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Line outage contingency analysis including the system islanding scenario

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Abstract

The paper describes an algorithm for determining the line outage contingency of a line taking into account of line over load effect in remaining lines and subsequent tripping of over loaded line(s) leading to possible system split or islanding of a power system. The optimally ordered sparse $[B']$, $[B'']$ matrices for the integrated system are used for load flow analysis to determine modified values of voltage phase angles $[\delta]$ and bus voltages $[V]$ to determine the over loading effect on the remaining lines due to outage of a selected line outage contingency. In case of over loading in remaining line(s), the over loaded lines are removed from the system and a topology processor is used to find the islands. A fast decoupled load flow (FDLF) analysis is carried out for finding out the system variables for the islanded (or single island) system by incorporating appropriate modification in the $[B']$ and $[B'']$ matrices of the integrated system. Line outage indices based on line overload, loss of load, loss of generation and static voltage stability are computed to indicate severity of a line outage of a selected line.

Keywords: Contingency; Line outage; Rotating mass; System islanding

1. Introduction

Line outage contingency indices provide a measure of the overall effect on the system due to that line outage. Line outage contingency indices for a power system based on its operating conditions indicates the relative severity of the line outage contingency for the system operation. These help operator to take some corrective/preventive measure so as to prevent large system disturbances (over loading of lines) leading to cascade tripping and system collapse.

Ejebe and Wollenberg [1] have reported a pioneering work in which they have formulated a method of contingency ranking based on system performance indices (PI) which are functions of bus voltages and line flows and the corresponding limits. This method also uses Tellegen's theorem to calculate PI sensitivities to these outages. The ranking is done by ordering these PI sensitivities in descending order. Irissari and Leven [2] have proposed a method for contingency ranking based on DC load flow, which is computationally less complex. Mikolinnas and Wollenberg [3] have presented an improved version of the Megawatt PIs by including all terms in the infinite Taylor's series expansion for all the change in the performance index due to different outage. Irissari and Sasson [4] have proposed an improved computational procedure based on DC load flow method, which requires one forward–backward substitution to compute performance index for line outage. Vemuri and Usher [5] have presented a unified approach to find sensitivity of performance index for single branch outage, generation/load outage and combination of them.

Most of the literature on contingency ranking based on analytical methods show that ranking by PI methods are widely accepted [6]. The megawatt performance index, PI_{MW} is used as an index for quantifying the extent of line overloads in terms of megawatt flows and their MW limits. However, megavoltampere performance index PI_{MVA} quantifies the line over load in terms of magavoltampere flows and their MVA limits. It has been reported that PI_{MVA} represents extent of line over load in true sense as MVA flow in a line corresponds to the line current in that line [1].

In certain cases outage of a line may split system into two islands or due to outage of a line, over load may appear in remaining line(s) and overloaded lines may trip leading to system split. Immediately after split, a power balance between generation, load and losses for each island must take place. Since, the power drawn by the loads do not change instantaneously, the imbalance in power is supplied/absorbed by the generators affecting a change in the kinetic energy (KE)

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of its rotating mass. Thus, change in electrical output of each generator in the island will be proportional to the KE of its rotating mass, i.e. its inertia (H). Therefore, in order to simulate the condition immediately after a system split, rescheduling of generation for the power balance in islands have to be done before a load flow can be carried out to obtain the line flows after islanding. Under such situation only PI_{MVA} may not reflect the overall effect on the system due to that line outage. The system voltage conditions are also taken into account to quantify the effect on the system due to that line outage. As such, voltage stability index is used to examine system voltage stability condition.

In this paper, PI_{MVA} along with voltage stability index are determined to quantify the line outage contingency of a power system. For this purpose, optimally ordered sparse $[B']$, $[B'']$ matrices are used to determine voltage phase angles $[\delta]$ and bus voltages $[V]$ for a line outage applying appropriate modifications of $[B']$, $[B'']$ and Y-bus matrices. Then using these modified $[V]$ and $[\delta]$ line flows for the remaining lines are computed, if any line over loading in line(s) are detected among the remaining lines, the over loaded lines are removed from the network and a topology processor is used to determine possible system islanding. When a system split is detected (indicated by c value or by the topology processor), appropriate modifications are carried out on the sparse $[B']$ and $[B'']$ matrices depending upon the change in network configuration. A slack bus is allocated for each island. For this a high value is placed at the diagonal element of $[B']$ and $[B'']$ matrices corresponding to that bus location. No change in matrix storage and ordering for sparse $[B']$ and $[B'']$ is required. In order to obtain a balance between generation, demand and loss in each island immediately following a system split, generation rescheduling is carried out by finding the change in generation for each generator based on its inertia and the total change in power required for power balance in the island. A load flow using the sparse and ordered $[B']$ and $[B'']$ matrices is carried out to determine the state of the islands and line flows are computed. Based on the system operating condition line outage contingency indices are computed.

2. Fast decoupled load flow analysis for islanded system

In a fast decoupled load flow analysis the solution matrix, $[B']$ and $[B'']$ matrices remain unchanged during load flow analysis [7]. Therefore, ordering and factorization for each of them are done once at the beginning only in a load flow program.

In a power system a slack bus is required to take care of system real and reactive losses. For the slack bus voltage magnitude (V) and voltage phase angle (δ) are known variables and so do not change during load flow iterations. Therefore, row and column of $[B']$ matrix corresponding to slack bus are not included while forming $[B']$ matrix in fast decoupled load flow analysis. The same effect can be achieved by using $[B']$ matrix having row and column corresponding to slack bus included but with a large (10^6) value in place of the diagonal element in $[B']$ matrix. Without loss of generality taking bus number 1 as the slack bus, the change in real power injection at bus bars can be expressed as:

$$\begin{bmatrix} \Delta P_1/V_1 \\ \Delta P_2/V_2 \\ \vdots \\ \Delta P_N/V_N \end{bmatrix} = \begin{bmatrix} 10^6 & B'_{12} & \cdots & B'_{1N} \\ B'_{21} & B'_{22} & \cdots & B'_{2N} \\ \vdots & \vdots & \vdots & \vdots \\ B'_{N1} & B'_{N2} & \cdots & B'_{NN} \end{bmatrix} \begin{bmatrix} \Delta\delta_1 \\ \Delta\delta_2 \\ \vdots \\ \Delta\delta_N \end{bmatrix} \tag{1}$$

Large value in place of diagonal element corresponding to slack bus allow no change in voltage phase angle (i.e. $\Delta\delta_1$ is very insignificant) for that bus while solving the above equations for $[\Delta\delta]$. Thus, the bus assigned as slack bus for an island will retain the required characteristic of a slack bus of a power system (where δ_i and V_i are defined variables) and $\Delta PV_i/\Delta V_i$ for the slack bus for an island is to be assigned as zero.

The islanded system are the subsystems of the main grid system, therefore, the factored $[B']$ and $[B'']$ matrices used for the load flow analysis of the grid system can be used for the islanded system with the following modifications:

1. For outage of line ij, $[B']$ matrix is modified by placing zero at positions ij and ji and subtracting B'_{ij} from B'_{ii} and B'_{jj} in $[B']$ matrix. Similar modifications are made in $[B'']$ matrix.
2. For each island a slack bus is required. For this purpose, in each island a generating bus with sufficient generation reserve and voltage phase angle close to the mean value of voltage phase angle for all the buses in the island is selected as a slack bus. This choice of slack bus results in faster convergence as maximum voltage angle difference (δ_{ij}) between buses in each island remains small thus complying with the FDLF method assumptions. Slack bus being the reference for voltage phase angle, it's voltage magnitude and voltage phase angle must remain unchanged during load flow analysis. To achieve this, large (10^6) values are put in place of the diagonal elements corresponding to the slack buses of the islands of $[B']$ and $[B'']$ matrices of the integrated system, which is already stored in ordered form. Now, reduction of $[B']$ and $[B'']$ matrices are carried out.
3. As the system get separated into number of islands, at the instant of bifurcation for each island generation—demand balance is obtained by modifying the generation in the island to balance the load in that island. This change in generation is calculated based on the relative inertia of the machines as follows:

Generation from each generator of an island are calculated as follows

$$P_{gij} = P_{Gj} + \frac{(P_{gti} - P_{GTi})H_j}{\sum_{j=1}^{N_i} H_j} \tag{2}$$

where

N_i total number of generator in ith island
P_{Gj} generation from jth generator before system bifurcation