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Wide area measurement based protection support during power swing

Pratim Kundu *, Ashok Kumar Pradhan

Department of Electrical Engineering, Indian Institute of Technology Kharagpur, India

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ABSTRACT

Oscillation in power system occurs following fault, tripping of generator or load change. Such oscillation causes relay maloperation which may further lead to cascade tripping. This paper proposes a method to prevent maloperation of relays during power swing condition using wide area measurements system (WAMS). Features derived from WAMS data are used for assessing power swing condition to help network protection decision. It classifies a power swing according to its severity and its effect on the operation of relays in the system. Integration of information obtained from the features using fuzzy logic based algorithm is applied to derive the decision. Relaying strategy in the system can be adjusted depending on the state of the area (safe, alert, high-alert and unstable). The performance of the algorithm is tested on an Indian power system.

Introduction

With continuously increasing power demand and evolution of power industry restructuring, power systems now-a-days operate more often closer to their stability limits. During steady state, a balance is maintained between generation and load. However, unexpected events, such as fault and loss of large load, disrupt the balance and give rise to electromechanical oscillation known as power swing [1]. Severe power swing, at times, leads to loss of synchronism between a generator and the rest of the utility system, referred to as out-of-step (OST) condition. All cases of power swing are not so severe; most of them result in impedance seen by distance relay entering into its operating zone and cause undesired line tripping. Most of the major disturbances that have occurred in the recent past are mainly due to relay maloperation [2]. Recent blackouts in India in July 2012 occurred as a result of zone 3 relay maloperation due to load encroachment which led to the collapse of a major part of the Indian grid [3]. The report states that the situation could have been avoided if proper blocking signals were issued or corrective actions were taken after the maloperation. System instability prediction algorithm [4,5] is used to predict loss of stability which can be employed for the safeguard of the power system. System disintegration can be averted if the relays are blocked during a stable event and trip signal issued for areas under the threat of instability.

To block relay operation during power swing, conventional method such as blinders or mho relay [6,7] scheme uses local voltage and current values and has limited performance during fast swing condition. Application of training based methods such as decision tree [8], neural network technique [9] and wavelet based methods [10] for blocking relay during swing becomes difficult to realize with increased complexity of the system. Rotor angle difference is the common criterion for assessing system stability during power swing [4,8,11,12]. In [13] controlled islanding operation is determined using rotor angle criteria, [14] uses a search algorithm based on load generation balance and line overloading criteria to determine islanding operation. Coherency based generator rescheduling for preventing transient stability is proposed in [15]. Techniques such as apparent impedance [16], energy function [17], and equal area criterion [18] are also available for evaluating effect of various disturbances in a system for real-time application. These methods mainly deal with assessment of system stability in post disturbance period. It does not provide any support to relay decisions to avoid maloperations during disturbances in the system. The r-rdot technique used to support relay decisions [6] uses the fact that the apparent resistance becomes small when the phase angle across an intertie is large to support relay decisions during severe power swings. But it cannot cope for more severe instability situation with very fast power swing.

A comprehensive decision logic for supporting relay decision during power swing can check maloperation and prevent escalation of disturbance in the system. Special protection scheme (SPS) and remedial action scheme (RAS) are response based approaches to prevent cascade failure of power system [19]. Blocking distance relay during swing and separation of the system into

* Corresponding author. Tel.: +91 3222 283098.
E-mail addresses: pratimkundu.ee@iitkgp.ac.in (P. Kundu), akpradhan@ee.iitkgp.ernet.in (A.K. Pradhan).

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intentional islands in response to an impending instability can be listed under SPS or RAS [8,20]. With recent advancement in wide area measurement, system detection of system disturbance and initiation of corrective/preventive strategy with system condition are feasible [13,21–23]. Phasor measurement unit (PMU) placed at various locations in the system provide voltage and current phasors which aid in monitoring system condition and deriving necessary action for maintaining integrity of the system [12,24]. PMU data is used for protection applications such as adaptive relaying [22], fault location [25] and backup schemes [21]. An online dynamic security assessment scheme for large-scale interconnected power systems using phasor measurements and decision tree is proposed in [13]. But these methods do not provide support to relays to prevent maloperation during power swing conditions.

Conventional relay decision logics are mainly based on the local area information available at the connection point. During an ongoing disturbance, due to variation in voltage–current signals at different buses, such relay logics find limitations. This paper proposes a fuzzy logic based integration of features extracted from WAMS data to classify power swing condition which is applied for relay operation in a system. Fuzzy logic is an important mathematical technique which is used for handling uncertainty in data [26]. A fuzzy logic based technique for improving power system stability by damping low frequency oscillation is proposed in [27]. In [28] determination of the nature of the fault by processing the symmetrical fault current components applying fuzzy logic is presented. A fuzzy rule based fault classification for series compensated line is done in [29]. In this work, four indices specially derived from PMU data are used to assess the dynamic system condition. During a disturbance, all the variables namely angle, voltage and frequency in a system undergo changes [30]. Indices obtained from such variables can be resourceful to evaluate the effect of a disturbance. Information obtained from a single feature is not sufficient to assess a power swing condition. Fuzzy logic is used to integrate all the features to derive a decision. Each area in the system classified in accordance with its response to the disturbance. This classification aids in deriving correct relay operation during power swing. The output provides signal to prevent maloperation of relay and to command specific relay to segregate an area from the system during out-of-step condition. An Eastern India system is used to validate the proposed method. Results show the accuracy of the method in supporting relay decision during power swing.

Wide area severity indices

Rotor angle based prediction of loss of synchronism between two areas can be derived when the angle difference between them exceeds a predefined threshold [1]. When the technique is applied for assessment of a disturbance and predicting its behavior, this criterion has limitation as it offers little preemption time. There are other criteria derived from various power system quantities to address stability of the system [31,32]. Assessment for all conditions of power system based on a single criterion is not possible. To address this problem, a combination of different indices is desired. In this work, four indices derived from angle, frequency, voltage and damping information are used to estimate the system condition for use in protection decision.

Angular deviation referred to Center of Inertia (COI): f1

The COI based rotor angle disturbance provides a robust index to observe the state of synchronism between the areas during a disturbance. At normal condition, a generator in a power system operates at a fixed angular difference with respect to a reference [1]. During a power swing, the angular differences among the generators start oscillating with respect to the reference. The COI reference for the system is defined as [24]:

$$\theta^{COI} = \frac{\sum_{i=1}^{n} H_i \theta_i}{\sum_{i=1}^{n} H_i} \tag{1}$$

where n = number of areas, H_i = equivalent moment of inertia of i^{th} area,

θ_i = equivalent angle of ith area.

Each area in a power grid is associated with an equivalent inertia for the combined generation of that area. For each area, the area angle is the average angle through all measurements: $\theta_i = \frac{1}{N_i}\sum_{m=1}^{N_i}\theta_m$ where N_i = number of measurements in ith area.

The angle of each area, calculated from voltage phasor data, is expressed in the COI reference frame as:

$$\theta_i^{COI} = \theta_i - \theta^{COI} \tag{2}$$

Corresponding index for ith area is defined as:

$$COI\_index_i = \theta^{COI}_{i_{prefault}} - \theta^{COI}_{i_{postfault}} \tag{3}$$

COI_index provides a good indication of the level of stress over a part of the system induced by the contingency. The index is calculated for all areas and a high value of the index shows that the impact of the disturbance is severe in that area.

Frequency based power imbalance index: f2

Power system frequency is dependent on the real power balance of the system. Following a major disturbance in a large system, there can be generation-load mismatch resulting in severe frequency excursions which degrade load performance, overload transmission lines and lead to system collapse. Thus, system frequency provides useful information regarding system generation and load imbalance. For a single machine system, the overall generator-load dynamic relationship between the incremental mismatch power $(\Delta p = \Delta p_m - \Delta p_l)$ and the frequency deviation (Δf) can be expressed by a simplified frequency response model [30]:

$$\Delta p = 2H\frac{d(\Delta f(t))}{dt} + D(\Delta f(t)) \tag{4}$$

where Δf is the frequency deviation, Δp_m be the mechanical power change, Δp_l be the load change, H the inertia constant and D the damping coefficient of load in the system. The disturbance power Δp for a case can be approximated as:

$$\Delta p = 2H\frac{\frac{d(\Delta f(t))}{dt}}{f_n} \tag{5}$$

where f_n = rated frequency, 50 Hz in this case.

For a multi-machine system, the dynamic behavior can be modeled as a single machine equivalent system connected to an infinite bus using following definition.

System frequency deviation f_{sys}:

$$f_{sys} = \frac{\sum_{i=1}^{n} H_i f_i}{\sum_{i=1}^{n} H_i} \tag{6}$$

The disturbance power for a multi-machine system becomes,

$$\Delta P = \sum_{i=1}^{n} \Delta p_i = \sum_{i=1}^{n} \frac{2H_i \frac{df_{sys}}{dt}}{f_n} \tag{7}$$

During a disturbance, the value of ΔP is calculated using (7) with PMU data received from each area. When the index repeatedly exceeds a threshold value within a period of time, then the system is assumed to be under severe threat. The threshold is decided based on the mismatch of power which leads to change in frequency of a system by a preset value. The change in this case is