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An application of global sensitivity analysis in evaluation of transmission line fault-locating algorithms

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Abstract

Computation of distance to fault on an electrical transmission line is affected by many sources of uncertainty, including parameter setting errors, measurement errors, as well as absence of information and incomplete modelling of a system under fault condition. In this paper we propose an application of the variance-based global sensitivity measures for evaluation of fault location algorithms. The main goal of the evaluation is to identify factors and their interactions that contribute to the fault locator output variability. The sensitivity measures are calculated using the sparse grid integration approach that requires smaller number of samples compared to quasi-Monte Carlo integration. In practice, such analysis can help in: selection of the optimal fault location algorithm (device) for a specific application, calibration process and building confidence in a fault location result. The paper concludes with application examples which demonstrate use of the proposed methodology in testing and comparing some commonly used fault location algorithms.

uncertainty and sensitivity analysis, sparse grid integration, quasi-Monte Carlo integration, electrical transmission line, fault location

1. Main text

The purpose of distance to fault location is to assist operating staff by indicating the point where a line has faulted in order to repair and speed up the return to service of such line. Furthermore, it provides information used to confirm correct protection relay operation and information for power system enhancement. High accuracy is needed for efficient dispatch of repair crews. Several factors affect the accuracy of fault location devices (R.Zivanovic and H.B.Ooi, 2007): combined effect of load current and fault resistance, influence of mutual effects (particularly on the zero sequence components), uncertainty about line parameters (particularly zero sequence components), insufficient accuracy of the line models (e.g. not-transposed lines are represented as being transposed), presence of parallel and shunt reactors and capacitors, measurement errors, short segments of transient waveforms (3-4 cycles) recorded during a fault before breaker opens and used for fault location algorithm, arcing and high-resistance faults, etc. Uncertainty in the above factors imposes a limit on the confidence in the fault location results. In this paper we present a systematic approach in evaluation of fault-locating algorithms. This approach is utilising the variance-based sensitivity analysis technique (I.M. Sobol, 1990). The goal of this analysis is to determine factors that mostly contribute to the fault locator output variability. Significant interactions between factors can be also determined.

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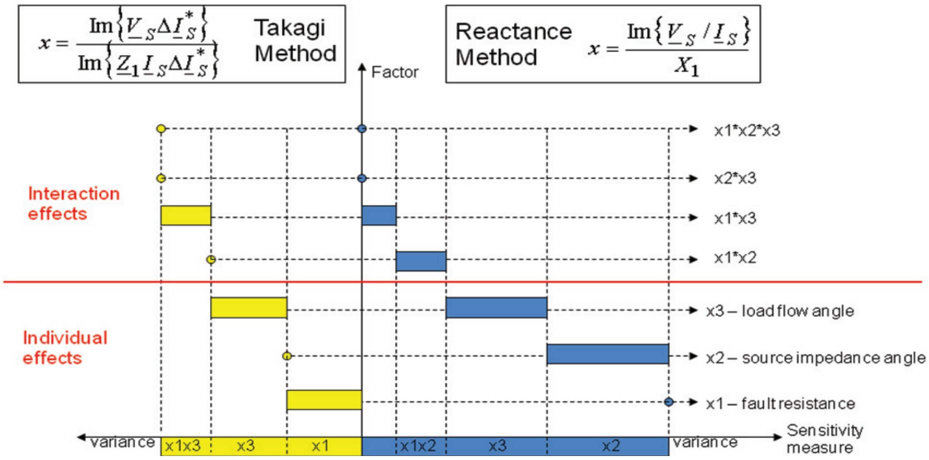
Systematic evaluation of some well know one-sided impedance-based fault location algorithms are performed by executing power system fault analysis program and fault locator repeatedly for a large number of factor values sampled from a specified grid of factor points (factor space). Factors considered were: fault resistance, load flow angle, X/R ratio through the system, zero-sequence impedance, etc. For each point in the factor space, the fault analysis software produces voltages and currents at fault locator device measurement point. These values are passed to fault locator and distance-to-fault results are collected. Sampled points in the input factor space and the corresponding fault location results are directly used to solve multidimensional integrals apparent in definitions of the variance-based sensitivity measures (I.M. Sobol, 1990). In the previous paper (R.Zivanovic and H.B.Ooi, 2007) we have presented the indirect approach in calculating sensitivity measures. This approach is based on fitting function that has Analysis of Variance (ANOVA) structure using quasi-regression (J. An and A.B. Owen, 2001). The fitted function links points in the input factor space with fault location results. The coefficients of this function are then used to calculate sensitivity measures (J. An and A.B. Owen, 2001). Comparison of these two techniques (direct and indirect), as applied in evaluation of fault location techniques, will be presented in this paper. The paper will also demonstrate advantages in using sparse grid integration (T.Gerstner and M.Griebel, 1998) in calculating sensitivity measures for this specific example. By using the sparse grid integration we achieved the same accuracy as with quasi-Monte Carlo but with a significantly smaller number of samples. A number of single-sided impedance-based fault location techniques are compared using the proposed evaluation procedure. Detailed results are presented in the paper. In this summary, as an example, we present results of sensitivity analysis of two single-sided fault locator algorithms: simple Reactance method and Takagi (T.Takagi, at al., 1982). These illustrative results are produced for three-phase short circuit fault half-way along the line. Uncertain factors are: load flow angle – x_3, source impedance angle (X/R) – x_2 and fault resistance – x_1. The figure below shows how output variances of those two methods (yellow and blue thick lines positioned below the “Sensitivity measure” axis) are apportioned to the uncertain factors and their interactions. We conclude form this figure:

1) Takagi is more robust since the output variability is smaller (yellow).
2) Takagi is sensitive to fault resistance, load flow angle and their interaction.
3) Reactance method is sensitive to source impedance angle and load flow angle as well as interactions between those two factors and fault resistance.



Notation:
x- distance to fault,
$\underline{V}_S, \underline{I}_S$ - measured fault voltage and current phasors (at fundamental frequency),
$\Delta \underline{I}_S^*$ - difference between pre-fault (load) and fault current phasors conjugate,
$\underline{Z}_1$ - line positive-sequence impedance (imaginary part is the reactance X_1), and
$\text{Im}\{*\}$ - imaginary part of a complex value.

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