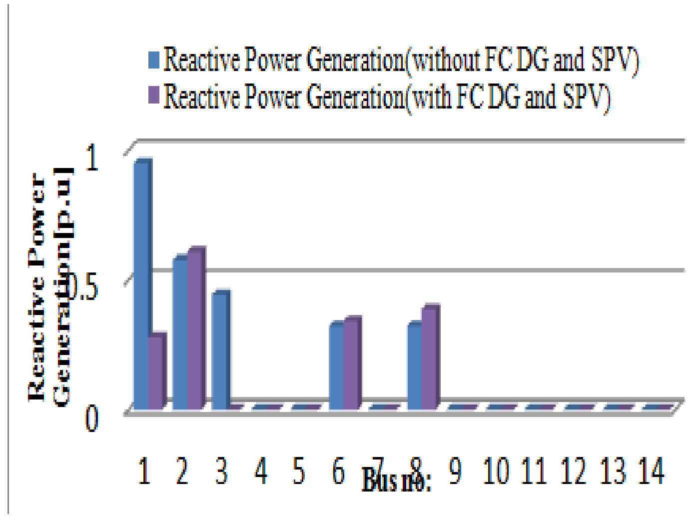

Fig. 8 Reactive Power Generation with and without FC DG and SPV

Figure 8 shows the bus reactive power generations at minimum active power loss using Fuel Cell DG and SPV at optimum location.

Figure 9 shows the bus generations at minimum active powe loss using Fuel Cell DG and SPV at optimum location. It is also clear that the slack bus generation has been reduced and the supply demand was balanced by using Fuel Cell DG at optimum location along with improving the system performance

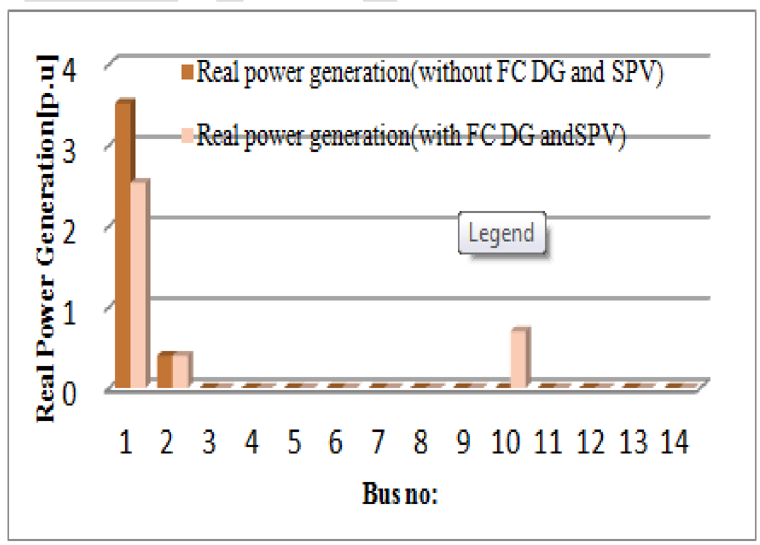

Fig. 9 Reactive Power Generation with and without FC DG and SPV

The active power flows in various lines are given in Figure 10. Except for line 7 and 13, the power carried through all other transmission lines is reduced which in turn reduces the losses.

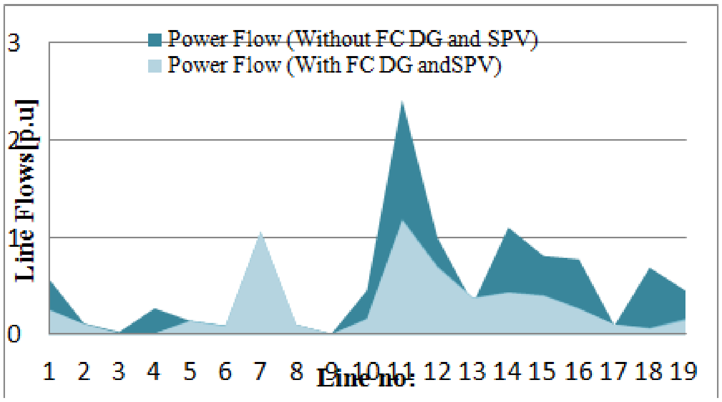

Fig. 10 Active power flow with and without FC DG and SPV

Table 2 shows the active power loss of the system with and without Fuel Cell DG and Solar PV

TABLE 2. ACTIVE POWER LOSS REDUCTION

	Active Power Loss[p.u]
Base model without FC DG and Solar PV	0.2945
Base model with FC DG and Solar PV	0.1634

From this table, it is clear that the total active power loss of the system is reduced by the optimal allocation of SOFC DG and Solar PV.

5 Conclusion

The new methodology proposed to optimally place the Fuel Cell DG and Solar PV so as to minimize the active power loss of the system using PSO has discussed in this paper.Particle Swarm Optimization algorithm, is easy to implement and the time taken for the iteration is less compared to other conventional methods and it is accurate .The results shows that the optimal allocation of fuel cell DG and Solar PV will minimize the real power loss and it is tested on IEEE 14 bus system.

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