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An approach for real power scheduling to improve system stability margins under normal and network contingencies

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Abstract

In the present day power system planning and operation, considerable interest is being shown in system security and stability analysis. Pattern of load sharing/generation scheduling that results in heavy flows tend to incur greater losses, threaten stability, security and ultimately making certain generation patterns undesirable. Generation schedules mainly based on economic criteria may lead to lower reserve margins and therefore diminished reliability is a serious concern for the systems. With increased loading of existing power transmission systems, the problem of voltage stability and voltage collapse has also become a major concern in power system planning and operation. While the voltage stability is more dependent on the reactive power sources/voltage profile in the system, it is also a function of real power flows. In this paper, network sensitivity between load voltages and source voltages to compute voltage stability index (L), is used as the basis to evaluate desirable load sharing for improving stability margins. The proposed method has been tested on typical sample systems and also on a practical 24-bus equivalent power system, and results are presented to illustrate the proposed approach.

Keywords: Planning and operation; System security; Stability analysis

1. Introduction

The present day power systems have evolved as large interconnected power grids to take advantages of integrated operation both technical and economical. Earlier, the individual power systems developed as self sufficient islands to match its generation to its load with system-wide planning for reserve margins, expected load growth, available generation sites and adequate transmission and reactive power capabilities. Interconnection of these island systems has great advantages to each individual system during normal operation and also during emergency conditions.

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 that are responsible to the prevailing system conditions, and minimizing the likelihood of blackouts resulting from various forms of instabilities [1].

The ability to maintain voltage stability in an interconnected power grid has become a growing concern in present day stressed power systems. The monitoring and analysis of power system security has also become an integral part of modern energy management systems.

In this paper, network sensitivity between load voltages and source voltages to compute voltage stability index (L) is used as the basis to develop an approach for load sharing/generation scheduling for improving stability margins. The proposed approach gives the most desirable generation scheduling for a given network under normal and network contingency condition for improving voltage stability in addition to improving the system angular stability.

2. Voltage stability index (L index)

Consider a system where n is the total number of buses with 1,2,..., g, g number of generator buses, and $g+1, \ldots, n$, remaining $(n-g)$ buses. For a given system

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operating condition, using the load flow (state estimation) results, the voltage stability L index is computed as [2]

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

where $j = g+1, \ldots, n$ and all the terms within the sigma on the RHS of Eq. (1) are complex quantities. The values of $\boldsymbol{F}_{ji}$ are obtained from the network $\boldsymbol{Y}$-bus matrix. For a given operating condition

$$\begin{bmatrix} \boldsymbol{I}_{\rm G} \\ \boldsymbol{I}_{\rm L} \end{bmatrix} = \begin{bmatrix} \boldsymbol{Y}_{\rm GG} & \boldsymbol{Y}_{\rm GL} \\ \boldsymbol{Y}_{\rm LG} & \boldsymbol{Y}_{\rm LL} \end{bmatrix} \begin{bmatrix} \boldsymbol{V}_{\rm G} \\ \boldsymbol{V}_{\rm L} \end{bmatrix} \qquad (2)$$

where $\boldsymbol{I}_{\rm G}$, $\boldsymbol{I}_{\rm L}$ and $\boldsymbol{V}_{\rm G}$, $\boldsymbol{V}_{\rm L}$ represent complex current and voltage vectors at the generator nodes and load nodes.

$[\boldsymbol{I}_{\rm G}] = [I_1, \ldots, I_n]^t$, injected currents of generator buses
$[\boldsymbol{I}_{\rm L}] = [I_{g+1}, \ldots, I_n]^t$, injected currents of load buses
$[\boldsymbol{V}_{\rm G}] = [V_1, \ldots, V_g]^t$, complex generator bus voltages
$[\boldsymbol{V}_{\rm L}] = [V_{g+1}, \ldots, V_n]^t$, complex load bus voltages

$[\boldsymbol{Y}_{\rm GG}]$, $[\boldsymbol{Y}_{\rm GL}]$, $[\boldsymbol{Y}_{\rm LL}]$ and $[\boldsymbol{Y}_{\rm LG}]$ are corresponding partitioned portions of network $\boldsymbol{Y}$-bus matrix. Rearranging the above Eq. (2) we get

$$\begin{bmatrix} \boldsymbol{V}_{\rm L} \\ \boldsymbol{I}_{\rm G} \end{bmatrix} = \begin{bmatrix} \boldsymbol{Z}_{\rm LL} & \boldsymbol{F}_{\rm LG} \\ \boldsymbol{K}_{\rm GL} & \boldsymbol{Y}_{\rm GG} \end{bmatrix} \begin{bmatrix} \boldsymbol{I}_{\rm L} \\ \boldsymbol{V}_{\rm G} \end{bmatrix} \qquad (3)$$

where $[\boldsymbol{F}_{\rm LG}] = -[\boldsymbol{Y}_{\rm LL}]^{-1}\,[\boldsymbol{Y}_{\rm LG}]$. F_{ji} are the complex elements of $[\boldsymbol{F}_{\rm LG}]$ matrix. This matrix gives the relation between load bus voltages and source bus voltages, which is used as basis for the desirable best load sharing/generation scheduling.

It can be shown that the stability limit is reached for $L_j = 1$, when two conditions are met [2]. The first requires that all generator voltages remain unchanged, amplitude and phase wise. The second calls for nodal currents, which respond directly to the current I_j and are indirectly proportional to the voltage V_j at the node j under consideration. The stability margin in this case is obtained as the distance of L from a unit value, i.e., $(1 - L)$.

While the different methods give a general picture of the proximity of the system voltage collapse, the L index gives a scalar number to each load bus. Among the various indices for voltage stability and voltage collapse prediction, the L index gives fairly consistent results. The advantage of this method lies in the simplicity of the numerical calculation and expressiveness of the results. The L indices for given load conditions are computed for all load buses and the maximum of the L indices gives the proximity of the system to voltage collapse. An L index value away from 1 (unity) and close to 0 (zero) indicates an improved voltage stability margin [3–6].

3. Approach for load sharing/generation scheduling

This paper concentrates on real power scheduling for achieving improved margin of stability. The L index is used as the basis for evaluating the most suitable real-power generation scheduling.

The L index is function of $\boldsymbol{F}_{ji}$ elements derived from the transmission network parameters and generator/load bus complex voltages (voltage magnitudes and angles). Considering an unloaded network with nominal voltage profile, it can be seen that the L-indices for the load buses are close to 0 (zero). For a given load distribution in the system, we can have many possible combinations of generation schedules. Reactive power controls such as, generator excitations, transformer taps and switchable VAR compensators can change the reactive power flows in the network and voltage profile (voltage magnitudes) and have influence on the voltage stability index. Different possible combinations of real power generation schedules to meet a given load demand give different real power flows in the network and voltage angles which also influence the voltage stability indices. The best load sharing is obtained by using the relative proportions of generation, which are evaluated, from the $\boldsymbol{F}_{\rm LG}$ matrix.

4. Evaluation of relative proportions of generation (RPG)

To illustrate the proposed method of load sharing/generation scheduling the following five-bus sample radial system 1 shown in Fig. 1 is considered.

4.1. Case 1: Equal line lengths

In this case it is assumed that the lines L1 and L2 are of 220 kV lines of equal length of 200 km each. The generators considered are two units of 250 MVA with step up transformers of 250 MV A each at both buses 1 and 2. The 220 kV line parameters in p.u. per 100 km are $r = 0.0166$, $x = 0.0826$ and $b/2 = 0.0694$. The generator $X_{\rm d}$ is considered 0.2 p.u. on its own base. The $[\boldsymbol{F}_{\rm LG}]$ matrix corresponding to the load/generator bus for the network is given by

$$[\boldsymbol{F}_{\rm LG}] = \begin{bmatrix} 0.9516 - 0.0072{\rm i} & 0.0540 + 0.0069{\rm i} \\ 0.0540 + 0.0069{\rm i} & 0.9516 - 0.0072{\rm i} \\ 0.5146 - 0.0026{\rm i} & 0.5146 - 0.0026{\rm i} \end{bmatrix}$$

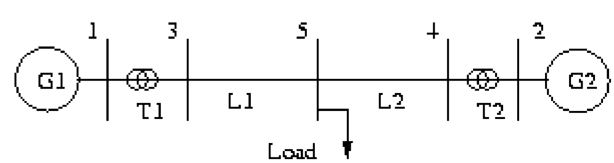

Fig. 1. Sample radial system 1.