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Experimental results and technique evaluation based on alienation coefficients for busbar protection scheme

R. Abd Allah *

Buraydah Colleges, Faculty of Engineering, Electrical Power Department, Qassim Region, Saudi Arabia

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ABSTRACT

In modern digital power protection systems, statistical coefficients technique is recently used for fault analysis. An alienation technique is developed for busbar protection against all ten types of shunt faults, which may locate in busbar protection zone, under different loading levels, fault resistances and fault inception angle. It does not need any extra equipment as it depends only on the three-line currents measurements, of all feeders connected to the protected busbar, which are mostly available at the relay location. It is able to perform fault detection, fault confirmation, faulty phase selection and determine the fault location in about a half-cycle period. Thus, the alienation technique is well suited for implementation in digital protection schemes. The technique is efficient to detect current transformer saturation conditions without needing any additional algorithm. The effects of DC components and harmonics are eliminated with estimation of alienation coefficients. The proposed scheme is applied for an experimental circuit. LABVIEW program and MATLAB package are used to implement the proposed technique.

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Introduction

A busbar is a critical element of a power system, as it is the point of convergence of many circuits, transmission, generation, or loads. The effect of a single bus fault is equivalent to many simultaneous faults and usually, due to the concentration of supply circuits, involves high current magnitudes. High-speed busbar protection is often required to limit the damaging effects on equipment and system stability or to maintain service to as much load as possible. Differential protection is the most sensitive and reliable method for protecting a station buses. The phasor summation of all the measured current entering and leaving the bus must be zero unless there is a fault within the protective zone. For a fault not in the protective zone, the faulted circuit is energized at a much higher level, near CT saturation or with varying degrees of CT saturation, giving rise to possible high false differential currents. Under ideal conditions, the secondary current developed by CT will be the primary current divided by the CT turns ratio. However, the CT secondary current will not be a sine wave when the flux in the CT core reaches into the saturated region. The factors affecting this are secondary burden, primary current magnitude, asymmetry in the primary current, remanent flux in the CT core, saturation voltage, fault inception angle and CT turns ratio [1]. Actually, the DC component has far more influence in producing severe saturation than the AC fault current. Direct current saturation is particularly significant in bus differential relaying systems, where highly differing currents flow to an external fault through the current transformers of the various circuits. Dissimilar saturation in any differential scheme will produce operating current. The problem of CT saturation is not popular in case of an internal fault conditions. Severe current transformer saturation will occur if the primary circuit DC time constant is sufficiently long and the DC component sufficiently high. The DC component arises because the current in an inductance cannot change instantaneously and the steady-state current, before and after a change, must lag (or lead) the voltage by the proper power-factor angle. Many methods are used to avoid the CT saturation. The problem of CT saturation is eliminated by air-core CT's called "linear couplers". In fact, these CT's have a disadvantage that very little current can be drawn from the secondary, because so much of the primary magneto-motive force is consumed in magnetizing the core. Another method is used to increase the size of the CT core to obtain a higher saturation voltage than a calculated value [2]. Another one uses special core material to withstand large flux density [3]. These options present mechanical and economic difficulties. Recently, many software techniques are provided to solve these problems and each method has its advantage and disadvantage. Some techniques uses a DC component equal and opposite to that in the primary circuit generated by a circuit added to the

* Tel.: +966 553851628.
E-mail address: Mohandes_ragab@yahoo.com

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secondary winding [4]. Other techniques used a magnetization curve and the equivalent circuit of a CT for compensating secondary current of CT during saturation condition; these techniques has practical difficulties, as it depends on CT parameters/characteristics and secondary burdens [5]. Also, Artificial Neural Networks (ANNs) are used in this area to learn the nonlinear characteristics of CT magnetization and restructures the waveform based on the learned characteristics. This method could not be applied to different CT's due to the variations of CT's saturation characteristics and the secondary burdens [6]. Some other algorithms prevent relay operation during CT saturation [7]. This may result in longer trip times. A method for compensating the secondary current of CT's is based on the ideal proportional transient secondary fault current. A portion of measured secondary current following the fault occurrence is described using regression analysis [8]. Another method utilizes four consequent samples, during the unsaturated portion of each cycle, for solving a set of equations to obtain the constants of the primary fault current equation for re-constructing the secondary current during the saturated part. The scheme calculates the correct primary time constant by repeating the calculations of the algorithm using different values of time constant and chooses the value that gives the smallest error [9]. A digital technique for protecting busbars presented in [10] uses positive- and negative-sequence models of the power system in a fault-detection algorithm. While phase voltages and currents are used to detect faults, parameters of the power system are not used. Another method called current phase comparison is presented in [11], which can achieve reliable busbar protection with minimum CT performance requirements. Thousands of RTDS test and MATLAB analyses have been performed, which proved that the stability of busbar protection can be greatly improved by this algorithm. The presented principle in paper [12] describes a methodology for protecting busbars. The method uses the ratio between the fault component voltage and the fault component differential current of the busbar to detect faults, which is defined as the fault component integrated impedance. The fault component integrated impedance of an external fault reflects the capacitance impedance of the busbar whereas that of an internal fault reflects the parallel connection result of the impedances of all the feeders connected to the busbar. As a result, the magnitudes of the integrated impedances are quite different between an external fault and an internal fault. A model parameter identification based bus-bar protection principle is proposed in paper [13]. An inductance model can be developed when an internal fault occurs on bus. By taking the inductance and the resistance of the model as the unknown parameters to be identified, the equivalent instantaneous impedance and the dispersion of the parameter can be calculated. Utilizing their difference, the external fault and the internal fault with different current transformer (CT) saturation extent can be distinguished. Through-out this work a new technique for busbar protection based on alienation coefficients is suggested. The technique measures the three-line currents of each circuit connected to the protected busbar, which are mostly available at the relay location. The alienation coefficient is calculated between input and output currents of each phase for busbar in order to make relay trip or no trip decision. The suggested technique takes into consideration the wide variations of operating conditions such as loading levels, fault resistance and fault inception angle.

Proposed technique

Basic principles

In this paper, LABVIEW software [14] is used to get reliable experimental results before, during and after different fault conditions which are located in and out the protective zone of busbar. Three-phase current signals of each circuit, connected to the busbar, are obtained and converted to discrete sampled form by data acquisition card. These current samples of each phase are processed online in MATLAB script (inserted in LABVIEW package) to get an alienation coefficient [15,16]. The coefficient is estimated between the input and output phase current signals of the busbar. The suggested technique is based on alienation concept in order to determine busbar fault type whether internal or external to make relay trip or no trip decision, respectively. The calculations of the alienation coefficients are processed for each two corresponding half-cycles of the two currents to get high-speed operation for busbar protection.

Alienation coefficients calculation

The variance between any two signals is defined as the alienation coefficient [17–19], which is obtained from correlation coefficient; thus alienation coefficient is a good proposed technique for making busbar protection against different fault conditions located on the busbar element. Alienation coefficient calculated between the two phase currents entering and leaving the bus can recognize a variance between them and to operate in response to it. This coefficient is derived from cross-correlation coefficient. Cross-correlation coefficient (r_a) is calculated between each two corresponding windows of the two sampled currents (i_{a1} and i_{a2}) entering and leaving the phase "*A*" bus, where the two windows are shifted from each other with a time interval $h\Delta t$. The coefficient (r_a) between the two signals (i_{a1} and i_{a2}) is given by Eq. (1). Our proposed technique uses the two signals shifted from each other when the time interval $h\Delta t = 0$, where $h = 0$. Also cross-correlation coefficients (r_b *and* r_c) are given by Eqs. (2) and (3), respectively.

$$r_a = \frac{\sum_{k=1}^{m} i_{al}(k) i_{a2}(k+h\Delta t) - \frac{1}{m}\sum_{k=1}^{m} i_{a1}(k)\sum_{k=1}^{m} i_{a2}(k+h\Delta t)}{\left(\sqrt{\sum_{k=1}^{m}(i_{a1}(k))^2 - \frac{1}{m}\left(\sum_{k=1}^{m} i_{a1}k\right)^2}\right) \times \left(\sqrt{\sum_{k=1}^{m}(i_{a2}(k+h\Delta t))^2 - \frac{1}{m}\left(\sum_{k=1}^{m} i_{a2}(k+h\Delta t)\right)^2}\right)} \tag{1}$$

$$r_b = \frac{\sum_{k=1}^{m} i_{b1}(k) i_{b2}(k+h\Delta t) - \frac{1}{m}\sum_{k=1}^{m} i_{b1}(k)\sum_{k=1}^{m} i_{b2}(k+h\Delta t)}{\left(\sqrt{\sum_{k=1}^{m}(i_{b1}(k))^2 - \frac{1}{m}\left(\sum_{k=1}^{m} i_{b1}k\right)^2}\right) \times \left(\sqrt{\sum_{k=1}^{m}(i_{b2}(k+h\Delta t))^2 - \frac{1}{m}\left(\sum_{k=1}^{m} i_{b2}(k+h\Delta t)\right)^2}\right)} \tag{2}$$

$$r_c = \frac{\sum_{k=1}^{m} i_{c1}(k) i_{c2}(k+h\Delta t) - \frac{1}{m}\sum_{k=1}^{m} i_{c1}(k)\sum_{k=1}^{m} i_{c2}(k+h\Delta t)}{\left(\sqrt{\sum_{k=1}^{m}(i_{c1}(k))^2 - \frac{1}{m}\left(\sum_{k=1}^{m} i_{c1}k\right)^2}\right) \times \left(\sqrt{\sum_{k=1}^{m}(i_{c2}(k+h\Delta t))^2 - \frac{1}{m}\left(\sum_{k=1}^{m} i_{c2}(k+h\Delta t)\right)^2}\right)} \tag{3}$$

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