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Modified PSO Based Optimal Control for Maximizing Benefits of Distributed Generation System

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Abstract**—**Deregulation in the power system industry and the invention of new technologies for producing electrical energy has led to innovations in power system planning. Distributed generation (DG) is one of the most attractive technologies that bring different kinds of advantages to a lot of entities, engaged in power systems. In this paper, a model for considering DGs in the power system planning problem is presented. Dynamic power system planning for reduction of maintenance and operational cost is presented in this paper. In addition to that, a modified particle swarm optimization (PSO) is used to find the optimal topology solution. Voltage Profile Improvement Index (VPII) and Line Loss Reduction Index (LLRI) are taken as benefit index of employing DG. The effectiveness of this method is demonstrated through examination of IEEE 30 bus test system.

Keywords**—**Distributed generation, line loss reduction index, particle swarm optimization, power system, voltage profile improvement index.

I. Introduction

TODAY, electrical power plays an exceedingly important role in the life of community and economic development of various sectors of society. In fact, the modern economy is totally dependent upon the electricity as a basic input. This in turn has led to the increase in the number of power stations and their capacities and the consequent increase in the power transmission lines which connect generating stations to the load centers. Thus, the importance of electricity transmission, operation and planning has been increased. Conventional electrical systems have been run by vertically integrated utilities with the focus on the engineering aspects and not economic issues [1]. As a result, quality of supply becomes high but, the cost will also be more. A number of recent drives have altered this situation in which it is the responsibility of the system operator to plan and develop the electric power system, schedule and dispatch generation, operate the electricity market and ensure system security. Annual energy demand has been increased on a large scale over the years.

The demand for electricity in India, the 6^{th} largest consumer of electricity has seen not only from the industrial sector but also from the domestic sector as well. However, the shortage in power generation due to the lack of availability of good quality of fossil fuels, scarcity of water, etc. has left both domestic as well as the industrial sector in a loss making situation and has led to the development of a new concept of distributed generation [2].

Distributed generation includes the application of small generators typically ranging in capacity from 1 kW to 30 MW, spotted throughout the power system near to the load and provides the increase in power demand with the combined effect of the large hybrid power generation system [3]. Distributed generation appears especially attractive to policymakers and regulators because it provides the option of reducing investments in transmission and distribution system and minimizing the transmission & distribution energy loss. Distributed generation has number of advantages like lower capital cost; modular construction and short assembly time. It also includes energy from renewable energy sources like fossil fuels, solar photovoltaic and wind turbines etc. On the other hand, voltage oscillation, increase in fault current, altering the power flow direction, etc. are some technical problems which may occur due to wrong placement of DGs in a network. Thus for obtaining their maximum potential benefits, proper location of DG in a power system is important. In this paper, proper size and location of DG has been found out by using modified PSO to reduce the transmission loss while maintaining the specified voltage at each bus of the power system. Calculation of DG location and size in the power system are now-a-days receiving special attention by the power engineers and researchers [4], [5].

The appearance of DG units, including a year dependent decision making variable, the impact of the electricity market as well as operation & maintenance cost and the cost of power losses has been considered in [6]. The optimal size and location of DG with voltage stability improvement was proposed by [7] considering different weighting factors based on criticality of load. Optimization of DG location and size problem considering real power losses and voltage stability index for 69 bus distributed system was carried out in [8]. The placement and size of DG with different DG models considering their bus available limits for a 38 bus distribution system was presented in [9].

The optimum size and allocation of DG units have been investigated using genetic algorithm and proves that the increasing the number of DG units for same penetration will reduce the losses of the system [10]. The technical benefits of installation of DG units in IEEE 14 bus system using genetic algorithm have been quantified in [11], [12]. The performance

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of allocating size and location of DG units using Artificial Bee Colony Optimization technique against PSO algorithm is presented in [13].

In [14], [15], the optimal locations of DG units were carried out depending on the stability index and the reduction of real power losses as well as for the improvement of voltage profile. The multistage optimization model presenting the most common alteration to a distributed network in the insertion of new branches with different cross sections, installation of new substations and the use of available capacity of distributed generation was explained in [16], [17].

Distributed generation is a new approach to overcome the voltage stability related problem which generates electricity near the customer's site. DG is installed within the local distribution system or very near to the consumer site, so that the power could be supplied directly when needed. However, the benefits of DG could be achieved, when it is implemented on the optimal location with an optimal size, otherwise it may lead to greater power loss than without DG, due to an inappropriate selection of location and size.

The sensitivity of real and reactive power losses with respect to size and operating point of DG has been studied for various types of loads and validated for constant impedance and constant current loads. Section II described a framework modeled successfully to estimate the optimal DG capacity investment to serve peak demands optimally integrated with the other traditional planning decisions. In Section III, the effects of distributed generation have been depicted by using the technical benefits of DG using modified PSO technique.

II. Model Description

In this section, the mathematical formulation of the proposed model is presented. The objective function (OF) and the optimization procedure are highlighted in this section.

A. Objective Function

The objective function (OF) for loss minimization comprises of the transmission loss from i^{th} bus to k^{th} bus followed by the equality and inequality constraints [18]-[20] may be given as,

$$F = \mathbf{min}(P_{loss}) = \sum_{k=1}^{n} I_k^2 R_k \tag{1}$$

where, P_{loss} =active power loss, n= total no. of bus lines. Subjected to constraints

$$V_i^{\mathbf{min}} \le V_i \le V_i^{\mathbf{max}} \tag{2}$$

$$V_{DG}^{\mathbf{min}} \le V_{DG} \le V_{DG}^{\mathbf{max}} \tag{3}$$

$$P_{DG}^{\mathbf{min}} \le P_{DG} \le P_{DG}^{\mathbf{max}} \tag{4}$$

where, V_i is the voltage magnitude of i^{th} bus, V_{DG} is the voltage magnitude at i^{th} bus, P_{DG} is the power injected by DG in the distributed system.

The basic power flow equation of the system may be given as,

$$S_i = P_i + jQ_i \tag{5}$$

The power flow equation considering DG as power source and the losses can be given as,

$$P_{DGi} + P_i = P_{Di} + P_L \tag{6}$$

$$Q_{DGi} + Q_i = Q_{Di} + Q_L \tag{7}$$

Subjected to,

$$P_i^{\mathbf{min}} \le P_i \le P_i^{\mathbf{max}} \tag{8}$$

$$Q_i^{\mathbf{min}} \le Q_i \le Q_i^{\mathbf{max}} \tag{9}$$

$$Q_{DG}^{\mathbf{min}} \le Q_{DG} \le Q_{DG}^{\mathbf{max}} \tag{10}$$

where, P_i, Q_i are the real and reactive power at i^{th} bus, P_{Di}, Q_{Di} are the real and reactive load at i^{th} bus

B. Distributed Generation

All types of Distributed Generation, or DG, includes the application of small generators, typically ranges from 1 kW to 30 MW [3], scattered throughout a power system, to meet the consumer demands. As ordinarily applied, the term distributed generation includes all use of generators, which may run with a standalone system or in conjunction with the power grid network. Some of the advantages of installing DG in the systems are:-

- Reduces peak electricity demand
- Reduces transmission and distribution network losses
- Lowers the greenhouse gas emissions (from increased fuel efficiency resulting from the use of waste heat in co-generation or tri-generation or renewable energy)
- Improves reliability of electricity supply, with greater energy security

Voltage profile improvement index and line loss reduction index are the two technical indices of DG considered in this paper.

Voltage Profile Improvement Index (VPII):

Voltage Profile Improvement Index is defined as the ratio between voltage profile when DG is connected to the system and voltage profile when system is running without DG.

$$VPII = \frac{VP_{wdg}}{VP_{wodg}} \tag{11}$$

where, VP_{wdg} is the measure of voltage profile of the system with DG connected and VP_{wodg} is the measure of voltage profile of the system without DG.

- If VPII<1; DG has not been beneficial.
- VPII>1; DG has improved voltage profile of the system

- VPII=1; DG has no impact on the voltage profile of system

Line Loss Reduction Index (LLRI):

Line losses are being the main concern while implementing the DG in the power system, as it depends on the rating and location of DG units, it may increase due to the high penetration level of DG. The ratio between total line losses in the system with DG and the total line losses in the system without DG is called as penetration.

$$LLRI = \frac{LL_{wdg}}{LL_{wodg}} \quad (12)$$

where, LL_{wdg} is the total line loss in the system with DG connected and LL_{wodg} is the total line loss in the system without DG.

- If LLRI<1; DG has reduced electrical line losses.
- LLRI>1; DG has caused more line losses.
- LLRI=1; DG has no impact on line loss of the system.

C. Modified PSO Based Optimal Control

PSO [21]-[26] is a population-based technique introduced by Kennedy and Eberhart in 1995. Theory of this technique is derived from observations of fish schooling and bird flocking behaviour. The optimization procedure of a PSO system begins with an initial population of random values. Optimal points after each iteration are calculated by updating various parameters. It also has memory of good solutions contained by all particles and the particles in the swarm share their information among themselves, which makes it attractive among other optimization algorithms. PSO provides a population based search procedure, i.e. it attains a population of optimal solutions to investigate or examine the search space concurrently.

In 2007, Selvakumar and Thanshkodi proposed a new concept of dissevering the behaviors of the standard PSO and developed a variant of PSO with an anti-predatory activity, named as anti-predatory PSO [27]. The proposed modified PSO algorithm is based on anti-predatory activity and it is different in a way that, the search of a solution is faster, optimum and fast convergent.

The population chosen in the algorithm is called the *swarm* and its individuals are called the *particles.* The particle corresponds to bird or fish position in the search space. Every particle has its position, speed and a fitness parameter can be used to decide good position or bad position. In the general PSO method, particles search the optimal solution with respect to two reference positions; one is the personal best value and another is the global best value. But, in the proposed modified PSO algorithm, there are four references, i.e. personal & global best value and personal & global worst value. The equations to update the particle velocity and position are given as:

$$v_{ij}^{r+1} = w^r v_{ij}^r + C_1R_1\left(Pb_{ij}^r - P_{ij}^r\right) + C_2R_2\left(P_{ij}^r - Pw_{ij}^r\right) + C_3R_3\left(Gb_j^r - P_{ij}^{r-1}\right) + C_4R_4\left(Gw_j^r - P_{ij}^r\right) \quad (13)$$

$$X_{ij}^{r+1} = X_{ij}^r + v_{ij}^r \quad (14)$$

where, P denotes personal and G denotes global value. The inertia weight factor is given by,

$$w = (w_{\max} - w_{\min}) \times \frac{iter_{\max} - iter}{iter_{\max}} + w_{\min} \quad (15)$$

The behaviour of proposed modified PSO has been divided into two dissimilar components. Cognitive behaviour comprises of a good experience component and a bad experience component. The social behaviour is divided into a global good experience and global worst experience. A good experience component of a swarm denotes that it has a memory of its previously visited best position. A bad experience component denotes that, it has a memory of its previously visited worst position. In this paper, the best result points are considered as food locations whereas the predators are taken as worst result points. The parameters used for proposed algorithm are given in Table I.

TABLE I
PARAMETERS OF MODIFIED PSO

Sl no.	Parameters	Values
1	No. of iteration	100
2	Population size	20
3	Acceleration factor C1 & C2	0.1-2
4	Acceleration factor C3 & C4	2
5	Inertia weight factor w_{max} & w_{min}	0.9 & 0.4
6	R1, R2, R3 & R4	Separately generated uniformly distributed random number in the range [0, 1]
7	P_b & G_b	Personal and global best value
8	P_w & G_w	Personal and global worst value

III. NUMERICAL RESULTS

A. System under Study

In this paper, IEEE 30 bus test system as shown in Fig. 1 is used which consists of six generator bus and 24 load buses. The results of load flow study and economic load dispatch to the test system with 30% increase in load are given in Table II.

After installing DG in 30th bus, the voltage magnitude of IEEE test system is as given in Table III. From Table III, it is clear that the voltage magnitude of 30th bus has been drastically changed and the transmission loss is 24.3 MW. Hence, the preferred location of DG will be 30th bus and to determine the size of DG, modified PSO technique is used.

B. Modified PSO Algorithm Used to Determine DG Size

Initialization: Initialize the population size, iteration count and acceleration coefficients (as given in Table I), i.e. c1, c2, c3, c4. Randomly create a set of real and reactive power.

Constraint check: Check the limits for voltage, real power and reactive power at each bus as mentioned in (2)-(4), (8)-(10).

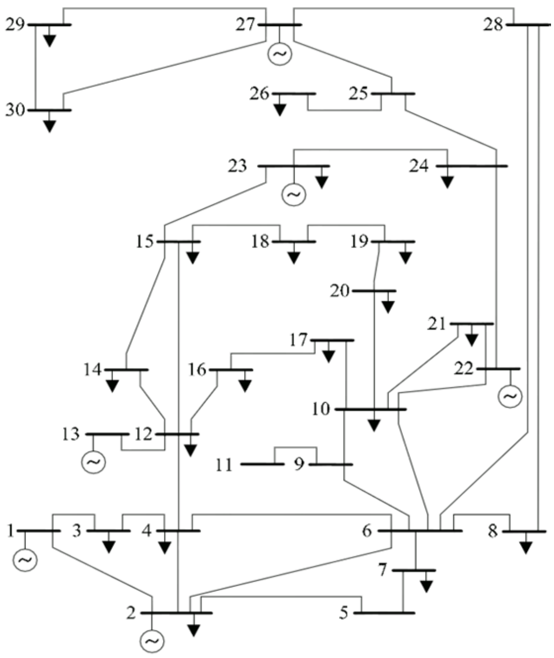

Fig. 1 IEEE 30 bus test system

TABLE II
VOLTAGE MAGNITUDES OF IEEE 30 BUS TEST SYSTEM

Bus No.	Voltage (in pu)	Bus No.	Voltage (in pu)
1	1.0600	16	1.0365
2	1.0424	17	0.9949
3	1.0248	18	0.9971
4	1.0160	19	0.9911
5	1.0057	20	1.0185
6	1.0122	21	1.0223
7	0.9932	22	1.0229
8	1.0073	23	0.9954
9	1.0460	24	0.9882
10	1.0356	25	0.9875
11	1.0765	26	0.9899
12	1.0506	27	1.0162
13	1.0635	28	1.0095
14	1.0335	29	0.9934
15	1.0286	30	0.9489

Evaluation of OF: The OF given in (1) for each set of particles is evaluated. The initial and final best position with minimum value of particle in the swarm is considered as personal best and personal worst value (*pbest* and *pworst*) respectively. The minimum and maximum value of OF is taken as global best and global worst value (*gbest* and *gworst*) respectively.

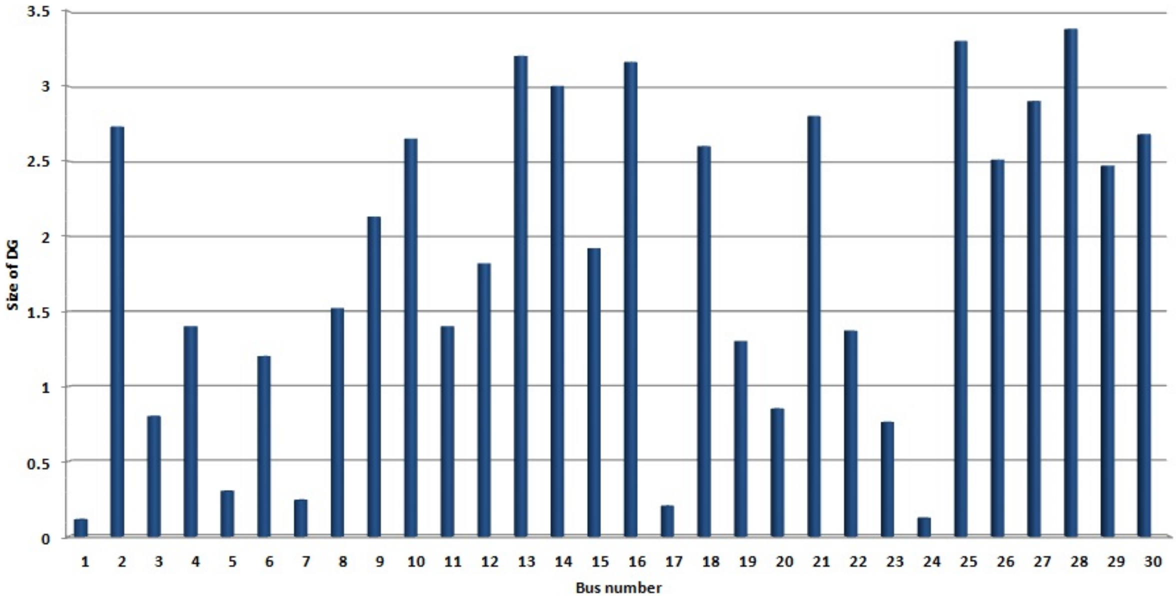

Fig. 2 Optimum DG size (in MW) obtained at each bus location

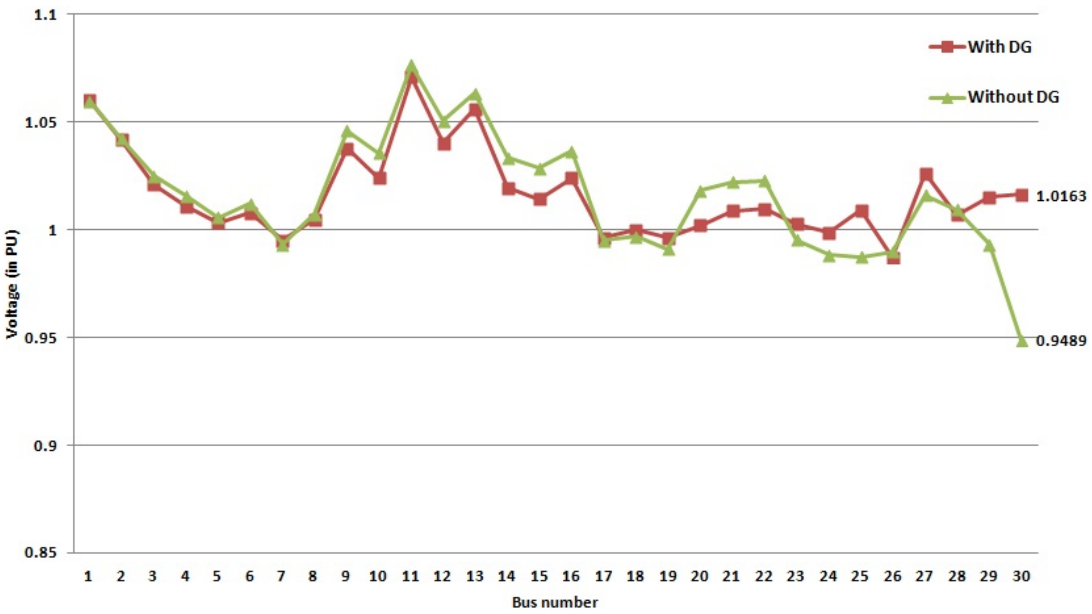

Fig. 3 Voltage profile of 30 bus system with DG connected and without DG

TABLE III
VOLTAGE MAGNITUDES OF SYSTEM AFTER INSTALLING DG

Bus No.	Voltage (in pu)	Bus No.	Voltage (in pu)
1	1.0600	16	1.0241
2	1.0418	17	0.9963
3	1.0209	18	1.000
4	1.0110	19	0.9963
5	1.0033	20	1.0020
6	1.0078	21	1.0089
7	0.9952	22	1.0098
8	1.0048	23	1.0028
9	1.0377	24	0.9988
10	1.0240	25	1.0091
11	1.0709	26	0.9871
12	1.0403	27	1.0261
13	1.0560	28	1.0069
14	1.0193	29	1.0151
15	1.0142	30	1.0163

Updating velocity and position: The velocity and position of the particles are updated using (13) and (14). Final best positions in the swarm are obtained comparing the initial and final values.

Checking terminal condition: Check if the desired condition is achieved otherwise repeat updating procedure.

Output: The best solution in the optimization procedure is obtained, i.e. the global best value (power transmission loss).

C. Technical Benefits of DG

The technical benefit indices are summarized in Table IV. The transmission loss of the system after installing DG is 18.08 MW. In the presented optimization method, size of DG is considered as the position of the particle which can vary between 0 to the sum of total loads connected to the system. The optimal size of DG at each bus, hence obtained is shown in Fig. 2. Fig. 3 shows the voltage profile of 30 bus system with and without DG connection.

TABLE IV
TECHNICAL BENEFIT INDICES FOR OPTIMAL DG LOCATION AT 30TH BUS AND OPTIMAL DG SIZE OF 1.66 MW

Sl. No.	Benefit indices	Values	% change
1	VPII	1.009	1.43% improvement
2	LLRI	0.744	28.7% reduction

IV. CONCLUSION

In this paper, the voltage profile improvement and line loss reduction have been successfully carried out for IEEE 30 bus test system to obtain the dispatched power of each generator. The low voltage bus is identified by using the load flow analysis of IEEE 30 bus test system. In order to find out the optimal placement of DG in the system, modified PSO technique is incorporated which is time-consuming and faster convergent. Also, a benefit of installing DG has been evaluated with proposed optimization technique.

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