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Performance evaluation of traction and utility network interface: Fault location and protection coordination

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ABSTRACT

Single phase AC traction systems pose unique challenges to power utilities at interface points of connection on the power delivery network. Traction systems are usually supplied from dedicated utility networks in order to minimise the negative effects that traction loads have on conventional three phase loads, particularly in instances where customer equipment may be sensitive to the quality of supply. The electric utility's power network is exposed to faults, short duration thermal overloads, temporary overvoltages, high magnitude transient recovery voltages, load unbalance and harmonics which emanate from the traction system. This research investigation evaluates and analyses Eskom's network and Transnet Freight Rail's network and presents a methodology for determining fault location and effective discrimination between electric utility and traction network faults. This is essential where there is a lack of protection coordination or difficulty in achieving coordination between the protective devices in each system. The method is further developed into a protection coordination philosophy to ensure that the utility's protection relays operate for utility network faults only, while the traction system relays operate for faults within the traction networks. The balance of this paper assesses the withstand capability of network equipment against temporary overvoltage caused by single phasing on the utility system; a performance evaluation of high magnitude transient recovery voltage following network faults, and determination of the minimum technical specification of equipment on the system. Results obtained and proposed solutions to minimise the levels of overvoltage for both the temporary and transient cases are presented and discussed.

1. Introduction

The network under is the electrical power supply to a freight rail company responsible for transporting coal from mines located in the central regions in South Africa to a port on the south eastern part of the country for export. The transportation of coal is a continuous operation where maintenance under dead conditions on the electrical systems of both the freight company and the utility company, is carried out once a year for a period of a week. Minor maintenance is usually carried out under live conditions to maximise the throughput of coal. Since coal is a vital export commodity generating billions in foreign exchange earnings for South Africa, it is imperative that the electric power network enabling the export, is both secure and operates at optimal availability [1].

Fig. 1 shows the interface of networks. The 25 kV traction system, owned and operated by Transnet is approximately 580-km in length and consists of double lines which are bi-directionally signalled. Eskom, the electric power utility provides 3 phase supply at 88 kV to Transnet over the expanse of the rail network. This is consumed at 33 individual substations consisting of 88/25 kV dual phase transformation with earth return on the substation secondary. Electric power is injected into the utility company's 88 kV network at 5 source points. The 88 kV feeders are run in closed loop between the source injections to improve the voltage regulation of the supply.

The 25 kV catenary line made up of numerous track sections is supplied electric power from alternate phases of the 88 kV 3-phase electric utility network. This configuration minimises network unbalance and associated voltage regulation in the overall system [2]. The phasing of the various stations is shown in Fig. 1 by means of phase colours (red, white and blue). For example, a track section supplied electric power from the red and white phases with substations feeding that section is denoted as "R-W".

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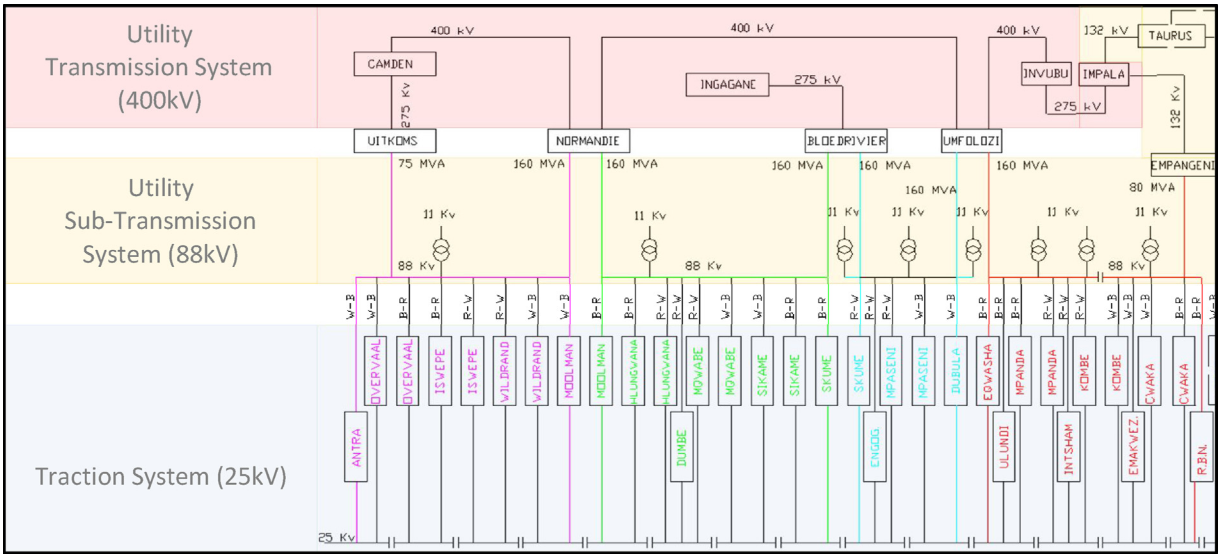

Fig. 1. Single line diagram of the traction and utility network interface [3]. (For interpretation of the references to colour in the text, the reader is referred to the web version of this article.)

2. Electric faults on the interface network

Electrical power networks are susceptible to faults, which may arise from environmental factors such as: storms, hardware malfunction, natural ageing of equipment or as a result of equipment being operationally overstressed. For the coal corridor [1] under consideration, a few hours downtime could lead to losses amounting to millions of dollars, hence it is of critical importance to locate, isolate and repair faulted sections as quickly as possible so that the system is restored. Due to poor protection co-ordination and grading between the utility and traction' company networks, situations arise where utility's feeders may trip for traction system faults. This leads to unnecessary line patrols and investigations by the utility company field staff. The time to restore the system can be extensive as no fault will be found on the utility system. Only by liaising with the traction company to isolate 25 kV track sections in a systematic manner and by repeated closing of 88 kV injections, can faults be narrowed down and ultimately isolated.

This inefficient practice instigated this research investigation. While it is easy to deduce that trips with indications of 3-phase or single-phase-to-ground faults can only emanate from the 88 kV system, single-phase-to-ground faults on the 25 kV traction network are also seen by the utility company's protection relays as phase-to-phase faults on the 88 kV line. This creates ambiguity with regards to fault location. Figs. 2 and 3 show typical results of fault current contributions from the utility company source injection for simulated faults applied to the 25 kV and 88 kV bus for a traction substation respectively.

Fig. 2 shows that a phase to ground fault applied on the traction single phase system, has fault current contributions from 2 phases that are 180° apart. This is not different from a phase to phase fault applied on the 3-phase utility system with one exception, the magnitude of fault current contribution. The 25 kV phase to ground fault has less contribution from the source as a result of the added impedance across the dual phase traction transformers.

Various methods of fault detection and protection relaying have been developed [4–8], with valuable transmission line protection support tools [9]. Subramani [10] compares some fault investigation methods in power systems, while Chen et al. [11] provides a comprehensive review on the methods for fault detection, classification and location in transmission lines and distributions networks. Conti [12], Conti and Nicotra [13] presents an analysis of these protection issues in the presence of dispersed generation as well as isolation to solve protection selectivity problems in medium voltage distribution networks. Chaiwan et al. [14] presents a fault location algorithm for parallel transmission lines based on the distributed parameter line model but independent of fault resistance. For long lines, it is known that the conventional fault impedance-based fault location methods may fail to correctly identify the fault point even when the line shunt capacitance effect is taken into account [15].

Yusuff et al. [16] proposed a line fault location scheme, combining stationary wavelet transform (SWT), determinant function feature (DFF), support vector machine (SVM) and support vector regression (SVR) based on the fault impedance and fault inception angles. Rafina and Jamal [17] developed a fault classification and location technique using advanced signal processing technique based on wavelet analysis to extract valuable information, and employ artificial intelligence tools to detect the type and location of the ground impedance in underground networks. Kawady and Stenzel [18] and Ban and Prikier [19] investigated the impact of various fault-locating error sources on a limited number of algorithms. Magnago and Abur [20], Robertson et al. [21], Sajedi et al. [22], Das et al. [23] and Salim et al. [24] are excellent resources for impedance-based fault location algorithms. The discussion in Ref. [20] is limited to one-ended methods, while [21] does not encompass all the impedance-based fault location algorithms described in the IEEE C37.114 Standard [25].

The lack of fault indications received at the utility company SCADA system further compounds fault identification and location. Following a utility trip between two 88 kV source injections, the common practice is first to completely strip the 25 kV traction system between the two sources, before attempting to reclose 88 kV sources [26]. If closing the 88 kV sources is successful, the systematic closing of the various 25 kV traction substations is practiced to locate faults. However, if upon stripping the 25 kV system, the 88 kV power source re-closure results in tripping, then the fault persists somewhere on the 88 kV system which only becomes restored once the fault has been located and repaired. Very often, faults are transient in nature and after the various control actions to isolate portions of network to locate the fault are performed, no fault may be detected. Thus, poor network visibility and understanding of