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OPTIMAL PLACEMENT OF DG UNDER STANDARD MARKET DESIGN BY USING PARTICLE SWARM OPTIMIZATION

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ABSTRACT

Distributed Generation (DG) can help in reducing the cost of electricity to the costumer, relieve network congestion and provide environmentally friendly energy close to load centers. Its capacity is also scalable and it provides voltage support at distribution level. Hence, DG placement and penetration level is an important problem for both the utility and DG owner. The restructured power markets are slowly maturing with standardizations like Standard Market Design (SMD). The key feature of SMD is the Locational Marginal Pricing (LMP) scheme. This thesis examines placement and penetration level of the DGs under the SMD framework. The proposed approach is illustrated by case study on IEEE 30 bus system. The objectives include reduction in T&D losses and improvement of voltage profile of the system, with due consideration of fixed and variable costs. The Optimal Power Flow (OPF) problem by placing DG in Deregulated Environment is solved using Particle Swarm Optimization (PSO) and results compared with Genetic Algorithm (GA) and observed that PSO gave best results for optimal size of DG and aimed objectives than the GA.

Keywords: Distributed Generation, SMD, LMP, OPF, PSO, Genetic Algorithm.

1. INTRODUCTION

Distributed Generation (DG) can help in reducing the cost of electricity to the costumer, relieve network congestion and provide environmentally friendly energy close to load centers. Its capacity is also scalable and it provides voltage support at distribution level. Hence, DG placement and penetration level is an important problem for both the utility and DG owner. There are number of important issues to be considered while carrying out studies related to the planning and operational aspects of a DG set. The planning studies include penetration level and placement evaluation, which are influenced by the type of DG. The connection to grid allows Injection of power into grid making the DG scheme more viable. The basic objective of [Celliand Pilo, 2002] is to minimize the total cost of operation including the fixed and variable costs. The costs of buying energy from transmission system and from DG units should be considered so as to have a proper assessment of the penetration level of a DG in distribution system. DG will influence the optimal dispatch of the system. The method for optimal placement of DG using Genetic Algorithm (GA) and its penetration level assessment by Optimal Power Flow (OPF) has been proposed by [Kulkarni et al., 2003]. The objectives include reduction in T&D losses and improvement of voltage profile of the system, with due consideration of fixed and variable costs. [Brown et al., 2001] presents a network capacity expansion algorithm capable of deferring T&D expansion by optimally siting DG units at new or existing substations. The final result is the determination of allowable penetration levels of distributed generation resources for a range of distribution feeders. The study is useful for determination of viable DG capacity in a typical distribution system.

II. DISTRIBUTED GENERATION

Distributed generation (or DG) generally refers to small-scale (typically 1 kW – 50 MW) electric power generators that produce electricity at a site close to customers or that are tied to an electric distribution system. Distributed generators include, but are not limited to synchronous generators, induction generators, reciprocating engines, micro turbines (combustion turbines that run on high-energy fossil fuels such as oil, propane, natural gas, gasoline or diesel), combustion gas turbines, fuel cells, solar photovoltaic's, and wind turbines.

In addition to meeting future energy needs, DG will also have significant importance in a deregulated environment. It can provide independence and flexibility to the consumers in planning and developing the installation as per the criticality of the load. It can minimize the investment made over T&D infrastructure by locating it near the load. It has potential to serve as an ancillary service. DG is best suited for demand side management programs. It can be viewed as an ancillary service for voltage control. It has energy attributes (such as the ability to recover waste heat) that distinguish it from central generation. Combined Heat and Power (CHP) systems can dramatically change site economics. These systems can compete with utility-supplied power in most service areas. DG can be used to attain higher levels of end-user reliability than those possible from central generating stations.

III. STANDARD MARKET DESIGN

It is time for the Federal Energy Regulatory Commission (FERC) to define the principles for a standard electricity market design and to begin consistently applying those principles to the market rules now being developed by Regional Transmission Organizations (RTOs). FERC's recent RTO orders make it abundantly clear that the fundamental purpose of forming independent RTOs is not merely to "operate the grid," nor only to ensure non-discriminatory access to essential grid facilities and services. In addition to these undisputed RTO responsibilities, an essential function of RTOs is to create and operate RTO-coordinated markets.

IV. LOCATIONAL MARGINAL PRICING

LMP is the lagrangian multipliers associated with the active power flow equations for each bus in the system.LMP at any node in the system is the dual variable for the equality constraint at the node. LMP is generally composed of three components, a marginal energy component, a marginal loss component and a congestion component. Considering the case of real power spot price at bus i, higher LMP implies a greater effect of active power flow equations of the node on total social welfare of the system. It thus provides indication that for the objective of social welfare maximization, injection of active power at that node will improve the net social welfare. As the DG is assumed to inject real power at a node, the mode with highest LMP will have first priority for DG placement.

The determination of LMPs is similar, but not identical, in the day-ahead and real-time markets. Day-ahead LMPs are output from the day-ahead market clearing process. Generation, demand, external contracts, and increment and decrement positions that clear in the day-ahead market settle at prices determined by day-ahead LMPs. The real-time market balances supply and demand as the system operates. Real-time LMPs are based on current power system operating data. Deviations between day-ahead and actual real-time positions settle at prices determined by real-time LMPs.

$$LMP_i=LMP^{energy}+LMP_i^{cong}+LMP_i^{loss}$$

Where,

LMP^{energy}–The component of the LMP that reflects the marginal cost of providing energy from a designated reference location.

LMP_i^{cong}– The component of LMP at a i^{th} node that accounts for the costs of congestion, as measured between that node and a reference Bus.

LMP_i^{loss} – The component of LMP at a i^{th} node that accounts for the marginal real power losses as measured between that node and a reference Bus.

V. OPTIMAL POWER FLOW

The Optimal Power flow module is an intelligent load flow that employs technique to automatically adjust the power system control settings while simultaneously solving the load flows and optimizing the operating conditions within specific constraints. Optimal Power Flow uses state-of-the-art techniques with barrier functions and infeasibility handling to achieve ultimate accuracy and flexibility in solving systems of any size. Basically the goal of an optimal power flow (OPF) is to determine the "best" way to instantaneously operate a power system. Usually "best" refers to minimizing the operating cost.

General OPF Problem Formulation:

In general, the mathematical formulation of the OPF problem can be formulated as anon-linearly constrained optimization problem as discussed below:

$$\text{Minimize } F(x, u)$$
$$\text{Subject to: } g_E(x, u) = 0$$
$$g_O(x, u) \le 0$$
$$g_C(x, u) \le 0$$

Proposed OPF Problem Formulation:

As any optimization problem, the OPF problem is formulated as a minimization or maximization to certain objective function in which it is subjected to a variety of equality and inequality constraints. The proposed objective function is mentioned:

The Objective Function:

Minimization of Generation Fuel Cost

The objective function is the minimization of the generation fuel cost of thermal units. Generally, the OPF generation fuel cost function can be expressed by a quadratic function as follows:

$$\text{Minimize } (F_T) = \sum_{i=1}^{N_G} F_i(P_{Gi})$$

Where,

$$F_i(P_{Gi}) = a_i + b_i P_{Gi} + c_i P_{Gi}$$

Where,

$$P_G = [P_{G1}, P_{G2} \ldots P_{Gn}]^T$$

The constraints:

The control variables for OPF include active power at all generator units, generator bus voltages, transformer tap positions and switchable shunt reactors. OPF constraints are divided into equality and inequality constraints.

The equality constraints are active/reactive power equalities. The inequality constraints include bus voltage constraints and generator reactive power constraints. Reactive source reactive power capacity constraints and the transformer tap position constraints, etc. Therefore, the above objective function is subjected to the below constraints.

a) Equality constraints:

The equality constraints of OPF reflect the physics of the power systems. They are enforced through the power flow equation. The net injection of the real and reactive power at each bus is to be zero as shown.

The power flow equation of the network

$P_{gi} - P_{Li} - P(V,\Theta)=0$ (Active power balance equation)

$Q_{gi} - Q_{Li} - Q(V,\Theta)=0$ (Reactive power balance equation)

Where,

V and ϴ are voltage magnitude and phase angles at different buses.

b) Inequality constraints

The inequality constraints of the OPF reflect the limits on physical devices in the power systems as well as the limits created to ensure system security. The types of inequality constraints are bus voltage limits at generations, maximum line loading limits and limits on tap settings. The inequality constraint on active power generation P_{gi} at each PV bus are,

Real power generation limits:

$$P_{gi}^{min} \le P_{gi} \le P_{gi}^{max}$$

Reactive power generation limits:
$Q_{gi}^{\ min} \le Q_{gi} \le Q_{gi}^{\ max}$
Bus voltage limit:
$V_i^{min} \le V_i \le V_i^{max}$
Line flow limit: $S_{ij} \le S_{ij}^{\ max}$
$S_{ji} \le S_{ji}^{max}$

VI. GENETIC ALGORITHM

The GA begins, like any other optimization algorithm, by defining the optimization variables, the cost function, and the cost. It ends like other optimization algorithms too, by testing for convergence. In between, however, this algorithm is quite different. We use genetic algorithm because the features of Genetic algorithm are different from other search techniques in the several aspects. First the algorithm is a multipath that searches many peaks in parallel and hence reducing the possibility of local minimum trapping. Secondly, GA works with a coding of parameters instead of the parameters themselves. The coding of parameter will help the genetic operator to evolve the current state into the next state with minimum computations. Thirdly, GA evaluates the fitness of each string to guide its search instead of the optimization function. The genetic algorithm only needs to evaluate objective function (fitness) to guide its search. Finally, GA explores the search space where the probability of finding improved performance is high.

Standard procedure of a genetic algorithm in optimal power flow:

Step-by-Step Algorithm for Genetic Algorithm Based OPF

1. Read the database for the generator data, bus data, capacitor/reactor data, transformer data and transmission line data.
2. Assume suitably population size (pop size), maximum number of generations or populations (gen max).
3. Set valid number of population counter. Pop_vn=0.
4. Randomly generate the chromosomes.
5. Run power flow using the Newton-Raphson method for each set of generating patterns P_{gi} corresponding to a particular generation and after that determine, slack bus generation, bus voltage magnitudes and phase angles at all the buses. Also calculate power flow in each transmission line of the system.
6. Check the following constraints,
   Check the voltage magnitude violation
   $V_i min \le V_i \le V_i max$
   Check the bus voltage phase angle
   $Ø_i^{min} \le Ø_i \le Ø_i^{max}$
   Check the MVA flows violation
   $MVA_{ij} \le MVA_{ij}^{max}$
   Check reactive power limits at all generator buses, if any of the above limits is violated, go to step 4.
7. If all the above constraints are satisfied, increment pop_vn by 1. If pop_vn less than or equal to pop_size, go to step 4, otherwise go to next step.
8. Calculate and then store the total cost of generation corresponding to each valid generation pattern of chromosome
9. Find and store minimum cost among all valid individual parents and corresponding generation pattern.
10. Check if random no. $r_i < c_r$ (crossover rate) for i=1 to pop size, select i_{th} chromosome. Apply the crossover operator to that individual.
11. Run power flow using Newton-Raphson method for each set of new generating patterns and hence determine, slack bus generation, bus voltage magnitudes and phase angles at all the buses. Also calculate power flow in each transmission line of the system.
12. Check system constraints as mentioned in step6.
13. If all the constraints are satisfied, the individual of the new population becomes valid otherwise it becomes invalid.

14. Apply the mutation operator to the calculated generation patterns.
15. Run power flow using the Newton Raphson and check all the constraints as mentioned in step 6.
16. If all the constraints are satisfied go to next step otherwise go to step 4.
17. Calculate the total cost of all valid patterns.
18. Find the optimum solution among all population groups.

VII. PARTICLE SWARM OPTIMIZATION

Particle swarm optimization (PSO) is a population based stochastic optimization technique developed by Dr. Kennedy and Dr. Eberhart in 1995, inspired by social behavior of bird flocking or fish schooling. PSO shares many similarities with evolutionary computation techniques such as Genetic Algorithms (GA).

The system is initialized with a population of random feasible solutions and searches for optima by updating generations. However, unlike GA, PSO has no evolution operators such as crossover and mutation. PSO algorithm has also been demonstrated to perform well on genetic algorithm test function. In PSO, the potential solutions, called particles, fly through the problem space by following the current optimum particles.

PSO Algorithm for OPF problem:

The various steps involved in the implementation of PSO to the OPF problem are-

1. Input parameters of system, and specify the lower and upper boundaries of each variable.
2. Initialize randomly the particles of the population. These initial particles must be feasible candidate solution that satisfies the practical operation constraints.
3. To each particles of the population, employ the Newton- Raphson method to calculate power flow and the transmission loss.
4. Calculate the evaluation value of each particle, in the population using the evaluation function.
5. Compare each particle's evaluation value with its pBest . The best evaluation value among the pBest is denoted as gBest
6. Update the time counter t = t+1
7. Update the inertia weight w given by

$W = W_{max} – (W_{max} - W_{min}) / iter_{max} = iter$

8. Modify the velocity v of each particle according to the mentioned equation.
   V (k,j,i+1) = w*V(k,j,i) + C1*rand*(pbestx (j,k) - x(k,j,i))+ C2*rand*(gbestx (k) - x(k,j,i))
9. Modify the position of each particle according to the mentioned equation. If a particle violates the its position limits in any dimension, set its position at the proper limit x(k,j,i+1)=x(k,j-1,i)+v(k,j,i)
10. Each particle is evaluated according to its updated position. If the evaluation value of each particle is better than the previous pBest , the current value is set to be pBest. If the best pBest is better than gBest , the value is set to be gbest.
11. If one of the stopping criteria is satisfied then go to Step
    Otherwise, go to Step6.
12. The particle that generates the latest gBest is the optimal value. The parameters that must be selected carefully for the efficient performance of PSO algorithm are:-

Both acceleration factors C1 & C2. Number of particles. The inertia factor.

The search will terminate if one of the below scenario is encountered:

|gbestf(i) - gbestf(i-1)| < 0.0001 for 50 iterations

Maximum number of iteration reached (500 iterations. Number of intervals N, which determine the maximum velocity v_k^{max}

The PSO algorithm for solving the OPF problem with anobjective function of minimization of generation fuel cost.

VIII. SIMULATION AND RESULTS

In the case of GA number of values that can be accessed between the minimum and maximum limit is decided by the number of bits selected for that parameter. So the accuracy of the parameters optimized depends on the number of bits selected. Here in this paper 12 bits are considered for each generated power output i.e.2^{12} so many values we can get.

Similarly the adequate numbers of bits are considered for the remaining parameters (like voltages, transformer taps, shunts and DG) also in case of GA.

For each generator output power 12 bits, for each voltages 8 bits, transformer taps 5 bits each, shunts 3 bits each and for DG 8 bits each are considered.

GA parameters:

Population size=60,+ Chromosomes length=179, Elitism probability=0.1500 Crossover probability=0.8, Mutation probability=0.01.

In the case of PSO single variable is considered for each control parameter. For generator power output 5 variables, voltages 6 variables, transformer taps 4 variables, shunts 9 variables and for DG 3 variables are considered.

PSO parameters:

Acceleration constants C1=2.05 & C2=2.05, Inertia factor (W) W_{min}=0.4 and W_{max}=1.2, Number of particles=60,

Number of variables=27.

TABLE-1: COST OF ENERGY WITH VARIOUS TYPES OF DGS

DG type	Initial cost ($/kw)	% η	% Availability	Life in years	Cost of energy ($/MWh)
Reciprocating engine	433	40	97	20	110
Mini gas turbine	420	29	97	20	120
Fuel cell	750	42	97	10	131

TABLE2: OPTIMAL LOCTION BASED LMP AND SIZE OF DG BY GA AND PSO FOR IEEE 30 BUS SYSTEM

Optimal Bus Location for DG Placement based on	Optimal size of DGby using GA in (p.u.)	Optimal size of DGby using PSO in (p.u.)	DG type
30	0.019765	0.020000	Mini gas turbine
26	0.009647	0.010000	Reciprocating Engine
19	0.009206	0.009694	Mini gas turbine

TABLE3: FUEL COST COMPARISION FOR IEEE30 BUS SYSTEM BY GA AND PSO WITHOUT DG AND AFTER PLACEMENT OF DG

Fuel cost without DG by GA in $/hr	Fuel cost without DG by PSO in $/hr	Fuel cost with GA After placement of DG in $/hr	Fuel cost with PSO After placement of DG in $/hr
803.083177	801.2885600	789.441332	787.751597

TABLE 4: CPU TIME COMPARISION FOR IEEE30 BUS SYSTEM BY GA AND PSO WITHOUT DG AND AFTER PLACEMENT OF DG

CPU time without DG by GA in (seconds)	CPU time without DG by PSO in (seconds)	CPU time with GA After placement of DG in seconds (seconds)	CPU time with PSO After placement of DG in seconds

360.3222	336.1163	357.2154	330.6782

TABLE5: COMPARISON OF LOSSES WITHOUT DG AND AFTER PLACEMENT OF DG WITH GA AND PSO

No.of lines	P_{loss}+q_{loss} without DG by GA	P_{loss}+q_{loss} without DG by PSO	P_{loss}+q_{loss} After placement of DG by GA	P_{loss}+q_{loss} After placement of DG by PSO
41	0.095263+j0.069747	0.09641+j0.033046	0.093843+j0.085423	0.092457+j0.091941

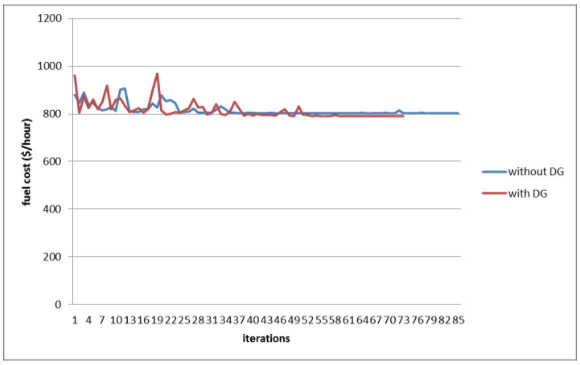

Fig 1: fuel cost without DG and after placement of DG with GA.

From the above graph we can observe that fuel cost has reduced after placement of DG.

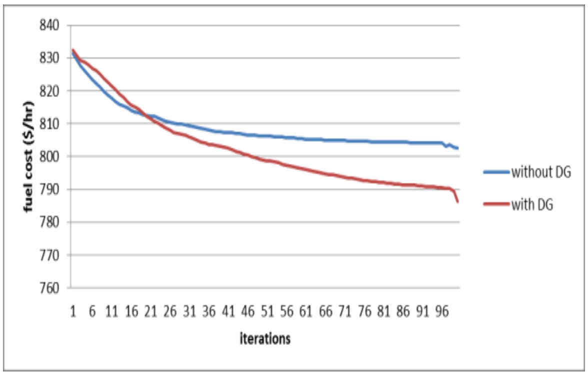

Fig 2: fuel cost without DG and after placement of DG with PSO.

Fuel cost without DG and after placement of DG with PSO. From the above graph we can observe that fuel cost has reduced with PSO after placement of DG better than GA.

IX. CONCLUSIONS

In this paper, an algorithm is proposed for solving the DG placement and penetration problem. The DG is a viable solution at a node provided that cost of grid electricity is higher than the DG electricity cost. LMP is used as an indicator of grid electricity cost at a node as it is sensitive to generation cost, losses and location of the node in the system. Installation of DG reduces the LMPs in the system. When LMP reduces below DG marginal cost, further addition of DG becomes economically unviable. To start with, the base case OPF of a system is solved. LMPs at system nodes correspond to the price of a unit power received at the node. The node with the highest LMP is a clear candidate for locating the DG since it will yield highest returns. The optimal location is founded based on LMP values. The Optimal Power Flow (OPF) problem by placing DG at exact locations in Deregulated Environment is solved using Particle Swarm Optimization (PSO) and results compared with Genetic Algorithm (GA) and observed that PSO gave best results for optimal size of DG, minimum fuel cost and reduction in losses than the GA.

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