PSO Based Optimal Reactive Power Dispatch (ORPD) Considering Multi-Contingencies

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***Abstract*—A stable power system can be subjected to voltage fluctuations due to poorly regulated reactive power flow that causes system instability. Reactive power is closely related to system voltage control, therefore, it is crucial to ensure the correct amount of reactive power is supplied to the system loads to achieve smooth power system operation and avoid voltage collapse from occurring. This paper presents the implementation of Particle Swarm Optimization (PSO) technique for solving ORPD problem considering multiple contingencies *(N-m)*. The technique was implemented with the aim to improve voltage stability and minimize total transmission losses of the system. The IEEE 30-bus system was tested with generator outage in order to simulate the impact of disturbance to the power system transmission and distribution.**

***Index Terms*— EP; Multi-contingencies; ORPD, PSO; Stability Index; Transmission Losses.**

I. INTRODUCTION

Nowadays, the power transmission systems have been changed a lot. The voltage deviation due to load variation and power transfer limitation was experienced due to reactive power unbalance which has drawn attention to better utilize the existing transmission line. The shortage of reactive power can cause the generator and transmission line failure leading to blackout or collapse in a system [1]. It also causes a higher impact on power system security and reliability [6]. Hence, the electrical energy demand increases continuously from time to time. This increase is due to the fact that few problems could appear with the power flows through the existing electric transmission networks. If this situation is uncontrollable, some lines located on the particular paths might become overloaded [2]. Due to the overloaded conditions; the transmission lines will have to be driven close to or even beyond their transfer capacities. Consequently, the transmission line outage in a power system was reported to be the main issue towards voltage instability as well as generator outage contingency [3-4]. The line outage may cause violations of bus limit, transmission line overloads and lead to system instability [5]. While the generator outage can be caused by the failure of the generator; this may interrupt system delivery and lead to system instability [6].

During a contingency, the operating generators fail to operate and cause the reactive power supply by the generators suddenly drop in the system. Therefore, the system also has to improve the reactive power level to prevent voltage collapse in the system. Furthermore, power scheduling has also resulted in the change in power flow in the network and hence affects the system voltage profiles. Therefore, voltage stability in the system will be affected. Voltage stability is important to maintain a secure power system operation. Therefore, an efficient voltage stability analysis technique is required in order to perform the voltage stability study accurately with the less computational burden. Studies have shown that voltage stability can be improved by means of real and reactive power rescheduling in a power system [7 – 10]. Basically, real and reactive power planning could be controlled by reactive power dispatch, compensating capacitor placement, transformer tap changer setting and installation of FACTS devices. Hence, this paper shows a technique for dispatching the reactive power at voltage-controlled buses in order to improve voltage stability in power system and at the same time minimizing the total losses in the system under multi-contingencies.

The implementation of ORPD involved optimization process. There are numerous optimization techniques such as Tabu Search, linear programming, non-linear programming, Simulated Annealing (SA), Genetic Algorithm (GA), Evolutionary Programming (EP), Evolutionary Strategy (ES), Imperialist Competitive Algorithms (ICA) and Genetic Programming (GP). The application of EP in the ORPD optimization was reported as a reliable technique for improving the voltage stability condition and voltage profile in power systems as reported in [11-13, 16].

In this paper, Particle Swarm Optimization (PSO) will be utilized as the optimization technique to optimize the reactive power dispatch for loss minimization considering generator outage occurs in the system. An efficient particle swarm optimizing technique will be used to identify the optimal reactive power to be dispatched to provide the maximum power quality improvement.

II. PROBLEM FORMULATION

In ORPD; the objective function selected for optimization is the minimization of Static Voltage Stability Index (*SVSI*) hence the voltage stability is improved as well as minimization of transmission power losses in power system. The aim for the ORPD is to optimize a certain objective subject to different sets of equality and inequality constraints. The equality constraints are the nodal power balance equations, while the inequality constraints are the limits of all control or state variables. The control variables are switchable shunt capacitor banks and real power settings in the generator.

A. Objective Function

The objective function is in term of voltage stability improvement with *SVSI* taken as the fitness. *SVSI* is a technique that indicates the stressfulness of a line in the transmission system. It uses as the measuring instrument in predicting the sensitivity lines by using the sensitivity index analysis. In this technique, the reactive power at the selected bus is increased until it reaches the instability point. At that particular point, load that is connected to the bus is being defined as the maximum loadability. It is formulated based on a line or a bus. *SVSI* is proposed from the existing technique proposed by L. Qi [14]. The mathematical formulation for *SVSI* is given as in Equation (1).

$$SVSI_{ji} = \frac{2\sqrt{\left(X_{ji}^2 + R_{ji}^2\right)\left(P_{ji}^2 + Q_{ji}^2\right)}}{\left|\left|V_i\right|^2 - 2X_{ji}Q_{ji} - 2R_{ji}P_{ji}\right|} \tag{1}$$

where the active power and reactive power are P_{ji} and Q_{ji}, the line resistance and reactance are R_{ji} and X_{ji} and the voltage magnitude and angle are $|V|$ and δ. The subscript i and j denote variables associated with bus i and bus j.

The line that exhibits the highest rate of change of *SVSI* is considered as the critical line referred to a bus while the value of maximum reactive load at *SVSI* value closed to 1 is assigned as the maximum permissible load [14].

B. Equality and Inequality Constraint

The ORPD is subject to the constraint of equality in reactive and active power balance as shown in Equation (2) [12].

$$\begin{aligned}
&Q_i - Q_{Gi} + Q_{Di} = 0\\
&Q_i = Q_{Gi} - Q_{Di} -\\
&V_i \sum_{j\in N_i} V_j\left(G_{ij}\sin\theta_{ij} - B_{ij}\cos\theta_{ij}\right) = 0, \quad i \in N_{PQ}\\
&P_i - P_{Gi} + P_{Di} = 0\\
&P_i = P_{Gi} - P_{Di} -\\
&V_i \sum_{j\in N_i} V_j\left(G_{ij}\cos\theta_{ij} - B_{ij}\sin\theta_{ij}\right) = 0, \quad i \in N_{B-1}
\end{aligned} \tag{2}$$

Hence, inequality constraints on control variable limits; generator reactive power capability limits, generator active power capability limits, and voltage constraints are given by equation (3);

$$\begin{aligned}
&Q_{Gi_{\min}} \le Q_{Gi} \le Q_{Gi_{\max}} \quad && i \in N_G\\
&Q_{ci_{\min}} \le Q_{ci} \le Q_{ci_{\max}} \quad && i \in N_c\\
&P_{Gi_{\min}} \le P_{Gi} \le P_{Gi_{\max}}, \quad && i \in Slackbus\\
&V_{i_{\min}} \le V_i \le V_{i_{\max}} \quad && i \in N_B
\end{aligned} \tag{3}$$

where g_k is the conductance of branch k, n_s is the slack (reference) bus number; N_{PQ} is PQ bus number, N_{PV} is PV bus number, N_B is the total number of buses, N_{B-1} is the total buses excluding slack bus, N_c is the possible reactive power source installation buses number, N_E is the branch number, N_i is the numbers of buses adjacent to bus i including bus i, θ_{ij} is voltage angle different between bus i and bus j(rad), Q_i and Q_j are the reactive power on the sending and receiving buses; Q_G is the generated reactive power, V_i and V_j are the voltage magnitude at the sending and receiving buses, G_{ij} and B_{ij} is the mutual conductance and subceptance between bus i and bus j and $P_{K_{Loss}}$ is the total active power loss in the system.

III. PARTICLE SWARM OPTIMIZATION (PSO)

In this section, the fundamental of PSO algorithms and the ways how to relate ORPD parameters under generator outages will be explained briefly. PSO technique is applied by considering it in as a search space [9]. Consider an optimization problem of D variables. A swarm of N particles is initialized in which each particle is assigned a random position in the D-dimensional hyperspace such that each particle's position corresponds to a candidate solution for the optimization problem [15]. In this paper, x is defined as a particle's position or coordinate and v is defined as the particle's current velocity. The fitness value that obtains from the fitness equation is representing how good each x in the swarm solves the problem. P_{best} is defined as the best previous position of a particle while G_{best} is defined as the best particle among all particles in the swarm. Each particle records its own personal best position (P_{best}) and knows the best positions found by all particles in the swarm (G_{best}). Next, all particles in the swarm will be updated until the global optimal position is found.

The velocity and position of the particles are updated using these equations:

$$\begin{aligned}
v_i^{k+1} = w \times v_i + c_1 * rand_1 * \left(P_{best\,i} - x_i^k\right) +\\
c_2 * rand_2 * \left(G_{best\,i} - x_i^k\right)
\end{aligned} \tag{4}$$

$$x_i^{k+1} = x_i^k + v_i^{k+1} \tag{5}$$

where w is an inertia weight given by Equation (6).

$$w = w_{\max} - \frac{w_{\max} - w_{\min}}{iter_{\max}} \times iter \tag{6}$$

c_1 is the acceleration constants and the recommended value is 2.05 each. From the equation above, component v_i^k or known as the previous velocity is scaled by an inertia weight, w. This component is often known as "habitual behavior" [15]. The $P_{best\,i}$ is a linear attraction towards its previous best position. It is scale by the acceleration constant c_1 and a random number. A different random number is assigned for each calculation. The complete analytical study has been made only for the moment in the case of a single particle and with acceleration constant coefficient (non-random) [9]. For a single particle, the update is only based on the best performance of its particle. It will not take into account about its neighbour best performance and will not use it as an informant to update its velocity and position. Acceleration constants c_1 represent the weight of the stochastic acceleration terms that push a particle toward P_{best}. Small values allow a particle to roam far from target regions [15]. The solution methodology for the PSO technique is outlined in the general flowchart shown in Figure 1.

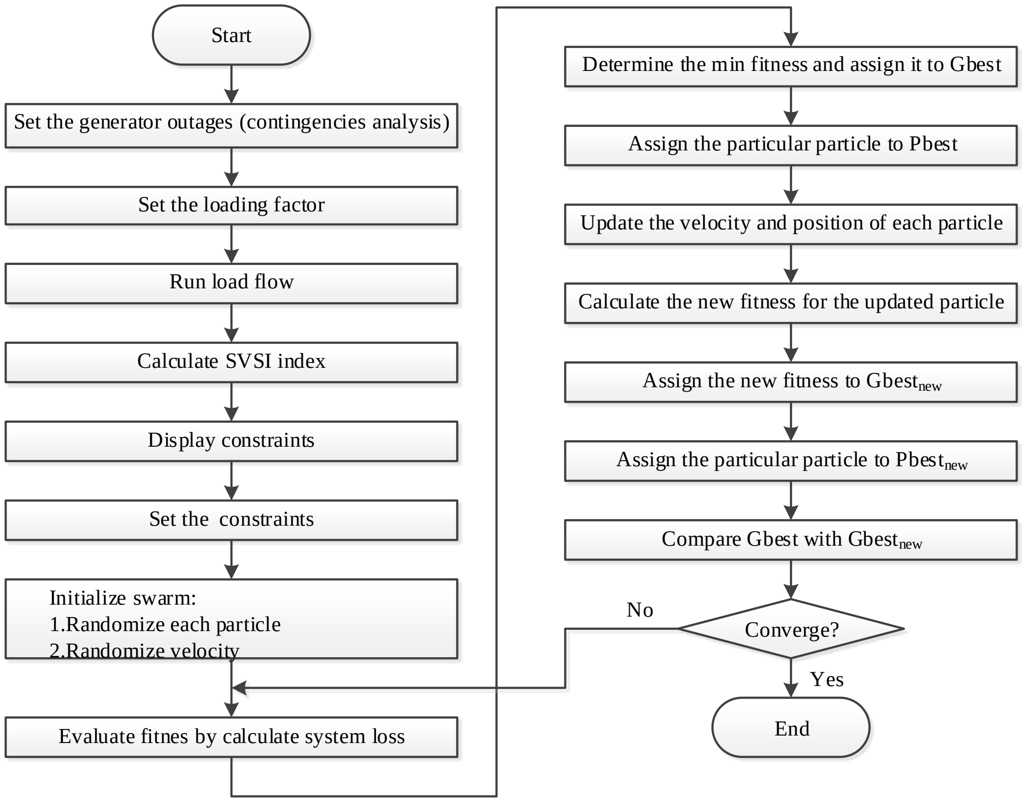

Figure 1: Flowchart for implementation of PSO optimization method to determine the ORPD

IV. GENERATOR OUTAGE RANKING

The IEEE 30-bus RTS system has 6 generator buses and 24 load buses with 41 interconnected lines. In this study, all generators are removed consecutively one at a time except for generator at bus 1, since this generator is taken as the swing bus or reference bus. The maximum SVSI values evaluated for all load variation on every generator outage are sorted in descending order in order to identify the critical generator ranking. The results are tabulated in Table 1. From the table, it is observed that generator 13 is ranked the highest with SVSI value 0.1695 followed by generator 11 with SVSI value0.1694. A generator 13 and 11 are connected to transformer tap changer. From the first until the fourth-ranked, the highest SVSI value was evaluated at line 5, which is connecting bus 2 to bus 5. However, when generator 5 was on outage; the highest SVSI value was obtained at line 15, which connects buses 4 and 12. Therefore a combination of several generators 2, 11 and 13 were selected to be disconnected during the analysis in this paper.

Table 1
Generator Outage Rank Based *SVSI* in the IEEE 30-Bus RTS (Base Case)

Rank	Gen Outage No.	Line No.	*SVSI*
1	13	5	0.1695
2	11	5	0.1694
3	2	5	0.1634
4	8	5	0.1611
5	5	15	0.1463

V. RESULTS AND DISCUSSIONS

In the beginning, the multi-contingencies (N-m) consist of several outages namely generator outages are implemented into the power system. The selections of outages are based on the most severe generator in the system to maximize the performance of the system. In IEEE 30-bus RTS system, several generator outages are considered during the process. The results are divided into two parts. The first part presents the results for ORPD with SVSI as the objective function and the second part presents the results of the comparative studies implemented between EP. In this study, ORPD is performed to the system with bus 26 subjected 25 MVAr loading and population of 10. Table 2 tabulates the effect of a different number of generator outage to SVSI, transmission losses and voltage profile for this bus.

A. SVSI as the Objective Function

As tabulated in this table, it is observed that all the SVSI values reduce as compared with pre-ORPD with respect to generator outage number variation. It implies that the voltage stability has been improved. In addition, voltage profiles in the system are also improved and transmission losses are minimized as a result of the implementation of ORPD considering generator outage occurs in the system. It can be seen that at generator outage no=2, 11 and 13, the SVSI value is improved from 0.4482 to 0.219 while the transmission loss is reduced from 25.762 MW to 16.516 MW with the reduction of 35.9%. In addition, the voltage has been improved from 0.6984 p.u. to 1.0206 p.u.. The results for others selection of generator outage are indicated in the same table. The value for Qg5 and Qg8 identified by the ORPD scheme is also shown in the same table. Those values are the optimized reactive power to be controlled by the generators in order to improve the voltage stability condition and transmission losses in the system.

Table 2
Effect of ORPD With Load Subjected to Bus 26 Using PSO (Loading, QL = 25 MVAr)

Generator Outage No.	Analysis	*SVSI*	Total Loss (MW)	% ΔLoss	Q_{g2}	Q_{g5}	Q_{g8}	Q_{g11}	Q_{g13}	V_m (p.u)
							MW			
0	Pre	0.3636	22.267	26.7	28.085	34.941	54.632	21.586	17.693	0.7831
	Post	0.2113	16.328		77.703	-63.921	229.91	33.723	10.437	1.0394
13	Pre	0.3878	22.745	42.5	39.272	39.761	53.029	23.895	-	0.7564
	Post	0.2083	13.087		-18.814	32.093	180.302	64.722		1.0471
13, 11	Pre	0.4427	24.176	19.5	39.003	36.558	60.293	-	-	0.7032
	Post	0.2153	19.457		73.328	-75.648	297.957			1.0295
13, 11, 2	Pre	0.4482	25.762	35.9	-	43.633	67.508	-	-	0.6984
	Post	0.219	16.516			-25.299	281.201			1.0206

Table 3
Comparison results for ORPD between PSO and EP When Bus 26 Was Reactively Loaded

Line Outage No.	Pre			Post							
				PSO				EP			
	SVSI	Voltage (p.u.)	Loss ((MW)	*SVSI*	Voltage (p.u.)	Loss (MW)	ΔLoss (%)	*SVSI*	Voltage (p.u.)	Loss (MW)	ΔLoss (%)
0	0.3636	0.7831	22.267	0.2113	1.0394	16.328	26.7	0.2947	0.8821	8.014	64
13	0.3878	0.7564	22.745	0.2083	1.0471	13.087	42.5	0.365	0.7815	9.376	58.8
11,13	0.4427	0.7032	24.176	0.2153	1.0295	19.457	19.5	0.3379	0.8143	8.174	66.2
2, 11, 13	0.4482	0.6984	25.762	0.219	1.0206	16.516	35.9	0.3468	0.8032	7.845	69.5

B. Comparative Studies

The results of comparative studies with EP when the load was subjected to bus 26 are tabulated in Table 3. From the table, it is observed that when PSO is used to optimize the ORPD, it gives better results as compared to EP in terms of voltage stability; SVSI and voltage profile, however, EP manage to outperform PSO in terms of transmission losses. At generator outage number 2, 11 and 13, PSO method managed to reduce the *SVSI* value from 0.4482 to 0.219, while EP only managed to reduce the *SVSI* value to 0.3468. In addition, PSO also outperforms EP in increasing the voltage profile in the system from 0.6984 p.u. to 1.0206 p.u. instead of EP which is only able to increase to 0.8032 p.u. On the other hand, EP method has outperformed PSO in total transmission losses reduction from 25.762 MW to 7.845 MW with the 69.5% reduction compared with PSO which only minimized to 16.516 MW.

VI. CONCLUSION

The two techniques have been successfully tested on the IEEE 30-bus RTS. The result indicated that these techniques had improved the result for all cases. The result shows that PSO technique outperformed EP in terms of voltage stability improvement and voltage profile. For future work, the larger test system can be incorporated together to achieve the similar task.

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