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Unsymmetrical short-circuit analysis for distribution system considering loads

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ABSTRACT

Short circuit analysis is an essential tool for determining the short-circuit-current rating of the protective devices and different substation equipments to be installed in a distribution system as well as for co-ordination of the protective devices. Usually, the effect of load is neglected during short-circuit analysis, which introduces inaccuracy in the calculated values of short-circuit current. To address this issue, this paper proposes an efficient and accurate short-circuit fault analysis method for balanced and unbalanced distribution system considering the effect of loads. Comparison of the results obtained by the proposed method with those obtained by time-domain simulation using PSCAD/EMTDC establishes the accuracy of the proposed method.

Introduction

During normal operating conditions, the currents through the elements of a power system are well within their specified values. On occurrence of faults, the currents far in excess of normal values usually start flowing through network elements. These excessively high currents, if not interrupted or limited, can cause serious damage to the equipments. It has been observed that 80% of service failures occur due to the faults in distribution systems [1]. The occurrence of fault affects system's reliability, security, and power quality. The system must be protected against flow of heavy short-circuit currents by disconnecting the faulty section of system by means of appropriately rated circuit breakers and other protective equipments. Different types of faults in power system are single line-to-ground (SLG), line-to-line (LL), double-line-to-ground (LLG), and triple line-to-ground (LLLG) faults.

The process of evaluating the system voltages and currents under various types of short-circuits is called fault analysis [2]. Fault analysis is necessary to improve the customer service reliability and security. Due to the integration of distributed generation (DG) and changes in distribution network topologies owing to network reconfiguration, short-circuit currents may change from time to time. Therefore, a suitable fault analysis method is required for calculating the new settings of the protective elements (reclosers, sectionalizer switches, fuses etc.). Also short-circuit calculations are required to determine the short-circuit ratings of new switchgear and substation equipment to be installed in the system. Fault analysis can also be helpful in estimating the size of the additional reactors or fault current limiters which may be required to be inserted in the system to limit the short-circuit currents to a safe value which is below the withstand capacity of the installed circuit-breakers.

Conventional fault analysis methods are symmetrical-component-based [2,3]. In [4], an error analysis of the symmetrical component based fault analysis methods for distribution system was carried out and it was shown that the maximum error can be as high as 8.53%. This was attributed to the unbalanced nature of distribution system which can have single and two phase lines, unbalanced loads and untransposed feeders leading to unbalanced impedance matrix [4]. As distribution systems are generally unbalanced in nature; therefore fault analysis methods based on phase variable approach [5–18] give better results. In [5,6], a method based on triangular factorization of the admittance matrix is proposed to simulate different types of fault. A three-phase impedance matrix based fault analysis method for unbalanced radial distribution systems was introduced in [7,8]. A method based on phase coordinate representation of power system component was presented in [9] for short-circuit calculations of unbalanced distribution systems. Hybrid compensation methods [10–14] have been developed for fault analysis in which compensating currents have been provided for the loops in the system, faults and distributed generators (DGs). In [15–18], another short-circuit analysis method for radial and weakly meshed distribution network is proposed, which is based on two relationship matrices namely, [BIBC] and [BCBV]. The [BIBC] matrix represents the relationship between

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injected bus currents and branch currents, while the [BCBV] matrix gives the relationship between branch currents and bus voltages. In [19], a fault analysis algorithm that includes the fault resistance in the calculation of fault currents is introduced.

To the best of our knowledge, in the literature, the loads are neglected in the calculation of post fault branch currents and bus voltages. However, in [20–22] it is indicated that the load model can be critical in short circuit analysis.

To investigate the effect of loads on the short-circuit behavior of a distribution system, two types of fault cases (SLG and LLG) for different test systems have been simulated on PSCAD/EMTDC [23] platform. Table 1 shows the fault current supplied by source considering loads (I_{swl}) and neglecting loads (I_{swol}). It can be observed that (I_{swl}) is always more than (I_{swol}). Furthermore, the difference in the values increases with the system size. In general, as the real distribution systems are quite large as compared to the test systems considered, this difference can be quite substantial and influence the rating of the protective devices installed at the substation. Hence, it is important to consider the loads in the short-circuit calculations.

Therefore in this paper, a technique for short-circuit analysis is proposed which is based on bus admittance matrix $[\mathbf{Y_{bus}}]$ of the distribution network, considering the loads during short-circuit calculations. The results obtained by the proposed method have also been compared with those obtained by [BIBC] matrix based approach [16] and time domain simulation carried out with PSCAD/EMTDC software [23]. The remainder of this paper contains three sections. In Section 'Short circuit analysis considering loads', the proposed short circuit analysis method for different types of unsymmetrical faults is described in detail. Test results on IEEE-123 bus radial as well as modified meshed unbalanced distribution system are discussed in Section 'Test results and discussions'. In this section, the performance of the proposed method has been evaluated for different types of faults as well as for multiple faults (simultaneous occurrence of more than one type of fault). Finally, Section 'Conclusion' concludes the paper.

Short circuit analysis considering loads

System modelling

Let us consider an n-bus 3-phase, unbalanced radial distribution system having (n-2) 3-phase lines, one 2-phase, and one 1-phase line as shown in Fig. 1. Distribution lines between bus i and g, and, g and h are representing 2-phase and 1-phase lines respectively. Bus-1 is the substation bus and $\bar{V}_s^a, \bar{V}_s^b$, and $\bar{V}_s^c$ are the voltages of phase a, b, and c of bus-1 respectively. $\bar{z}_{ij}^{aa}, \bar{z}_{ij}^{bb}$, and $\bar{z}_{ij}^{cc}$ are the self-impedances of phase a, b, and c of line between bus i and j respectively. $\bar{z}_{ij}^{ab}, \bar{z}_{ij}^{bc}$, and $\bar{z}_{ij}^{ac}$ are the mutual impedances between phases a and b, b and c, and a and c of line between bus i and j respectively. The line impedance matrix between buses i and j is given as

$$\bar{\mathbf{z}}_{\mathbf{ij}}^{\mathbf{abc}} = \begin{bmatrix} \bar{z}_{ij}^{aa} & \bar{z}_{ij}^{ab} & \bar{z}_{ij}^{ac} \\ \bar{z}_{ij}^{ba} & \bar{z}_{ij}^{bb} & \bar{z}_{ij}^{bc} \\ \bar{z}_{ij}^{ca} & \bar{z}_{ij}^{cb} & \bar{z}_{ij}^{cc} \end{bmatrix}; \quad \bar{z}_{ij}^{pq} = \bar{z}_{ij}^{qp}; \; p, q = a, b, c; \; p \neq q \tag{1}$$

Table 1
Case study to observe the effect of load currents in fault analysis.

System	Fault type	Fault bus	Faulty phase	I_{swl} (kA)	I_{swol} (kA)	Error (%)
7-Bus [16]	SLG	5	a	1.9106	1.8657	2.35
	LLG		a and b	3.0552	3.0101	1.48
IEEE-13 Bus [24]	SLG	675	a	2.8126	2.6842	4.6
	LLG		a and b	4.3864	4.307	1.81
IEEE-37 Bus [24]	SLG	724	a	1.3045	1.2234	6.22
	LLG		a and b	1.4444	1.3687	5.24

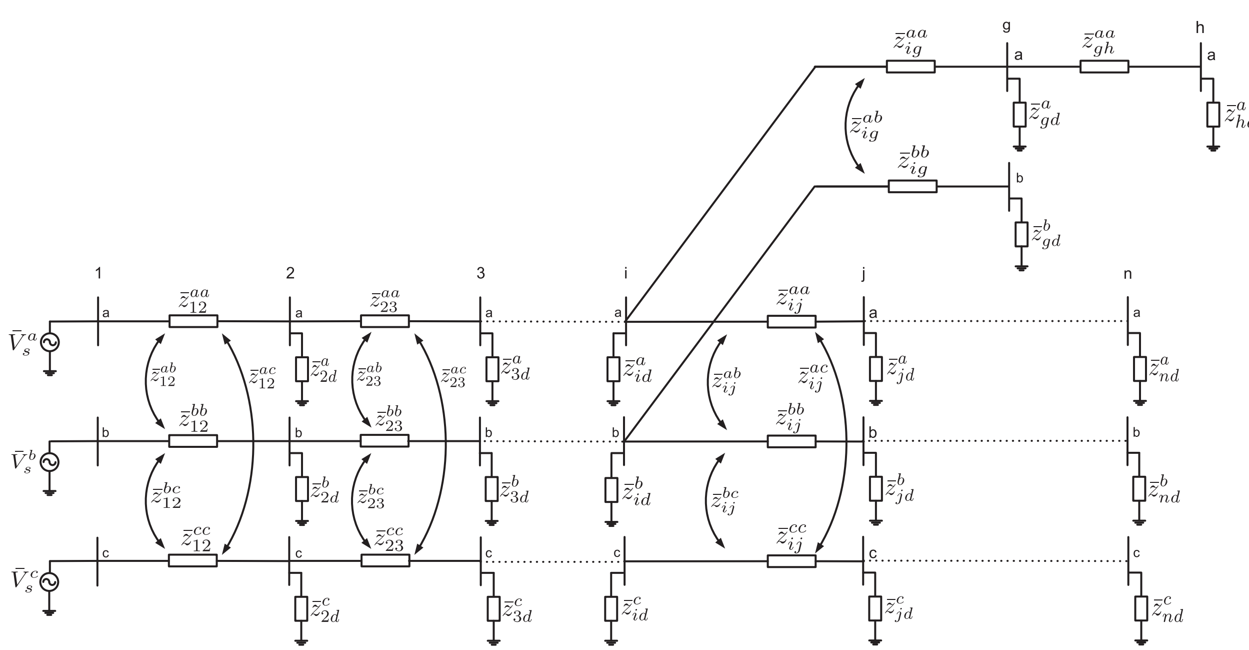

Fig. 1. An n-bus unbalanced radial distribution system.