Optimal Power Flow Considering Intermittent Wind Power Using Particle Swarm Optimization

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Abstract- Inclusion of renewable generation in the existing network is necessary due to the increase in raw material cost for generating electricity and growing demand. Optimal power flow incorporating wind generation is solved using Particle swarm optimization (PSO) in this paper. Weibull distribution function is used for modelling the intermittent nature of wind farm and then it is incorporated in the existing power system network. A direct cost function of the wind power purchased is presented in the paper. Cases without and with wind power are solved using PSO due to its ability in solving the non linear problems. The analysis is carried out on IEEE 30 bus test system and the obtained results are compared with the few existing methods. From the results it can be inferred that this method provides enhanced results.

Keywords Optimal power flow; Wind; PSO; weibull distribution.

1. Introduction

In recent years, optimal power flow (OPF) approach plays crucial role in the field of power system for operation and control for increasing power generation for efficient power generation in order to meet the electricity demand of the world. OPF occurs in power generation system due to improper placing of generation system and inconsistent load applied to generating unit [1]. In order to evaluate the efficient functioning of the power generation system certain parameters are considered for evaluations like voltage stability of the generation system, losses, fuel cost associated with power generation and losses. For certain security constraints fuel value related to power generation system are not exhibited [2].To achieve optimum target of the system OPF is set to specific control values of generation unit further based on the optimum values equality and inequality factors also examined for target generation time of system [3]. This equality and in equality factors of power generation system indirectly optimized by other factors like control variables, operational efficiency of dependent variables [8]. In worldwide most of the researchers have found that OPF main objective function is to reduce fuel cost of generating system. Researchers projected completely different mathematical formulations of the OPF drawback which can be termed into linear, non-linear or mixed number linear drawback. Drawbacks found in inconsistent power generation optimization in existing are giant scale problem, nonlinear generation of power and stability of generation unit. To overcome existing drawback associated with OPF various programming techniques are developed like mathematical, linear, nonlinear programming and newton methods are developed [4]. Power generation system has certain internal drawbacks like improper sizing of power generation system which leads to sub linearity and drawbacks of non-linearity of power generation. For solving improper placing and sizing of the power generation system nonlinear and quadratic functions are adopted but this techniques have difficulty in handling algebraic or mathematical functions of the system [7].To overcome this drawback associated with existing system various heuristic approaches are developed which is also known as genetic algorithm for examples like programming, tempering, PSO, Chaos optimization, Tabu search etc are developed to overcome problems in OPF without affecting power generation value of system [6, 9-10]. In this research developed an objective function of minimizing generation cost with minimized voltage stability value of generation system. The developed objective function will be evaluated in wind power generation system with wind system efficiency of the proposed approach is evaluated and analyzed [5].

1.1 Proposed work:

In this paper optimal power flow is solved for a system comprising of both wind and thermal generators. Intermittent nature of wind farm is assumed to follow weibull distribution. Two different types of wind farms with different shape factors are considered for analysing the performance. Partial swarm optimization carried out to solve OPF problem owing to the simplicity of constrained solving problems. The upcoming contents in the paper is given below.

In section 2 OPF problem incorporating wind power is discussed. In Section 3 the steps involved in solving OPF using particle swarm optimization is given. In section 4 modelling of wind farm using weibull distribution is presented. Section 5 the results obtained using PSO are presented for the cases without and with wind power generation are presented and comparisons are made. Finally the conclusions of the proposed method are given.

2. Problem Formulation

The most important aim of the OPF problem is to curtail the generating cost. In this research, equality and inequality constraints of power system are considered.
This generation cost function is formulated as

Minimize $F_j(P_j)$

$$F_j(P_j) = \sum_{j=1}^{n}(a_j P_j^2 + b_j P_j + c_j) \tag{1}$$

Where F_j is generating fuel cost

a_j, b_j, and c_j are quadratic coefficient of fuel cost

Equality Constraints

The Power balance equation for the test system is given by

$$\sum_{j=1}^{m} P_j - P_d - P_l = 0 \tag{2}$$

where P_d is the demand in MW
P_l is the transmission loss in MW

Transmission losses calculated using B-coefficient method are represented by

$$P_l = \sum_{i=1}^{n}\sum_{j=1}^{n} P_i B_{ij} P_j \tag{3}$$

Inequality Constraints:

Active Power Constraint: The active power generation limits for the thermal generators are given by

$$P_{gi}^{\min} \le P_{gi} \le P_{gi}^{\max} \tag{4}$$

where $P_{gi}^{\min}, P_{gi}^{\max}$ are lower and upper limits of active power generation of the i[th] unit

Voltage Constraint: Voltage at the load buses must be within the specified limits and is given by

$$V_i^{\min} \le V_i \le V_i^{\max} \tag{5}$$

Transmission line constraint: The active power flow in the transmission lines must be within prescribed limits and are expressed as $S_i \le S_{i,\max}$ $i = 1, 2, ...NTL$ (6)

2.1 Optimal Power Flow incorporating wind Power

The power balance equation is modified as

$$\sum_{j=1}^{n} P_j + \sum_{i=1}^{m} P_{iw} - P_D - P_L = 0 \tag{7}$$

The cost corresponds to generated wind power is given by

$$F_i(P_{iw}) = d_i(P_{iw}) \tag{8}$$

where d_j is the direct cost of solar power of j[th] generator purchased from the utility

The total cost of combined wind thermal system is given by

$$\text{minimize } T(P_g) = F_j(P_j) + F_i(P_{iw}) \tag{9}$$

3. Particle Swarm Optimization with Wind Integrated Optimal Power flow

In 1995, Kennedy and Eberhart initially presented the PSO strategy, propelled by social conduct of creatures, such as and birds flocking and fish schooling [11]. PSO, as an enhancement instrument, gives a inhabitants-based search method in which particles change their positions (states) with respect to time. In the PSO framework, particles fly around in a intricate search space. Amid flight, every particle confirms its position as indicated by its own particular participation, and the participation of neighboring particles, making utilization of the best position experienced without anyone else and its neighbors[12]. The swarm heading of a particle is characterized by the arrangement of particles neighboring the particle and its past experience.
For an N-dimensional problem like OPF, PSO algorithm is illustrated as follows. Let *P*, *V* and *i* be the particle position, velocity and no of particles in the search space. Out of the obtained solutions of each particle the best previous solution will be saved in *Pbest*. Out of all the *Pbest* values the best solution is termed as *Gbest*. Using the current velocity and distance between *Pbest* & *Gbest* the updated velocity and position are given by following equations[13].

$$V_{ij}^{(iter+1)} = w * V_{ij}^{(iter+1)} + c_1 * \text{rand}1 * (Pbest_{ij} - P_{ij}^{iter}) + c_2 * rand2 * (Gbest_{ij} - P_{ij}^{iter}) \tag{10}$$

$$P_{ij}^{(iter+1)} = P_{ij}^{iter} + V_{ij}^{(iter+1)} \tag{11}$$

Suitable determination of the inertia weight gives a harmony in the middle of local and global exploitation and exploration, and results in fewer iterations to discover an adequately best solution.
The equation for setting inertia weight is given by

$$w = w_{\max} - \frac{w_{\max} - w_{\min}}{iter_{\max}} * iter \tag{12}$$

Where, w - is the inertia weighting factor

$iter_{max}$ - Total iterations

$iter$ – present iteration number

3.1 Steps for solving Optimal Power flow using PSO

1. According to limited number of each unit, initialize the individuals of population randomly. The velocities with in maximum and minimum value are generated from velocities of the various particles.
2. The number of generating units in the test system gives the dimension of the problem. PSO parameters considered are Population = 10, Iterations = 200 Weights = [0.9, 0.4], where the combination is set according to power equation regarding balance constraints.
3. Randomly generate particles between the bound limits of the participating generators. If there are N number of units, the j[th] particle is represented by $P_j=[P_{j1},P_{j2},....,P_{jN}]$
4. The cost function of all the units are solved using equation(1) and these values are considered as Pbest.
5. Each *pbest* and every values of *pbest* is compared in the population. The positive outcome evaluation value compared amid the *pbest* is represented as *gbest*.
6. Randomly generate particle velocities in the range $[-V_i^{max}, V_i^{max}], V_i^{max} = \frac{P_{i\max} - P_{i\min}}{R}$, R- number of intervals. Calculate the new velocity of all the dimensions using equation (10).
7. Now update the position of each particle using equation (11). Constraint of velocity components appears in the limits according to the following conditions are verified as V_d^{max} and V_d^{min}
8. Calculate the objective function for the updated velocity and position.
9. If the latest value obtained is superior than the old Pbest, update Pbest to the latest. If the obtained Pbest is better than Gbest, update the Gbest by Pbest. Repeat until stopping criteria is met.
10. If maximum iterations is attained by individual of evaluation value, The particle which gives the Gbest is the best generation of each unit with lower generation cost.

4. Modelling of Wind Farm

The uncertainty in wind speeds are modelled using weibull distribution function. The probability distribution function of wind speed is represented by[14]

$$f_v(V) = (k/c).(v/c)^{(k-1)}.e^{-(v/c)^k} \quad (13)$$

where *K* is shape factor and *c* is scale factor.

The expected output power of a wind turbine is given by

$$P_{wr} = \begin{cases} 0 & v < v_{in} \text{ or } v > v_{out} \\ (a*v^3 + b*\mathrm{P_r}) & v_{in} \le v \le v_r \\ \mathrm{P_r} & v_r \le v \le v_{out} \end{cases} \quad (14)$$

where $a = \frac{\mathrm{P_r}}{(v_r^3 - v_{in}^3)}$, $b = \frac{v_{in}^3}{(v_r^3 - v_{in}^3)}$ are the constants.

The estimated wind power output is given by

$$P_{we} = P_w \times f_v(V) \quad (15)$$

Table 1. Specifications of the wind Turbine

Wind Farm 1		Wind farm 2	
Kw1	1	Kw2	2
C1	15	C2	15
Vin1	3m/s	Vin2	3 m/s
Vout1	30 m/s	Vout2	30 m/s
Vr1	12 m/s	Vr2	12 m/s
Pr1	50MW	Pr2	50MW
d1	2$/hr	d2	2.25$/hr

Two wind farms of 50 MW capacity, are chosen for the analysis. The data related to wind turbines is given in Table 1. The output from wind farms is calculated using the weibull distribution function and is incorporated as negative demand in the test system. The probability of wind output from the wind farm 2 is plotted in Fig 1.

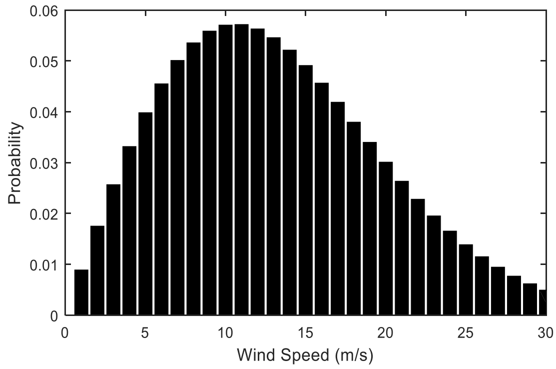

Fig.1. Probability density function of wind farm 2

5. Results and Discussion

Optimal power flow incorporating wind power generation is solved using PSO technique. Active power constraint, Voltage constraint and Transmission line constraint are included in the system.

Table 2. Generator cost coefficient and Active power limits of IEEE 30 bus system

Unit	ai ($/MW²)	bi ($/MW)	ci	Pg min	Pg max
1	0.00375	2	0	50	200
2	0.0175	1.75	0	20	80
3	0.0625	1	0	15	50
4	0.00834	3.25	0	10	55
5	0.025	3	0	10	30
6	0.025	3	0	12	40

The proposed methodology is tested on IEEE 30 bus system and the results are compared. The power generation limits and generator cost coefficients of the test system are given in Table 2.

5.1 OPF without considering wind power generation

In this case the power generated by thermal generators is considered and the optimal power flow is solved. The main objective here is minimisation of fuel cost and maintaining the voltage profile in the desired limits. Care is also taken such that the lines are operated in their thermal limits. The results obtained for the case are furnished in Tables 3 and 4. In Table 3 the obtained results are compared with some recent methods. It may be noted that the cost obtained using this method is 800.6665 $/hr which is less than the other methods. The PSO algorithm took 10.132 sec to converge for the optimal solution which proves its efficiency in solving non linear problems.

Table 3. Comparison of generation cost in IEEE 30 bus system

Method	G1 (MW)	G2 (MW)	G3 (MW)	G4 (MW)	G5 (MW)	G6 (MW)	PG (MW)	COST ($/hr)
RGA[15]	174.04	46.8	22	23.9	11	14.5	292.24	804.02
GAF[16]	174.966	50.353	21.451	21.176	12.667	12.11	292.723	802.0003
TS[17]	176.04	48.76	21.56	22.05	12.44	12	292.85	802.29
MDE[18]	175.974	48.884	21.51	22.24	12.251	12	292.859	802.376
RCBBO[19]	177.159	48.561	21.4289	21.2958	11.9903	12.0004	292.435	800.8703
PPSO	176.532	48.774	21.494	21.592	12.0387	12	292.431	**800.6665**

In Table 4 the voltage profile obtained at the generator buses is given and also compared with the other methods. The power loss for the case is also less compared to others.

Table 4. Comparison of Voltage profile and Power loss

Parameter	RCBBO[19]	MDE[18]	PPSO
V1	1.0851	1.05	1.06
V2	1.0651	1.0382	1.043
V3	1.0331	1.0113	1.01
V4	1.0384	1.0191	1.01
V5	1.1	1.0951	1.082
V6	1.0408	1.0837	1.071
PL (MW)	9.03	9.459	9.03

The convergence curve obtained for minimizing the cost using PSO algorithm is shown in Fig 2. From the figure it is observed that the algorithm converges to a best value in few iterations.

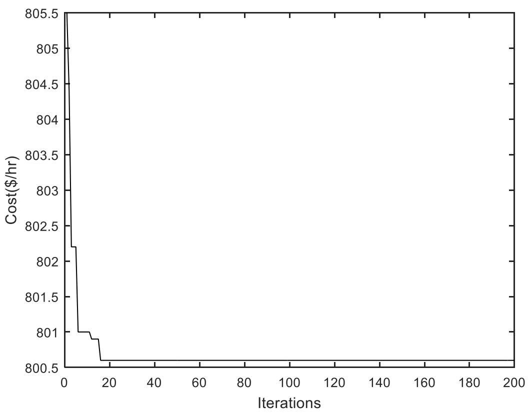

Fig. 2. Cost optimization in IEEE 30 bus system without wind energy.

5.2 OPF considering wind power generation:

Here OPF is carried out considering wind power generation in the existing system. Two wind farms of 50MW capacity with different shape factors are considered for the study. It is assumed that the wind power produced is sold to the public utility based on a fixed tariff. The obtained output from the wind farm is incorporated in the system and the OPF is carried out. The results are furnished in Tables 5 and 6. In Table 5 cases without and with wind power are compared in terms of generation and power loss. It is observed that the power loss is very low compared to the case without wind.

Table 5. Comparison of OPF without and with wind power generation

Parameter (MW)	Without Wind	With Wind
G1	176.5322	143.0481
G2	48.774	40.38001
G3	21.49417	18.10216
G4	21.59226	10
G5	12.03878	10
G6	12	12
WG1	-	34.2418
WG2	-	21.6346
PG	292.4314	289.4067
PL	9.03	6.0067

From Table 6 it is observed that the cost obtained for combined system with wind and thermal units is 723.2053$/hr which is very low value compared to the case without wind power. The convergence curve for the case with wind power is shown in Fig 3.

Table 6. Comparison of Cost witout and with wind Power

Generating Units	Without wind	With Wind
P_T(MW)	292.4314	233.5303
P_{w1} (MW)	-	34.2418
P_{w2} (MW)	-	21.6346
C_{Ther}($/hr)	800.6665	606.0438
C_{w1}($/hr)	-	68.4836
C_{w2}($/hr)	-	48.6778
Cost ($/hr)	800.6665	723.2053
Iterations	200	200

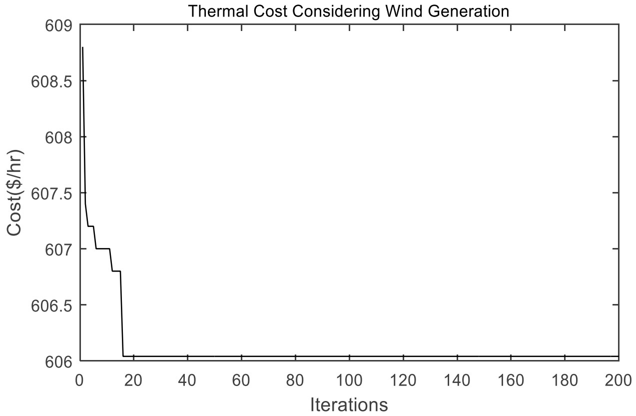

Fig. 3. Cost optimization in IEEE 30 bus system with wind energy

From the results obtained it is inferred that losses decreases with the increased penetration of wind power in the system and also the cost for meeting the demand is also minimized.

6. Conclusion

In this paper optimal power flow considering both wind and thermal power generators is solved. Cases without and with wind power generation are conducted. The intermittent nature of Wind farm is modelled using weibull distribution function and the obtained output is incorporated in the system. The analysis is performed on IEEE 30 bus system using PSO algorithm and the results are compared through some other methods. Increase in wind power output leads to reduction in system operating costs and also losses are minimised. It is also proved that PSO algorithm helps in achieving quick convergence in all the cases for obtaining optimal cost.

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