PowerWorld - A Software Approach to Transmission Line Fault Analysis

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Abstract—The fault analysis is done for the three phase symmetrical fault and the unsymmetrical faults. The unsymmetrical faults include single line to ground, line to line and double line to ground fault. The method employed is bus impedance matrix which has certain advantages over thevenin’s equivalent method. The advantage of this approach over conventional method is to make the analysis of three typical unsymmetrical faults, namely single-line-to-ground fault, line-to-line fault and double-line-to-ground fault more unified. So it is unnecessary to cumbersomely connect three sequence networks when calculating the fault voltages at each bus and fault currents flowing from one bus to its neighboring bus. The results have been obtained using the POWERWORLD Simulator, which uses the method of Bus Impedance Matrix.

Index Terms- Bus impedance matrix, fault analysis, powerworld, thevenin’s equivalent.

I. INTRODUCTION

The steady state operating mode of a power system is balanced 3-phase ac. However due to sudden external or internal changes in the system, this condition is disrupted. When the insulation of the system fails at one or more points or a conducting object comes in contact with a live point, a short circuit or fault occurs. A fault involving all the three phases is known as symmetrical (balanced) fault while one involving only one or two phases is known as unsymmetrical fault. Majority of the faults are unsymmetrical. Fault calculations involve finding the voltage and current distribution throughout the system during the fault. It is important to determine the values of system voltages and currents during fault conditions so that the protective devices may be set to detect the fault and isolate the faulty portion of the system.

II. FAULTS IN A THREE PHASE SYSTEM

1. Symmetrical three-phase fault
2. Single line-to-ground fault (SLG)
3. Line-to-line fault (LL)
4. Double line-to-ground fault (DLG)

The most common type of faults by far is the SLG fault, followed in frequency of occurrence by the LL fault, DLG fault, and three-phase fault.

Out of the above four faults, two are of the line-to-ground faults. Most of these occur as a result of insulator flashover during electrical storms. The balanced three-phase fault is the rarest in occurrence and the least complex in so far as the fault current calculations are concerned. The other three unsymmetrical faults will require the knowledge and use of symmetrical components. Unsymmetrical faults cause unbalanced currents to flow in the system. The method of symmetrical components is a very powerful tool which makes the calculations of unsymmetrical faults almost as easy as the calculations of a three-phase fault.

To analyze un-symmetrical faults, one needs to develop positive-, negative-, and zero-sequence networks of the power system under study, based on which one further needs to work out the impedance of three thevenin equivalent circuits as viewed from faulty point. Then the positive-, negative- and zero-sequence components of phase-a faulty-point-to-ground current can be calculated. To calculate three-phase currents flowing from one bus to its neighboring bus and three-phase voltages at each bus, one needs to connect three sequence networks uniquely for each type of fault. This may make circuit drawing very cumbersome. Furthermore by using the network with three sequence networks connected, it is impossible to appreciate the impedance matrix approach to calculate the sequence voltage at each bus when fault occurs.

To overcome these two drawbacks, paper [1] introduces a new approach to unify the analysis of
three typical unsymmetrical faults, namely single-line-to-ground fault, line-to-line fault and double-line-to-ground fault. This new method allows the analysis of three typical unsymmetrical faults to share all steps except one. The only different step is how to calculate the positive-, negative-, and zero-sequence components of phase-a-to-ground fault current at faulty point. It also makes impedance matrix approach more understandable when used to calculate the sequence voltages at each bus.

All the above four faults (1, 2, 3, 4) are being solved using the bus impedance matrix and the same results are obtained from the powerworld simulator.

III. BUS IMPEDANCE MATRIX METHOD

We can work out a universal representation of all three typical un-symmetrical faults. This representation is valid with the imposition of different fault conditions for each typical unsymmetrical fault, such as for the single-line-to-ground fault, such as for the single-line-to-ground fault, the fault conditions being $V_{ka}=Z_f I_{fa}$, $I_{fb}=I_{fc}=0$.

In the following formulation, per-unit system is adopted. Zero-sequence voltage at each bus contributed by equivalent current source is determined by

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Fig. 1. Single line to ground fault

Fig. 2. Line to line fault

Fig. 3. Double line to ground fault
\[
\begin{bmatrix}
Y_{11}^{(0)} & Y_{12}^{(0)} & \cdots & Y_{1k}^{(0)} & \cdots & Y_{1n}^{(0)} \\
Y_{21}^{(0)} & Y_{22}^{(0)} & \cdots & Y_{2k}^{(0)} & \cdots & Y_{2n}^{(0)} \\
\vdots & \vdots & \ddots & \vdots & \ddots & \vdots \\
Y_{k1}^{(0)} & Y_{k2}^{(0)} & \cdots & Y_{kk}^{(0)} & \cdots & Y_{kn}^{(0)} \\
\vdots & \vdots & \ddots & \vdots & \ddots & \vdots \\
Y_{n1}^{(0)} & Y_{n2}^{(0)} & \cdots & Y_{nk}^{(0)} & \cdots & Y_{nn}^{(0)}
\end{bmatrix}
= \begin{bmatrix}
0 \\
0 \\
\vdots \\
-1_{fa}^{(0)} \\
0
\end{bmatrix}
\]

where

\[
Y^{(0)} =
\begin{bmatrix}
Y_{11}^{(0)} & Y_{12}^{(0)} & \cdots & Y_{1k}^{(0)} & \cdots & Y_{1n}^{(0)} \\
Y_{21}^{(0)} & Y_{22}^{(0)} & \cdots & Y_{2k}^{(0)} & \cdots & Y_{2n}^{(0)} \\
\vdots & \vdots & \ddots & \vdots & \ddots & \vdots \\
Y_{k1}^{(0)} & Y_{k2}^{(0)} & \cdots & Y_{kk}^{(0)} & \cdots & Y_{kn}^{(0)} \\
\vdots & \vdots & \ddots & \vdots & \ddots & \vdots \\
Y_{n1}^{(0)} & Y_{n2}^{(0)} & \cdots & Y_{nk}^{(0)} & \cdots & Y_{nn}^{(0)}
\end{bmatrix}
\]

is the admittance matrix for the sub-transient or transient zero-sequence network.

Then

\[
\begin{bmatrix}
V_{1f}^{(0)} \\
V_{2f}^{(0)} \\
\vdots \\
V_{kf}^{(0)} \\
\vdots \\
V_{nf}^{(0)}
\end{bmatrix}
= \begin{bmatrix}
Y_{11}^{(0)} & Y_{12}^{(0)} & \cdots & Y_{1k}^{(0)} & \cdots & Y_{1n}^{(0)} \\
Y_{21}^{(0)} & Y_{22}^{(0)} & \cdots & Y_{2k}^{(0)} & \cdots & Y_{2n}^{(0)} \\
\vdots & \vdots & \ddots & \vdots & \ddots & \vdots \\
Y_{k1}^{(0)} & Y_{k2}^{(0)} & \cdots & Y_{kk}^{(0)} & \cdots & Y_{kn}^{(0)} \\
\vdots & \vdots & \ddots & \vdots & \ddots & \vdots \\
Y_{n1}^{(0)} & Y_{n2}^{(0)} & \cdots & Y_{nk}^{(0)} & \cdots & Y_{nn}^{(0)}
\end{bmatrix}
\begin{bmatrix}
0 \\
0 \\
\vdots \\
-1_{fa}^{(0)} \\
0
\end{bmatrix}
\]

\[
= \begin{bmatrix}
0 \\
0 \\
\vdots \\
-1_{fa}^{(0)} \\
0
\end{bmatrix}
\]

Where, 

\[
Z^{(0)} = \begin{bmatrix}
Z_{11}^{(0)} & Z_{12}^{(0)} & \cdots & Z_{1k}^{(0)} & \cdots & Z_{1n}^{(0)} \\
Z_{21}^{(0)} & Z_{22}^{(0)} & \cdots & Z_{2k}^{(0)} & \cdots & Z_{2n}^{(0)} \\
\vdots & \vdots & \ddots & \vdots & \ddots & \vdots \\
Z_{k1}^{(0)} & Z_{k2}^{(0)} & \cdots & Z_{kk}^{(0)} & \cdots & Z_{kn}^{(0)} \\
\vdots & \vdots & \ddots & \vdots & \ddots & \vdots \\
Z_{n1}^{(0)} & Z_{n2}^{(0)} & \cdots & Z_{nk}^{(0)} & \cdots & Z_{nn}^{(0)}
\end{bmatrix}
\]

So

\[
\begin{bmatrix}
V_{1f}^{(0)} \\
V_{2f}^{(0)} \\
\vdots \\
V_{kf}^{(0)} \\
\vdots \\
V_{nf}^{(0)}
\end{bmatrix}
= \begin{bmatrix}
Z_{11}^{(0)} & Z_{12}^{(0)} & \cdots & Z_{1k}^{(0)} & \cdots & Z_{1n}^{(0)} \\
Z_{21}^{(0)} & Z_{22}^{(0)} & \cdots & Z_{2k}^{(0)} & \cdots & Z_{2n}^{(0)} \\
\vdots & \vdots & \ddots & \vdots & \ddots & \vdots \\
Z_{k1}^{(0)} & Z_{k2}^{(0)} & \cdots & Z_{kk}^{(0)} & \cdots & Z_{kn}^{(0)} \\
\vdots & \vdots & \ddots & \vdots & \ddots & \vdots \\
Z_{n1}^{(0)} & Z_{n2}^{(0)} & \cdots & Z_{nk}^{(0)} & \cdots & Z_{nn}^{(0)}
\end{bmatrix}
\begin{bmatrix}
-1_{fa}^{(0)} \\
-1_{fa}^{(0)} \\
\vdots \\
-1_{fa}^{(0)} \\
-1_{fa}^{(0)} \\
\vdots
\end{bmatrix}
\]

In a similar way, positive-sequence voltage at each bus contributed by equivalent current source as is determined by

\[
\begin{bmatrix}
\Delta V_{1f}^{(0)} \\
\Delta V_{2f}^{(0)} \\
\vdots \\
\Delta V_{kf}^{(0)} \\
\vdots \\
\Delta V_{nf}^{(0)}
\end{bmatrix}
= \begin{bmatrix}
Y_{11}^{(0)} & Y_{12}^{(0)} & \cdots & Y_{1k}^{(0)} & \cdots & Y_{1n}^{(0)} \\
Y_{21}^{(0)} & Y_{22}^{(0)} & \cdots & Y_{2k}^{(0)} & \cdots & Y_{2n}^{(0)} \\
\vdots & \vdots & \ddots & \vdots & \ddots & \vdots \\
Y_{k1}^{(0)} & Y_{k2}^{(0)} & \cdots & Y_{kk}^{(0)} & \cdots & Y_{kn}^{(0)} \\
\vdots & \vdots & \ddots & \vdots & \ddots & \vdots \\
Y_{n1}^{(0)} & Y_{n2}^{(0)} & \cdots & Y_{nk}^{(0)} & \cdots & Y_{nn}^{(0)}
\end{bmatrix}
\begin{bmatrix}
\Delta V_{1f}^{(0)} \\
\Delta V_{2f}^{(0)} \\
\vdots \\
\Delta V_{kf}^{(0)} \\
\vdots \\
\Delta V_{nf}^{(0)}
\end{bmatrix}
\]

This gives
If pre-fault current is ignored, then the pre-fault voltage at each bus is the same and equal to that at fault bus \( k \) before fault occurs, which is assumed to be \( V_f \). So the positive sequence voltage at each bus when fault occurs can be written as follows.

Following figure shows the single line diagram of a four bus system. Let the bus number 4 be faulted. Let us perform the fault analysis for faults (1, 2, 3, 4). using powerworld.
SINGLE LINE TO GROUND FAULT VOLTAGES

DOUBLE LINE TO GROUND FAULT VOLTAGES

TABLE II

LINE TO LINE FAULT VOLTAGES

TABLE V

IN-LINE FAULT VOLTAGES

TABLE III

THREE PHASE BALANCED FAULT VOLTAGES

IV. CONCLUSION

This paper presents a method to tackle typical un-symmetrical faults. It is found that the bus impedance matrix method involves comparatively less computations than the thevenin’s equivalent method. The software approach using powerworld for analyzing the faults involves the use of the stated method. This further makes the calculations less tedious, regardless of the complexity of the powersystem. The proposed approach has another advantage over traditional method that it is more intuitive when matrix approach is adopted to tackle a fault problem.

TABLE IV

V. REFERENCES
[1] Daming Zhang, "An alternative approach to analyze un-symmetrical faults in power system".