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Optimal Placement of Solar PV in Distribution System using Particle Swarm Optimization

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Abstract: Solar PhotoVoltaics (SPV) are among the fastest growing energy resources in the world. Most of the SPV had been installed in the distribution systems as distributed generation. Now, a day's Distributed generations (DGs) play an important role in distribution networks. Among many of their merits, loss reduction and voltage profile improvement can be the salient specifications of DG. Studies show that non-optimal locations of DG units may lead to losses increase, together with bad effect on voltage profile. So, this paper presents a new methodology using Particle Swarm Optimization(PSO) for the placement of Solar PV in the radial distribution systems. The proposed algorithm will identify the optimal location of Solar PV with minimum active power losses.. The developed algorithm has been tested on modified IEEE 14-bus test. The result shows a considerable reduction in the total power loss in the system and improved voltage profiles of the buses.

Keywords- Distributed Generators (DG); Fuel Cell ;Solar Photo Voltaics (SPV); Particle Swarm Optimisation(PSO)**;**

I. INTRODUCTION

Distributed generation is any electricity generating technology installed by a customer or independent electricity producer that is connected at the distribution system level of the electric grid [1]. It can be said that DO is associated with the use of small generation units located close to or in the load centers. The effects of DO on voltage profile, line losses, short circuit current and system reliability are to be evaluated separately before installing it in a distribution network. 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].

The benefits of DG are numerous [4, 5] and the reasons for implementing DGs are an energy efficiency or rational use of energy, deregulation or competition policy, diversification of energy sources, availability of modular generating plant, ease of finding sites for smaller generators, shorter construction times and lower capital costs of smaller plants and proximity of the generation plant to heavy loads, which reduces transmission costs. Also it is accepted by many countries that the reduction in gaseous emissions (mainly CO2) offered by DGs is major legal driver for DG implementation [6].

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 impacts. Some of them 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, they are totally silent, producing no noise at all, and have no mechanically moving parts [7].

Optimal placement and sizing of PVS units in distribution systems is a complex combinatorial optimization problem [8]. Recently, metaheuristics optimization methods are being successfully applied to combinatorial optimization problems in power systems particularly in DG allocation and sizing. In [8]-[12], the DG placement problem was presented using genetic algorithm (GA) technique. The placement problem presented in [8] is evaluated based on the relation of benefit obtained by the installation of DG and the investment and operational cost incurred in their installation. The authors in [9] presented the steps of DG allocation in two separate ways, i.e. not continuous, the optimal location is determined first, and then the optimal size of the DG is solve second. The work presented in [13]

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discussed the combination of genetic algorithm (GA) and simulated annealing (SA) while evolutionary programming optimization technique was used in [14] to solve the DG allocation problem. In [15] tabu search algorithm is presented. As in [8], the authors in [14]-[15] discussed the placement of DG in two separate ways, the optimal location is determined first, and then the optimal sizing of the DG is second. One of the metaheuristics optimization recently developed was Particle Swarm Optimization (PSO). Comparing to another algorithms, Particle Swarm Optimization [16] 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 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, Solar PV is 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 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.

II. Proposed Methodology & Modeling

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

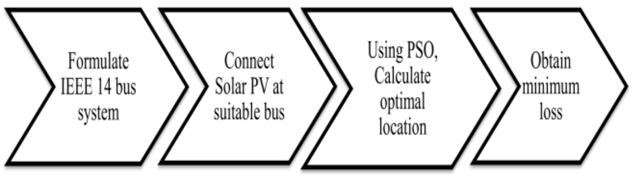

Fig. 1 Proposed Methodology

A. *Modeling of Power System Components*

IEEE 14-bus system with Solar PV 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 Solar PV model has been explained in the next section.

B. *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[19].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 [18].

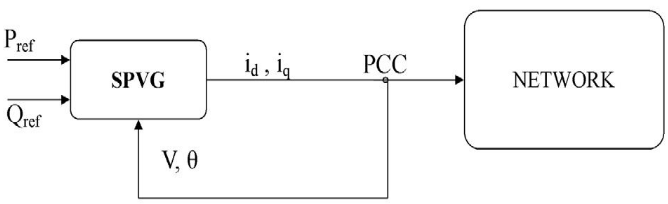

Fig.2 SPVG Model 1

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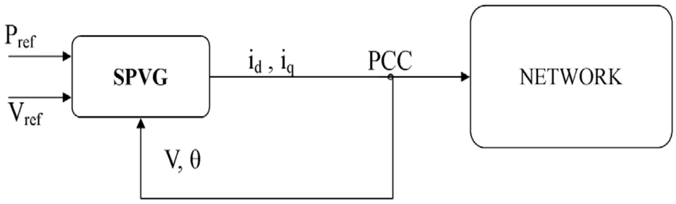

Fig.3 SPVG Model 2

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.

III. PROBLEM FORMULATION

A. *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 Solar PV. Accordingly, the objective function has been formulated for any time (t) as:

Minimize,

$$F = \sum_{k=1}^{ntl} P_{LK} \quad (1)$$

Subjected to the following equality constraints

$$\left.\begin{aligned} P_i &= P_{Gi} - P_{Di} - \sum_{j=1}^{N_b} V_i V_j Y_{ij} Cos(\delta_i - \delta_j - \theta_{ij}) \\ Q_i &= Q_{Gi} - Q_{Di} - \sum_{j=1}^{N_b} V_i V_j Y_{ij} Sin(\delta_i - \delta_j - \theta_{ij}) \end{aligned}\right\} \quad (2)$$

And the following inequality constraints

$$\left.\begin{aligned} Q_{Gi_{min}} \le Q_{Gi} \le Q_{Gi_{max}} \qquad & i=1, \ldots\ldots\ldots, N_G \\ V_{i_{min}} \le V \le V_{i_{max}} \qquad & i=1, \ldots\ldots\ldots, N_b \end{aligned}\right\} \quad (3)$$

$$| P_{ij} | \le P_{ij}^{max} ; ij = 1, \ldots\ldots. N_l \quad (4)$$

Where

F is the objective function.

P_{LK} is the active power loss in the K_{th} line.

ntl is the number of lines in the system

N_b is the set of buses indices

N_G is the set of generation bus indices

Y_{ij} and θ_{ij} are the magnitude and phase angle of element in admittance matrix

P_{gi} and Q_{gi} are the active and reactive power generation at bus i

P_{di} and Q_{di} are the active and reactive power load at bus i

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V_i is the voltage magnitude at bus i.

B. 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:

$$V_i^{k+1} = \omega^k V_i^k + a_1 rand_1 * (P_{besti}^k - X_i^k) + a_2 rand_2 * (G_{best}^k - X_i^k) \quad (5)$$

$$X_i^{k+1} = X_i^k + V_i^{k+1} \quad (6)$$

In the updating, a new velocity for each particle based on its previous velocity is V_i^k determined. The particle's location at which the best fitness (P_{besti}^k) and the best particle among the neighbours (G_{best}^k) have been achieved. The learning factors, $a1$ and $a2$, 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 (6).

C. PSO Algorithm

Step 1: Input line data, bus data, PV data, voltage limits, line limits and PSO settings.
Step 2: Identify the best location for Solar PV placement by the calculation of total active power loss of the system and connect the Solar PV to that particular bus.
Step 3: Calculate the base case power flow with 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 P_{best} is set as the current position and G_{best} is set as the best initial particle.
Step 6: The new velocity, v_{i+1} and the new position, x_{i+1}, is calculated using equations (5) and (6) and the values of the current G_{best} and P_{best}.
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 P_{best} 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 G_{best}. If the objective value is better than the objective value of G_{best}, then update G_{best} and its objective value with the position and objective value of the new best particle. If not, maintain the previous G_{best}.
Step 10: If the stopping criterion is met, then output G_{best} 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 Solar PV resulting in minimum total active power loss for the system.

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Figure 4 gives the flowchart of the Proposed algorithm.

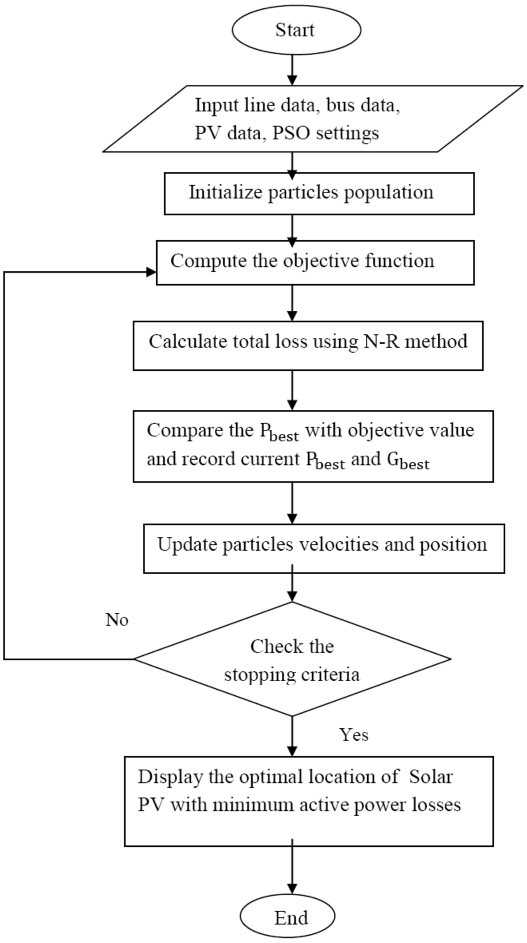

Fig. 4 Flow Chart of Proposed Algorithm

IV. RESULT & DISCUSSION

A. *Specification of Test system*

The proposed solution method was tested on an IEEE 14 bus test system, shown in Figure.5. The network consists of 6 generators, of which one is slack and there are 20 lines. The results consist of two steps. The first step is to access the best location of 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 4. Bus-2, 13 are PV buses and 3, 6 and 8 are synchronous compensator buses.

Solar PV have been connected to any of the bus (other than slack bus and buses connected to transformers), voltage and angle settings of slack bus and Solar PV ratings are considered for minimising the active power loss. Loads were modeled as constant power loads (PQ load) and were solved by using Newton Raphson Power flow Routine. The program was coded in MATLAB

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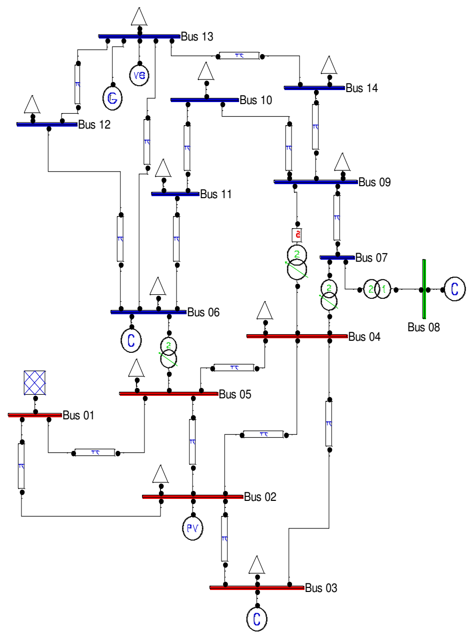

Fig. 5 IEEE- 14 Bus system with Solar PV

The base case without Solar PV bus voltage level is compared against the base case with Solar PV voltage limit in Figure 6. The figure shows that optimal placement of Solar PV adjusted the voltages of PV buses and slack bus for minimising the losses. The figure clearly states that all the bus voltages are within the set limits at minimum active power loss with Solar PV at optimum location.

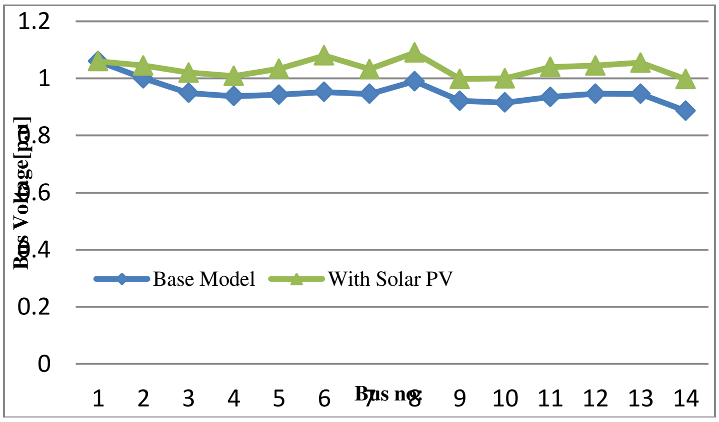

Fig. 6 Typical voltage levels with and without Solar PV

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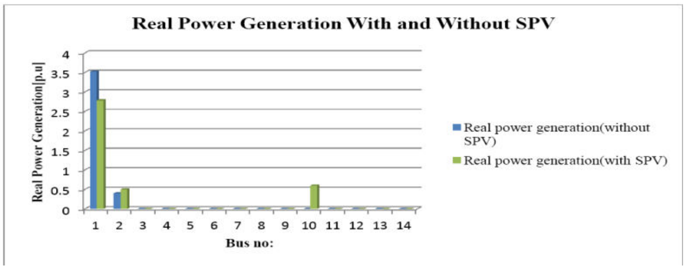

Fig.7 Real Power Generation With and Without Solar PV

Figure 7 shows the bus generations at minimum active power loss using SPV at optimum location.

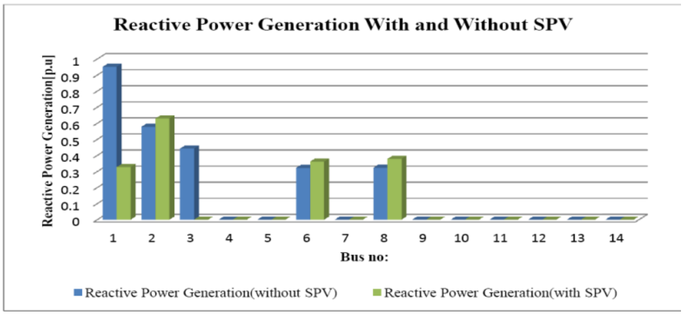

Fig. 8 Reactive Power Generation With and Without Solar PV

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

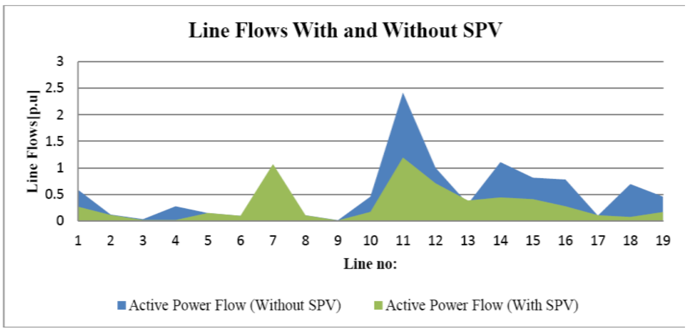

Fig.9 Reactive Power Generation With and Without Solar PV

The active power flows in various lines are given in Figure 9. Except for line 7 and 13, the power carried through all other transmission lines is reduced which in turn reduces the losses.

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TABLE I. ACTIVE POWER LOSS REDUCTION

	Active Power loss[p.u]
Base model without Solar PV	0.2945
Base model without Solar PV	0.1930

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

V. CONCLUSION

The new methodology proposed to optimally place the 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 Solar PV will minimize the real power loss and it is tested on IEEE 14 bus system.

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BIOGRAPHY

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