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A Comparative Study of Different Methods for Power System Stability Improvement

Akila E.
Assistant Professor, Department of Electrical, Department of General Engineering
Shree Rayeshwar Institute of Engineering and Information Technology, Shiroda, Goa, India

Abstract:
The voltage stability control problem has become an important concern for utilities transmitting power over long distances. This paper presents a comparative study of different approaches for reactive power control with the purpose of improving the voltage stability and angular stability of a power system. The following methods are compared with respect to cost, voltage stability and angular stability and losses, namely Economic Load dispatch, Real power scheduling based on Relative Proportion of Generations (RPG), evaluated by F_{LG} *matrix and without Real Power scheduling. In both the methods optimal locations and sizes of SVC devices are also provided based on voltage stability criterion using L-Index. The approaches are tested on IEEE 14 bus and IEEE 30 bus system on peak load conditions under normal and contingency conditions.*

Keywords: *L-index, Voltage stability, angular stability*

1. Introduction

The present day power systems have developed into large interconnected power grids in order to exploit all the advantages of integrated operation, both technical and economical[5]. The goal of the interconnected power grid operator is to achieve the best possible security for the network with available facilities. This requires tools for assessing the vulnerability of the grid to possible contingencies, implementing protection and controls, and minimising the likelihood of blackouts resulting from various forms of instabilities. The ability to maintain voltage stability in an interconnected power grid has become a thing of growing concern especially due to stressed operation of power systems. The monitoring and analysis of power system security has become an integral part of modern electrical energy management system[6].

The modern trend is, to use static VAR compensation by which over voltage can be avoided, transient stability limits can be increased and voltage instability of power system can be prevented[6].

D. Thukaramet al[2] have proposed an approach for selection of location and size for static VAR compensation (SVC) for system voltage stability improvement. The analysis is based on voltage stability index (L-index). L-index is found to be highly reliable in quantifying the proximity of the current operating condition of the system with respect to voltage collapse.

According to K. Visakhaet al[2], the pattern of load sharing / generation scheduling that results in heavy flow tends to incur greater losses, threaten stability and security thereby making certain generation patterns undesirable. Generation schedules mainly based on economic criteria may lead to lower reserve margins and hence diminished reliability. With increased loading of existing power transmission systems, the problem of voltage instability has become a cause of major concern in power system planning and operation. Even though the voltage stability mainly depends on the reactive power sources / voltage profile in the system, it is also a function of real power flows to some extent.

In this paper, a comparative study of three methods-Economic Load Dispatch, Real power scheduling based on Relative Proportion of Generations (RPG) and without real power scheduling is done. In all these methods the optimal sizes and locations of SVC devices is also done based on the voltage stability index (L-Index). Also the effect of system losses is treated as part of demand and the losses are allocated to different load buses based on Relative Proportions of Losses (RPL).The methods are tested on Standard IEEE bus test systems under normal and contingency conditions. However, the methods are compared with respect to cost, voltage stability, and angular stability and system losses.

2. Economic Load Dispatch (ELD)

Economic Load Dispatch (ELD) is one of the essential real-time analysis tools. The objective is to minimize the production cost without violating the constraints such as power balance constraints and generator power limits. This technique is been applied widely especially in advanced countries. The system losses are also accounted in terms of loss co-efficient, which can be computed for the given system. However, if any changes in the system network take place the loss co-efficient has to be re-calculated. It may be noted that, the calculation of loss co-efficient is done by computer using standard software package. It is further noted that, ELD is carried out once in every five minutes during the real-time operation of the power system in order to derive maximum benefit in terms of minimum production cost.

2.1. Problem Formulation

The optimal load dispatch problem including transmission losses is defined as

Min $F_T = \sum_{n=1}^{nb} F_n$ …………… (1)

Subject to the power balance condition,

$$P_D + P_L - \sum_{n=1}^{g} P_n = 0 \quad \ldots\ldots\ldots\ldots (2)$$

Where P_L is the total system loss, which is assumed to be a function of generated powers and P_D is the total system demand. Making use of the Lagrangianmultiplierλ, the auxiliary function is given by

$$F = F_T + \lambda\ (P_D + P_L - \sum_{n=1}^{g} P_n$$

The partial differential of this expression when equated to zero gives the condition for optimal load dispatch, i.e.

$$\frac{\partial F}{\partial P_n} = \frac{\partial F_T}{\partial P_n} + \lambda \langle \frac{\partial P_L}{\partial P_n} - 1 \rangle = 0$$

$$\text{or } \frac{\partial F_T}{\partial P_n} + \lambda \frac{\partial P_L}{\partial P_n} = \lambda \ldots. (3)$$

Here, the term $\partial P_L / \partial P_n$ is known as the incremental transmission loss at plant n and λ is known as the incremental cost of received power in Rs. / MW hr.

The equation (3) is a set of n equations with (n+1) unknowns. Here, n generations are unknown and λ is also unknown. These equations are known as coordination equations because they coordinate the incremental transmission losses with the incremental cost of production.

To solve these equations, the loss formula equation (4) is expressed in terms of generations and is approximately expressed as

$$P_L = \sum_{m=1}^{g} \sum_{n=1}^{g} P_m B_{mn} P_n \ldots\ldots\ldots\ldots (4)$$

Where, P_i&P_j = the source loadings, B_{ij} = the transmission loss coefficient matrix element

The formula is derived on the basis of the following assumptions

i. The equivalent load current at any bus remains a constant complex fraction of the total equivalent load current
ii. The generator bus voltage magnitudes and angles are constant.
iii. The power factor of each source is constant.

The sources of co-ordination equation (3) requires the calculation of $\partial P_L / \partial P_n$ which is obtained from equation (4) as

$$\frac{\partial P_L}{\partial P_n} = 2 \sum_{m=1}^{g} B_{mn} P_m \quad \ldots\ldots\ldots (5)$$

Also

$$\frac{\partial F_T}{\partial P_n} = F_{mn} P_n + f_n \qquad \ldots\ldots (6)$$

$\therefore$The coordination equation (3) may be rewritten as

$$\mathbf{F_{nn} P_n + f_n} + \lambda \sum_{m=1}^{g} \mathbf{2\ B_{mn} P_m} = \lambda \ldots (7)$$

Collecting all co-efficient of P_n, we obtain

$$P_n(F_m + 2\ \lambda B_{mn}) = -\ \lambda\ (\sum_{m \neq n} 2 B_{mn} P_m) - f_n + \lambda$$

Solving for P_n we obtain

$$\mathbf{P_n} = \frac{\mathbf{1 - \left(\frac{f_n}{\lambda}\right) - 2\ \sum_{m \neq n} B_{mn} P_m}}{\mathbf{\frac{f_{nn}}{\lambda} + 2\ B_{nn}}} \quad \ldots\ldots\ldots (8)$$

To arrive at an optimal load dispatching solution, the simultaneous solution of the coordination equations along with the equality constraint (2) should suffice and any standard matrix inversion subroutine could be used. But, because of the fact that, plants might go beyond their loading conditions, it becomes necessary to solve a new set of equations and thus by the process of elimination this could be done. This would be very time consuming in a large interconnected system. Therefore, an iterative procedure would be used. The iterative procedure involves a method of successive approximation, which rapidly converges to the correct solution.

3. Relative Proportions of Generations (RPG)

The Relative Proportions of Generation (RPG) to meet demand at each of the load buses of the given power system network, are obtained by using the absolute values of the elements of [F_{LG}] matrix. The RPG values are used as a basis for determining real power generation scheduling[6]. The Real power generations are calculated using the formula

$$\mathbf{P_{Gi}} = \sum_{\mathbf{j=g+1}}^{\mathbf{n}} \left|\mathbf{F_{ji}}\right| \mathbf{P_{Dj}} \ldots\ldots.. (1)$$

Where,

P_{Gi} = Power Generation at generator bus 'i'
P_{Dj} = Power demand at each load bus 'j'
F_{ji} = Elements of [F_{LG}] matrix

Note that, the system losses are neglected in the equation (1).

The F_{LG} matrix gives the relation between the load bus voltages and source bus voltages. The elements of this matrix are used as basis for load sharing / generation scheduling under RPG method. Different possible combinations of real power generation schedules give different real power flows in the network and different voltage angles, which greatly influence the voltage stability indices. Generated powers, as calculated on the basis of RPG, are found to improve voltage stability and angular stability margins[6].

4. Effect of System Losses and Reactive Power Compensation

The system losses may be computed by conducting load flow analysis using the generations obtained by RPG method. These losses are treated as part of demand and hence allocated to different load buses by using the newly introduced concept of Relative Proportions of Losses (RPL). Then, new generations are computed by using RPG method and the Modified Load Demands. The formulae for Relative Proportions of Losses (RPL) and Modified Load Demands are given by equation (2) & (3).

Relative Proportions of Losses (RPL)

$$\boldsymbol{\alpha_j} = \frac{\boldsymbol{P_{Dj}}}{\sum_{\boldsymbol{k=g+1}}^{\boldsymbol{n}} \boldsymbol{P_{Dk}}} \quad \ldots\ldots\ldots\ldots.. (2)$$

Where,

α_j = Relative proportion of losses with respect to load bus 'j'
P_{Dj} = Real Power demand at load bus 'j'
P_{Dk} = Real power demand at load bus 'k'

Modified Load Demands

$$P_{Dj}^{new} = P_{Dj}^{old} + \alpha_j P_{Loss}^{old} \ldots\ldots\ldots. (3)$$

Where,

P_{Dj}^{new} = new demand at load bus 'j' including system loss
P_{Dj}^{old} = old demand at load bus 'j' including system loss obtained in the previous iteration
P_{loss} = Total system loss

IV. L-INDEX BASED ON VOLTAGE STABILITY

L_j parameter clearly indicated the degree of stress experienced by the system. L_j is called Votlage stability Index.

$$L_j = \left| 1 - \frac{\sum_{i=1}^{g} F_{ji} V_i}{V_j} \right| \ldots\ldots\ldots\ldots (4)$$

Where, [F] = - [Z_{LL}] [Y_{LG}]

Further, $\sum_{j=g+1}^{n} L_j^2 = (L_{g+1}^2 + L_{g+2}^2 + \ldots\ldots + L_n^2 \ldots (5)$

EVALUATION OF VOLTAGE STABILITY AND ANGULAR STABILITY IMPROVEMENT

The voltage stability and angular stability of the power system network are evaluated by using L-index and bus voltage angle values. L-index values away from 1 and close to 0 indicate better voltage stability margin. The higher values of L-indices are indicative of more critical buses and hence the maximum of L-index [$L_{j\,max}$] is an indicator of proximity of the system to voltage collapse condition. Moreover, summation of squares of all L-indices (ΣL_j^2) gives a relative indication of over-all voltage stability of the system for the given operating conditions[4]. The absolute values of bus voltage angles as well as the relative differences of the angles of the connected buses should be small so that the angular stability of the system is better.

5. Simulation Study

All the methods have been tested on IEEE 14-bus test system and IEEE 30-bus test system on peak load (with and without line outage contingency). The results are given in tabular column and graphs.

IEEE 14-bus test system results (ΣL_j^2 value and operating cost in Rs./hr.)

Methods	Normal		Contingency	
	Peak Load	**Peak Load + SVC**	**Peak Load**	**Peak Load + SVC**
ELD	0.4066, 2726.454	0.2616, 2707.630	0.4220 2727.382	0.2560 2707.507
Without RPG	0.5436, 3324.916	0.3551, 3319.292	0.5711 3325.842	0.3652 3319.635
With RPG	0.4679 2996.280	0.3448 2990.652	0.4880 2996.151	0.3434 2989.051
With RPG + Losses	0.4775 3042.126	0.3567 3037.096	0.4988 3042.398	0.3519 3037.774

Table 1

IEEE 30-bus test system results (ΣL_j^2 value and operating cost in Rs./hr.)

Methods	Normal		Contingency	
	Peak Load	**Peak Load + SVC**	**Peak Load**	**Peak Load + SVC**
ELD	2.5352 1874.476	0.8483 1862.071	2.6070 1874.788	0.8688 1859.501
Without RPG	3.0597 2112.296	1.1294 2100.692	3.1350 2112.712	1.1270 2099.974
With RPG	2.9209 2033.798	1.0615 2027.576	2.9948 2031.803	1.0820 2024.147
With RPG + Losses	2.9690 2061.901	1.0904 2056.186	3.0445 2059.749	1.1109 2052.740

Table 2

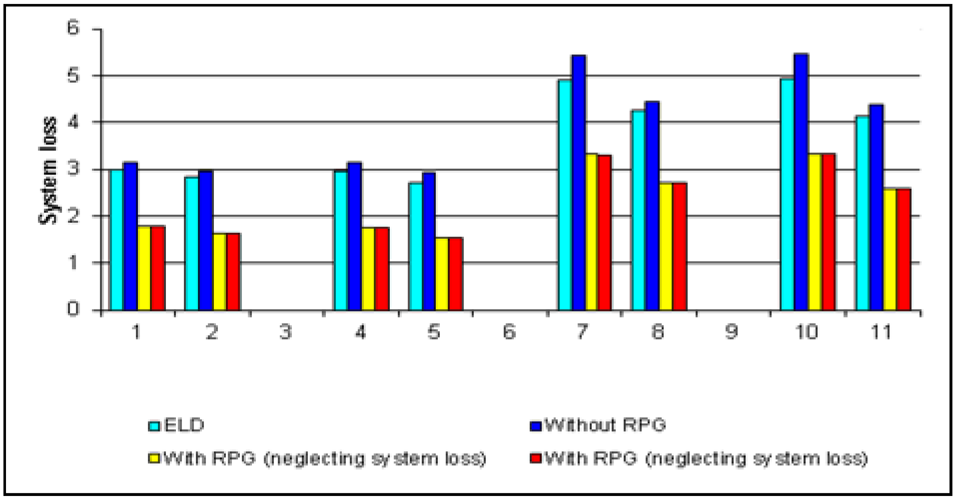

Figure 1: Comparison Graph for System Loss

6. Conclusion

This paper gives a comparative study of Economic Load dispatch, Relative Proportion of Generations (RPG) which is evaluated on the basis of F_{LG} matrix and Relative Proportions of Losses (RPL). These methods are tested on standard IEEE 14-bus and IEEE 30-bus system under normal and contingency conditions, with and without reactive power compensation and neglecting / including system losses for power system stability improvement.

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