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Voltage Stability Improvement by Reactive Power Rescheduling Incorporating PSO Algorithm

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Abstract: *In this paper, reactive power rescheduling is done to keep the voltage stable. Due to system disturbances the active as well as reactive power flows changes. Generators being always connected to the system reactive power rescheduling of generators can be effectively done. Therefore it is selected as the suitable method for voltage control. The voltage and reactive power management is studied from the generator's point of view to minimize generator reactive power loss. To reduce the reactive losses optimization procedure is used. The simulations are done using MATLAB.*

Keywords: *Voltage stability, Reactive power rescheduling, Particle Swarm Optimization (PSO).*

I. INTRODUCTION

The operation of any electric power system shows that the frequency and the voltage are the main indicators of proper system operation. Disturbance in the system operation causes variation in these two parameters separately or jointly. In case of severe disturbances, the frequency or voltage variations may be abnormally high indicating the loss of system stability. Frequency variation is caused by the real power mismatch, while voltage is the indicator of the reactive power mismatch [1,2,3].

For the system reliability, both active and reactive power consumptions are to be controlled properly. As there is a direct link between the voltage and the reactive power, it is possible to control the voltage to desired values by the control of the reactive power [3]. During normal operation state, the reactive power balance is kept in such a way that the voltages are within the accepted limits. If there is no change between reactive power generation and consumption ,then the voltage will be maintained within the prescribed limits. If there is a mismatch in reactive power generation and consumption level in the system, it will result in an inappropriate voltage profile [4]. Reactive power generation and consumption have to be very close to each other to avoid excessive reactive power transmission. It is due to this fact that reactive power transmission is a highly localized service. The various voltage control methods which are commonly used are under load tap changers, load shedding and installation of new generating units, synchronous condensers, FACTS devices, capacitor banks and reactive power rescheduling [1].

Voltage instability and power system security should be analyzed at various decision stages from planning to real-time implementation. T. Van Cutsem in [5] discussed the methods which can be used for analysis are classified in four categories: contingency analysis, loadability limit determination[6-8], determination of security limits, and preventive and corrective control.

Contingency analysis finds the system response on a particular operating point to credible contingencies that may cause or lead to voltage instability or even ultimately give way to voltage collapse. The system should be operated in such a way that it is enabled to survive the credible contingencies by providing proper pre- and post-contingency controls[9-11]. These can be accomplished by a) static methods based on load flow, modified load flow, multi-time scale simulation, and b) time-domain methods. In this paper contingency analysis is carried along with optimization technique to keep the voltage stable.

Generator reactive power is used to control voltage .The amount of reactive power injection keeps the voltage stable. It also depends on the capacity of the generator. Keeping in mind the above mentioned two facts, optimization techniques will give the best results. Among the different optimization techniques, evolutionary computation techniques give rapid solutions[12]. These optimization algorithms are widely used due to their high precision for modelling engineering problems and simple programming in computers. Particle Swarm Optimization is an effective tool for analysis as it gives better results with few parameters to adjust.

II. REACTIVE POWER RESCHEDULING

The generators are the primary and main source of reactive power. Generator supplied reactive power is especially an effective resource due to a) its superior performance at low voltage in comparison to static reactive devices, b) fast response of excitation system to changes, and c) having a large reactive power supply range. Therefore we can select reactive power rescheduling from the generator side which provides an effective way to the control of voltage at the load buses[1].

III. Problem Formulation

From the discussions above we concentrate on reactive power rescheduling. The reactive power losses reduce the amount of reactive power availability in the circuit. By optimizing the losses we can find the condition with less reactive loss and the voltage remaining stable during contingencies. Therefore the problem is formulated for normal operating condition as given below.

$$\boldsymbol{Minimize\ f_x = \sum_{i=1}^{N_b} Q_{loss}} \qquad (3.1)$$

N_b No of branches
Q_{loss} Reactive power loss

With power flow constraints

$$\boldsymbol{P_g - P_d - P_{loss} = 0} \qquad (3.2)$$
$$\boldsymbol{Q_g - Q_d - Q_{loss} = 0} \qquad (3.3)$$

$\boldsymbol{P_g}$- Active power generation
$\boldsymbol{P_d}$ - Active power demand
$\boldsymbol{P_{loss}}$ - Line losses (active power)
$\boldsymbol{Q_g}$- Reactive power generation
$\boldsymbol{Q_d}$- Reactive power demand
$\boldsymbol{Q_{loss}}$- Line losses(reactive power)

And active and reactive power and voltage constraints

$$\boldsymbol{P_{gmin} \leq P_g \leq P_{gmax}} \qquad (3.4)$$
$$\boldsymbol{Q_{gmin} \leq Q_g \leq Q_{gmax}} \qquad (3.5)$$
$$\boldsymbol{V_{imin} \leq V_i \leq V_{imax}} \qquad (3.6)$$

$\boldsymbol{P_{gmin}}$- Minimum active power generation
$\boldsymbol{P_g}$- Active power generation at the particular instant
$\boldsymbol{P_{gmax}}$- Maximum reactive power generation
$\boldsymbol{Q_{gmin}}$ − Minimum reactive power generation
$\boldsymbol{Q_g}$ - Reactive power generation at the particular instant
$\boldsymbol{Q_{gmax}}$- Maximum reactive power generation
$\boldsymbol{V_{imin}}$ - Minimum reactive power generation
$\boldsymbol{V_i}$ - Voltage at *i* th bus at the particular instant
$\boldsymbol{V_{imax}}$ - Maximum reactive power generation

PARTICLE SWARM OPTIMIZATION

It is a population based search procedure used for solving optimization problems. This procedure is based on the behaviour of flocking birds. The birds in a swarm fly towards the position of food in a random manner. In a similar way the candidate solutions (individuals) called particles change their position with time and updating themselves in each iteration find the solution of the problem from a solution space.

Similar to seeking food, the solution to an optimization problem is found out from a solution space[13,14 ,15]. The accuracy and rate of convergence of this algorithm depends on the appropriate choice of particle size, maximum velocity of particles and discrete time index. There are no specific guidelines available to select the particle size. It may vary from problem to problem.

ALGORITHM FOR MINIMIZATION OF REACTIVE POWER LOSSES

The formulated problem is optimized using the PSO algorithm. The steps involved in this procedure is given below. The flow chart is shown in Fig.1.

Step 1: Input the parameters and specify the limits of each parameters. Initialize the population with a set of random solution.

Step 2: Newton-Raphson power flow algorithm is applied to calculate line flows and transmission loss.

Step 3: Parameters in the objective function are calculated and find the value of objective function for each particle. Compare this value with that value of the best solution in the population (pBest). The best solution among the pBest is taken as the best solution among all the particles inthe population (gBest).The pBest and gBest values are updated.

Step 4:The velocity and position of each particle is updated using equations 3.7 and 3.8. If any of the particle is outside limit set its position within the proper limit.

$$\boldsymbol{V_i(k+1) = V_i(k) + \gamma_{1i}\big(p_i - X_i(k)\big) + \gamma_{2i}\big(G - X_{i(k)}\big)} \qquad (\mathbf{3.7})$$
$$\boldsymbol{X_i(k+1) = X_i(k) \;\; + V_i\,(k)} \qquad (\mathbf{3.8})$$

i particle index
k discrete time index
V velocity of i th particle
X position of i th particle
p best position of i th particle (personal best)
G best position found by swarm (global best),
$\gamma_{(1,2)}$ random numbers on the interval [0,1] given to i th particle.

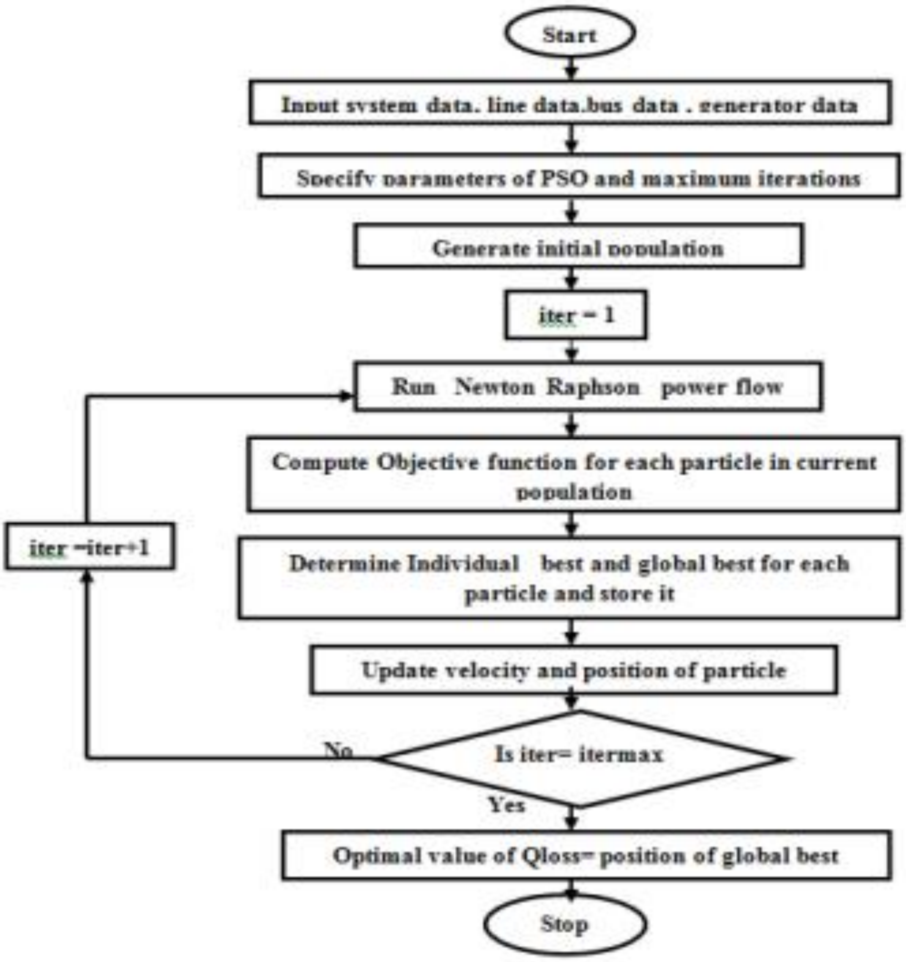

Fig 1. Flow chart of PSO algorithm

Step 5: If any one of the stopping criteria

- If the number of iterations after the last change of the solution is greater than a pre specified number.
- If he number of iterations reaches the maximum allowable number. is satisfied, then go to step 6.Otherwise repeat the steps 2,3 and 4.

Step 6: The particle that produces the latest gBest is the optimal value.

Table 1 PSO parameters

Parameters	**Optimal value**
Number of particles	50
Number of iterations	50
γ_1	2
γ_2	2
Initial inertia weight	0.9
Final inertia weight	0.4

IV. Simulation Results

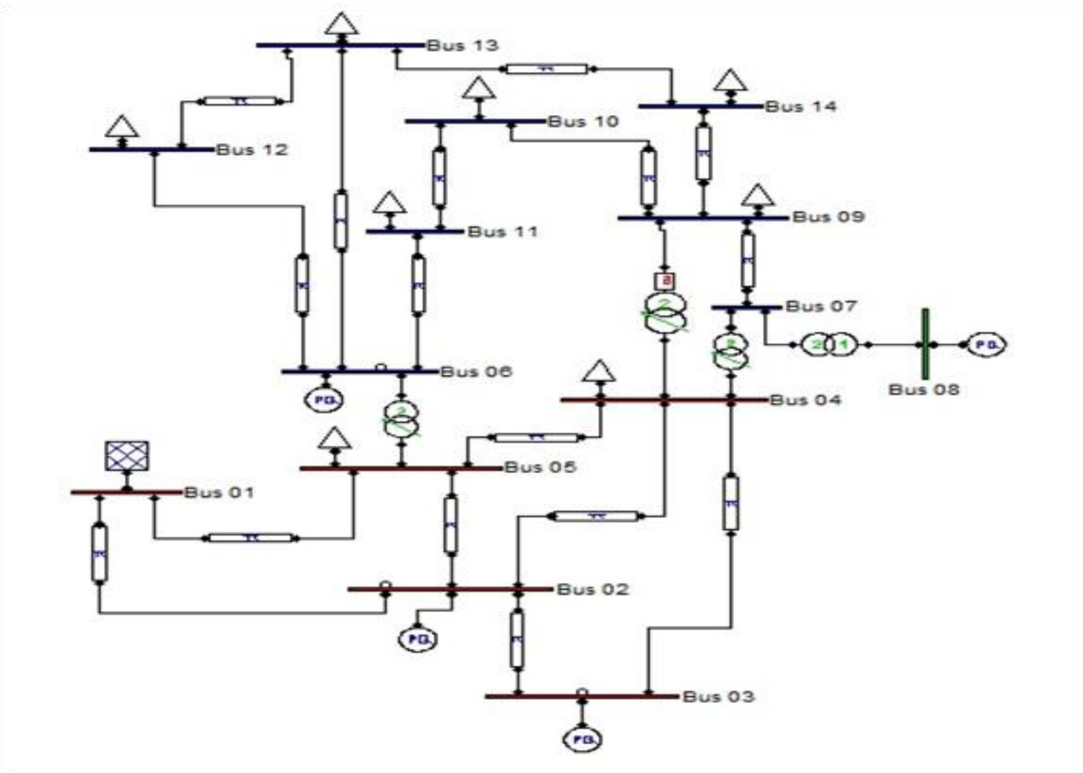

Fig 2.PSAT Simulink model of IEEE 14 Bus system

In order to find out the effectiveness of proposed approach, it was tested on IEEE 14 bus system. IEEE 14 bus system consists of 5 generators, 14 buses,16 lines,4 transformers and 11 loads as shown in Fig 2 .The system has generators located at buses 2, 3, 6 and 8 and 10 and four transformers with off-nominal tap ratio in line 4-7,4–9,5- 6 and 8-9. The lower voltage magnitude limits at all buses are 0.9 p.u. and the upper limit 1.1 p.u. Generator reactive power is optimized by calculating the minimum reactive power loss . Solution is found

by using Newton Raphson Power flow method (PSAT model)[15] and the program was coded in MATLAB software.
Power flow analysis was conducted and the voltage profile for normal condition was observed.

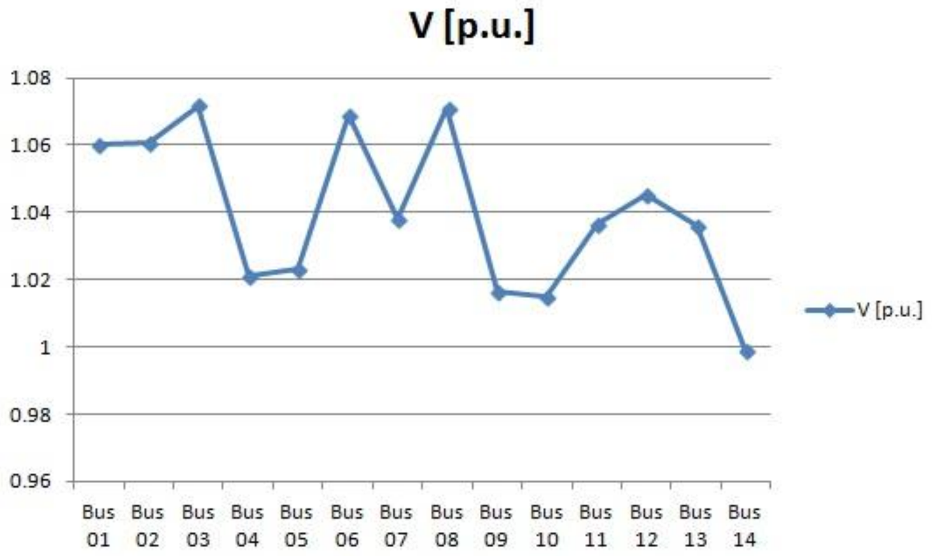

Fig 3. Voltage profile during normal condition

Fig 3. shows that the voltage is within permissible limits.(ie between 0.9 and 1.1 p,u).

A contingency (Increase in reactive load such as starting of induction motor or arc furnace) was simulated.

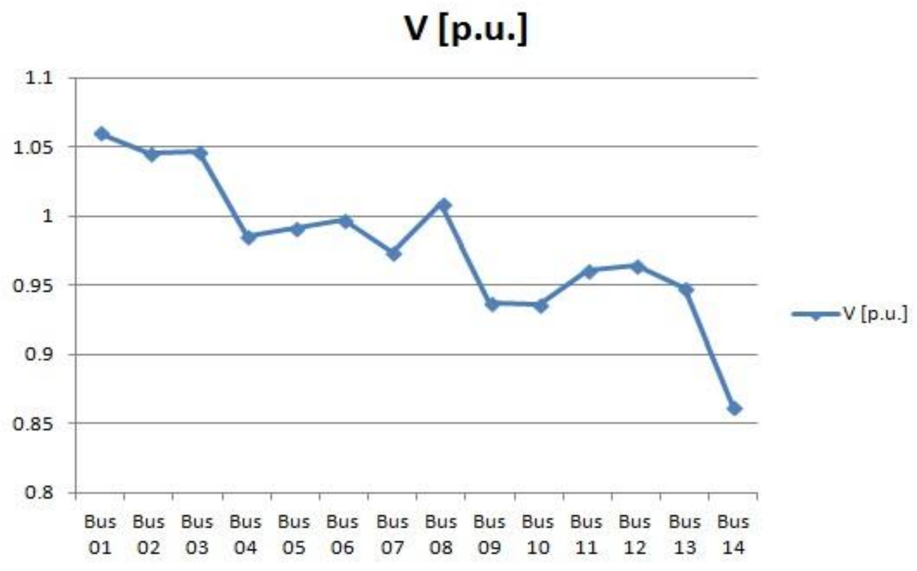

Fig 4.Voltage profile during contingency

The power flow analysis was again conducted and it was found that the voltage at bus no.14 has reduced below 0,9 p.u.(0.86216 p.u). There is an increase in reactive and active losses as found from the power flow results.

The above mentioned algorithm is used to find the optimum value of Qloss as well as the value of needed reactive power generations in the generators to keep the voltage stable. The convergence of Qloss after optimization is shown in Fig 5. Starting from a random value it reaches a minimum point which gives the optimal value.

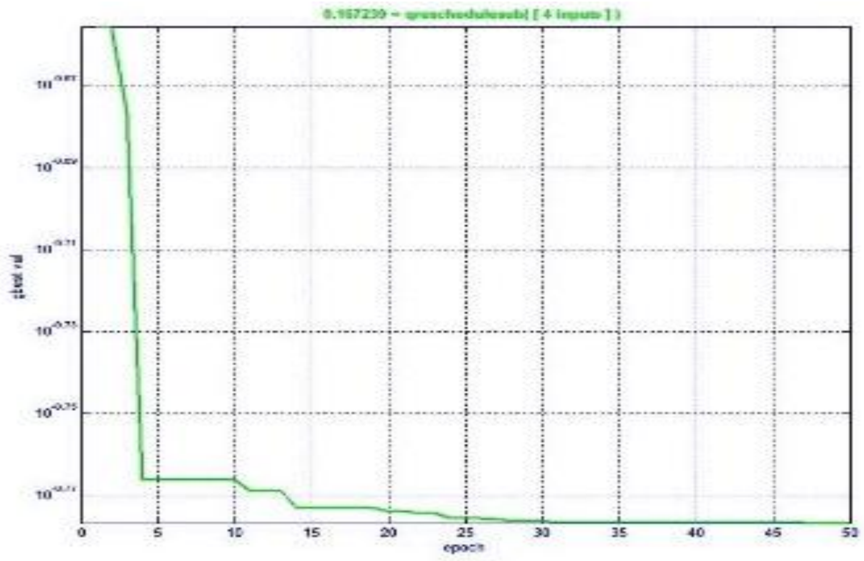

Fig 5. Convergence property of proposed algorithm

Fig 6. compares the voltage during normal condition, contingency condition and voltage after power flow using the values of reactive power to be injected to the generator buses. It indicates that with the optimization technique the voltage has improved during contingency.

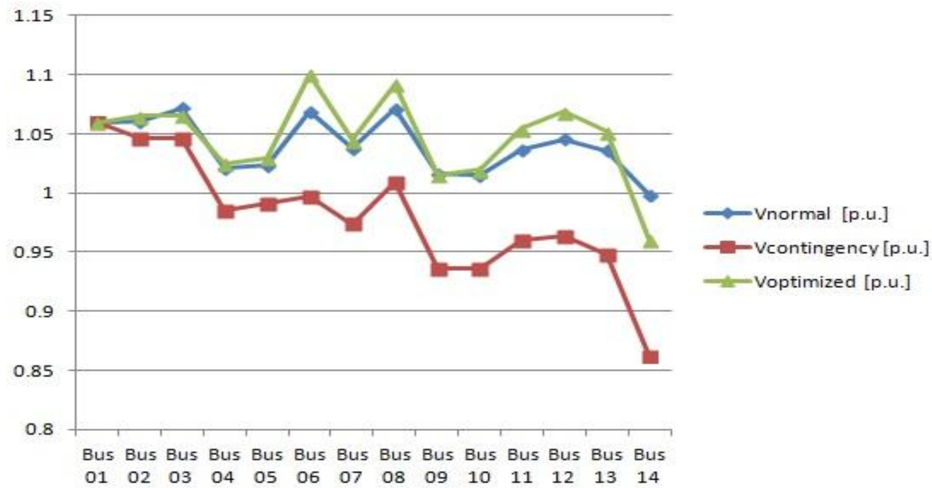

Fig 6.Comparison of voltages

Condition	Voltage at bus no 14 (p.u)	Reactive power at generator 2,3,4,8 (p.u)	Reactive losses (p.u)	Active Losses (p.u)
Normal	0.99868	0.3 0.3 0.2 0.2	0.12518	0.09046
Contingency	0.86216	0.3 0.3 0.2 0.2	0.25509	0.11696
After optimization	0.95996	0.4154 0.1783 0.5412 0.2907	0.16723	0.10738

Table 1.Result Analysis

The result analysis shown in the Table 1 . Indicates that with the optimization technique the voltage is within the limits ie.0.95996 p.u. with a contingency in the system. This is achieved by rescheduling generator reactive power with the help of Particle swarm optimization algorithm. The reactive power at generators 2,3,6,8 are set to the value of reactive power obtained after optimization. The power flow results indicate that the voltage has improved.

The value of reactive losses during contingency has increased to 0.25509 p.u and after optimization it has reduced to 0.16723 p.u. thus our objective of voltage stability along with reactive loss reduction is achieved.

The reactive power loss during contingency is 25.509 MVAR. The loss after optimization has decreased to 16.723 MVAR. Percentage reduction in losses is about 34.44%.This will give a cost reduction if we account it in terms of economic considerations. We can observe that the active power loss also get reduced which is an added advantage.

V. Conclusion

Reactive power rescheduling was applied in this paper and it was found that by using the Particle Swarm Optimization technique the reactive losses can be reduced along with the voltage stability achievement. The use of this technique proves to give an added advantage of reduction of active power losses.

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