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PSO Algorithm Based Reactive Power Optimization Using Matlab Programming

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ABSTRACT: The main objective of this paper is to minimize the total reactive support cost which includes reactive cost of generator & compensators while satisfying a set of equality and inequality constraints. This objective can be achieved by proper adjustment of reactive power control variables, such as reactive power outputs of generators and shunt capacitors. This paper proposes particle swarm optimization (PSO) algorithm which is one of the most recently introduced population based optimization technique to solve the reactive power optimization problem. The proposed PSO algorithm is applied to IEEE 14 bus system.

KEYWORDS: PSO Algorithm, NR load flow, Reactive Power Optimization, IEEE 14 Bus System

I. INRODUCTION

The role of Reactive power is important in supporting the real power transfer by maintaining voltage stability and system reliability. It is a critical element for a transmission system to ensure the reliability, stability of a power system. Reactive power control is one of the ancillary services to maintain voltage profile by injecting or absorbing reactive power in power system. Reactive power control has grown in importance due to that the need for economic operation of power systems has increased with the price of fuel. The extension of the transmission network in general is difficult because of high interest rates. In such cases the capacity of older transmission network is increased by providing reactive power control equipment at intermediate points along the transmission line.Reactive power optimization considers minimization of cost as objectives while satisfying the constraints that define satisfactory operation of the system. Reactive power optimization is an important function both in planning for the future and day-to-day operations of power systems. It uses all the reactive power sources judiciously, while planning suitable location and size of VAR compensation in a system. With increasing fuel costs and capital investments, economics of reactive power planning and scheduling have a tremendous effect on the profitable and reliable operation of a power system.

II. PROBLEM FORMULATION

The goal of reactive power optimization in power system is to minimize the price of reactive power generation. The cost of reactive power in the system includes the expenditure paid to generator units for their VAR support and the cost paid to reactive power compensators. Mathematically, the reactive power optimization problem can be expressed as [3]:

$$Min \quad F = \sum_{i \in N_G} C_{gqi}\left(Q_{gi}\right) + \sum_{j \in N_C} C_{cj}\, Q_{cj}$$

Where

$$N_G = Total\ No.of\ Generators$$
$$N_C = Total\ No.of\ Compensators$$

Subjected to the following equality and inequality constraints.

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Equality Constraints:

$$P_{gi} - V_i \sum_{j \in N} V_j \left(G_{ij} \cos\theta_{ij} + B_{ij} \sin\theta_{ij}\right) = 0$$

$$Q_{gi} - V_i \sum_{j \in N} V_j \left(G_{ij} \sin\theta_{ij} - B_{ij} \cos\theta_{ij}\right) = 0$$

Inequality Constraints:

$$P_{Gi}^{min} \le P_{Gi} \le P_{Gi}^{max}$$
$$V_i^{min} \le V_i \le V_i^{max}$$
$$Q_{Gi}^{min} \le Q_{Gi} \le Q_{Gi}^{max}$$
$$Q_{ci}^{min} \le Q_{ci} \le Q_{ci}^{max}$$

A. Reactive Cost of Generator:
The reactive cost of generator is represented by the following equation:

$$C_{gqi}(Q_{gi}) = \left[C_{gpi}(S_{gi,max}) - C_{gpi}\left(\sqrt{S_{gi,max}^2 - Q_{gi}^2}\right)\right] K_{gi}$$

Where
$S_{gi,max}$ is the maximum apparent power of generator i.
K_{gi} is reactive power efficiency rate which is usually between 5-10%.
C_{gpi} is the active power production cost, which is modeled as a quadratic function.

$$C_{gpi}(P_{gi}) = aP_{gi}^2 + bP_{gi} + c$$

Here P_{gi} is the active power output of generator and a, b, c are the generator cost coefficient.

B. Reactive Power Cost of Compensators:
The charge for using capacitors is assumed to be proportional to the amount of the reactive power output purchased and can be expressed as:

$$C_{cj}(Q_{cj}) = r_j Q_{cj}$$

Where r_j and Q_{cj} are the reactive power price and amount purchased, respectively, at location j. The depreciation rate of the capacitors can be set as the reactive price.

Solution:
First we develop a Multi-Objective cost function for reactive power, consisting of reactive cost of generators and compensators after that Perform load flow for IEEE 14 bus system using Newton-Raphson method. Then we Apply Particle Swarm Optimization algorithm for Reactive Power Optimization i.e. minimizes the reactive cost of generators and cost of reactive power compensators.

III. PROPOSED METHODOLOGY

The Particle Swarm Optimization algorithm (PSO) is a novel population-based stochastic search algorithm and an alternative solution to the complex non-linear optimization problem. The PSO algorithm was first introduced by Dr. Kennedy and Dr. Eberhart in 1995 and its basic idea was originally inspired by simulation of the social behavior of animals such as bird flocking, fish schooling and so on.The proposed PSO approaches were applied to solve the reactive power optimization problem in IEEE 14 bus system. Two different cases have been considered in this study.
In the first case, the objective is minimizing the reactive power cost without any Shunt Compensation and in the second case, the objective is minimizing the reactive power cost with Shunt Compensation of value $Y_c = G_c + jB_c = j0.066\ ohms$ at bus 12.

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The charge for using capacitors is assumed to be proportional to the amount of the reactive power output purchased and can be expressed as:

$$C_{cj}(Q_{cj}) = r_j Q_{cj}$$

Where r_j and Q_{cj} are the reactive power price and amount purchased, respectively. For example, if the investment cost of a reactive compensator is Rs.6200/MVAR, and its average working rate and life span are 2/3 and 30 years respectively then the cost of reactive compensator is given as:

$$r_j = \frac{investment\ cost}{operating\ hours} = \frac{Rs.6200}{\left[30 * 365 * 24 * \left(\frac{2}{3}\right)\right]} = Rs.0.0354/MVARh$$

Reactive power efficiency rate (K_{Gi}) which is usually between 5-10%. Here in this paperK_{Gi}= 7% is considered.

Development of Algorithm:
Step1: Perform the optimal power flow.
Step2: Reactive power is taken as the initial population.
Step3: Choose the population size and number of generation.
Step4: Select the reactive power injection as state variable.
Step5: Initial searching points and velocities are randomly generated within their limits.
Step6: p_{best} is set to each initial searching point. The best evaluated values among p_{best} is set to $G_{best.}$
Step7: New velocities are calculated using the equation.

$$v_{ij}^{t+1} = W_i v_{ij}^t + c_1 r_{1j}^t \left[p_{best,i}^t - x_{ij}^t\right] + c_2 r_{2j}^t \left[G_{best} - x_{ij}^t\right]$$

Step8: If $V_i(t + 1) < V_{min}$ then $V_i(t + 1) = V_{min}$and if $V_i(t + 1) > V_{max}$ then $V_i(t + 1) = V_{max}$.
Step9: New searching points are calculated using the Equation.

$$S_i(t + 1) = S_i(t) + V_i(t + 1)$$

Step10: Evaluate the fitness values for new searching point according to the objective function given below.

$$Min\ \ F = \sum_{i \in N_G} C_{gqi}\left(Q_{gi}\right) + \sum_{j \in N_C} C_{cj}\, Q_{cj}$$

If evaluated values of each agent is better than Previous p_{best} then set to p_{best}. If the best $G_{best}$is better than best p_{best} then set to G_{best}.
Step11: Stop criteria if Maximum number of generation is reached or optimal point is achieved.
Step12: To computes total power loss before compensation and after compensation.
Step13: To compute total reactive support cost from generators and reactive compensators.
Step14: To find the payment to generators and reactive Compensators.

IV. RESULT & DISCUSSION

A. IEEE 14 Bus System: In the IEEE 14 bus system as shown in figure 1, there are 14 buses, out of which 5 are generator buses. Bus 1 is the slack bus; 2, 3, 6 and 8 are taken as PV/generator buses and the rest are PQ/load buses. The network has 20 branches, 17 of which are transmission lines and 3 are tap-changing transformers. It is assumed that capacitor compensation is available at buses 12. Totally, there are eight control variable which consist of four PV/generator voltages, three tap-changing transformers and one shunt compensation capacitor bank.Bus datas and line datas are given in table 1&2 respectively.

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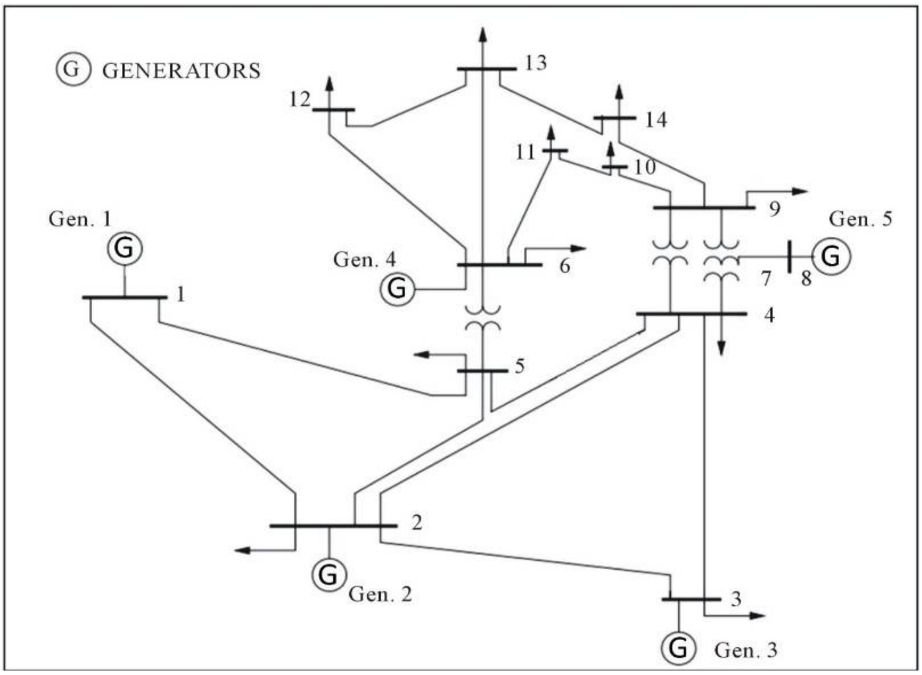

Figure 1: Line Diagram of IEEE 14 Bus System

Table 1: Bus Data- IEEE 14 Bus System

Bus No	Bus Code	Voltage Magnitude	Angle (Degree)	Load		Generator				Injected MVAR
				MW	MVAR	MW	MVAR	Q_{min}	Q_{max}	
1	**1**	1.060	0	0	0	0	0	0	0	0
2	**2**	1.045	0	21.7	12.7	40	42.4	-40	50	0
3	**2**	1.010	0	94.2	19.0	0	23.4	0	40	0
4	**0**	1	0	47.8	-3.9	0	0	0	0	0
5	**0**	1	0	7.6	1.6	0	0	0	0	0
6	**2**	1.070	0	11.2	7.5	0	12.2	-6	24	0
7	**0**	1	0	0.0	0.0	0	0	0	0	0
8	**2**	1.090	0	0.0	0.0	0	17.4	-6	24	0
9	**0**	1	0	29.5	16.6	0	0	0	0	0
10	**0**	1	0	9.0	5.8	0	0	0	0	0
11	**0**	1	0	3.5	1.8	0	0	0	0	0
12	**0**	1	0	6.1	1.6	0	0	0	0	0
13	**0**	1	0	13.5	5.8	0	0	0	0	0
14	**0**	1	0	14.9	5.0	0	0	0	0	0

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Table 2: Line Data- IEEE 14 Bus System

Sending End Bus	Receiving End Bus	Resistance P.U.	Reactance P.U.	Half Susceptance P.U.	Transformer Tap
1	**2**	0.01938	0.05917	0.0264	1
1	**5**	0.05403	0.22304	0.0246	1
2	**3**	0.04699	0.19797	0.0219	1
2	**4**	0.05811	0.17632	0.0170	1
2	**5**	0.05695	0.17388	0.0173	1
3	**4**	0.06701	0.17103	0.0064	1
4	**5**	0.01335	0.04211	0	1
4	**7**	0	0.20912	0	0.978
4	**9**	0	0.55618	0	0.969
5	**6**	0	0.25202	0	0.932
6	**11**	0.09498	0.19890	0	1
6	**12**	0.12291	0.25581	0	1
6	**13**	0.06615	0.13027	0	1
7	**8**	0	0.17615	0	1
7	**9**	0	0.11001	0	1
9	**10**	0.03181	0.08450	0	1
9	**14**	0.12711	0.27038	0	1
10	**11**	0.08205	0.19207	0	1
12	**13**	0.22092	0.19988	0	1
13	**14**	0.17093	0.34802	0	1

B. Load Flow: Load flow studies are important in planning and designing future expansion of power systems. The study gives steady state solutions of the voltages at all the buses, for a particular load condition. Different steady state solutions can be obtained, for different operating conditions, to help in planning, design and operation of the power system.

Table 3: Load Flow Analysis Result for IEEE 14 Bus System without Shunt Compensation

Maximum Power Mismatch = 5.18689e-09

Bus No	Voltage Magnitude	Angle (Degree)	Load		Generator		Injected MVAR
			MW	**MVAR**	**MW**	**MVAR**	
1	1.060	0.000	0.000	0.000	232.593	-15.233	0.000
2	1.045	-4.989	21.700	12.700	40.000	47.928	0.000
3	1.010	-12.749	94.200	19.000	0.000	27.758	0.000
4	1.013	-10.242	47.800	-3.900	0.000	0.000	0.000
5	1.017	-8.760	7.600	1.600	0.000	0.000	0.000
6	1.070	-14.447	11.200	7.500	0.000	23.026	0.000
7	1.046	-13.237	0.000	0.000	0.000	0.000	0.000
8	1.080	-13.237	0.000	0.000	0.000	21.030	0.000
9	1.031	-14.820	29.500	16.600	0.000	0.000	0.000
10	1.030	-15.036	9.000	5.800	0.000	0.000	0.000
11	1.046	-14.858	3.500	1.800	0.000	0.000	0.000
12	1.053	-15.297	6.100	1.600	0.000	0.000	0.000
13	1.047	-15.331	13.500	5.800	0.000	0.000	0.000
14	1.019	-16.072	14.900	5.000	0.000	0.000	0.000
Total			**259.000**	**73.500**	**272.593**	**104.509**	**0.000**

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Table 4: Load Flow Analysis Result for IEEE 14 Bus System with Shunt Compensation
Value of $Y_c = G_c + jB_c = j0.066\ ohms$ at Bus No. = 12
Maximum Power Mismatch = 5.18141e-09

Bus No	Voltage Magnitude	Angle (Degree)	Load		Generator		Injected MVAR
			MW	MVAR	MW	MVAR	
1	1.060	0.000	0.000	0.000	232.573	-15.283	0.000
2	1.045	-4.989	21.700	12.700	40.000	47.750	0.000
3	1.010	-12.748	94.200	19.000	0.000	27.650	0.000
4	1.013	-10.244	47.800	-3.900	0.000	0.000	0.000
5	1.017	-8.760	7.600	1.600	0.000	0.000	0.000
6	1.070	-14.440	11.200	7.500	0.000	8.670	0.000
7	1.046	-13.239	0.000	0.000	0.000	0.000	0.000
8	1.080	-13.239	0.000	0.000	0.000	20.676	0.000
9	1.032	-14.820	29.500	16.600	0.000	0.000	0.000
10	1.031	-15.035	9.000	5.800	0.000	0.000	0.000
11	1.047	-14.855	3.500	1.800	0.000	0.000	0.000
12	1.065	-15.654	6.100	1.600	0.000	0.000	0.000
13	1.053	-15.466	13.500	5.800	0.000	0.000	0.000
14	1.023	-16.123	14.900	5.000	0.000	0.000	0.000
Total			**259.000**	**73.500**	**272.454**	**89.463**	**0.000**

C. Reactive Power Cost Optimization Using PSO: The Cost Coefficients of generators, generation limits and parameters of PSO algorithm are given in table 5, 6& 7 respectively.

Table 5: Generator Cost Coefficients

Generator	a	b	c
1	0.00375	2.0	0.0
2	0.01750	1.75	0.0
3	0.06250	1.0	0.0
4	0.00834	3.25	0.0

Table 6: Generation Limits

Generator	MVAR (Min.)	MVAR (Max.)
1	-40	50
2	0	40
3	-6	24
4	-6	24

Table 7: PSO Parameters

No. of Particles	80
No. of Iteration	50
Acceleration Coefficient	$c_1 = c_2 = 2$
Max. and Min. Inertia Weights	$W_{min} = 0.4$ $W_{max} = 0.9$
Velocity Limits	$V_{min} = -0.5 * Q_{min}$ $V_{max} = 0.5 * Q_{max}$

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Table 8: Reactive Power Cost Optimization without Shunt Compensation

Output Variables	Result
Q_D	104.509
Q_{G1}	50
Q_{G2}	17.2590
Q_{G3}	13.2498
Q_{G4}	24
Power Mismatch	0.000161
Payment To Generators	4.7397
Real Power Loss Before Compensation	13.593
Reactive Power Loss Before Compensation	31.009

Table 9: Reactive Power Cost Optimization with Shunt Compensation

Output Variables	Result
Q_D	89.463
Q_{G1}	42.5831
Q_{G2}	12.1980
Q_{G3}	10.6822
Q_{G4}	24
Q_{C1}	14.900
Power Mismatch	0.000358
Payment To Generators	3.0792
Payment To compensators	0.5275
Total Payment	3.6066
Real Power Loss After Compensation	13.573
Reactive Power Loss After Compensation	15.963

V. CONCLUSION & FUTURE SCOPE

The optimal results such as total demand, individual generation of each generator and compensators, power mismatch, payment to generators & compensators and total payment for reactive power are presented in table 8 & 9. From the result data it is clear that when compensation is provided then reactive power losses are reduced and the reactive support cost is also reduced.

In PSO method selection of parameters are important. So that, the parameters may be optimized by using the Artificial Neural Network (ANN) method. We can apply other methods with PSO to improve the performance of the PSO method. This work may be extended for new optimization techniques, like Bacterial Foraging (BFO), Artificial Immune Systems (AIS) and Ant Colony Optimization (ACO).

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