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DT based intelligent predictor for out of step condition of generator by using PMU data

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ABSTRACT

Rotor angle instability of synchronous generators following large disturbances is regarded as a major threat for system dynamic security. Fast detection of out of step condition and disconnection of unstable generator is a vital requirement for avoiding any mechanical and thermal damage to the generator. In this paper, for early prediction of out of step condition of an unstable generator, a three stage decision tree based approach consisting of Fault Detector DT (FDDT), Clearance Detector DT (CDDT) and Instability Predictor DT (IPDT) is presented. The proposed approach by using a moving time window consisting of on line sampling vector data acquired by PMU, at the first and second stages detects the occurrence and clearance of the fault by FDDT and CDDT respectively. Then at the third stage IPDT will be activated for predicting out of step condition. The input data to each DT is a moving time window consisting of six consecutive sampling vector data. The nature of data used for FDDT and CDDT are electrical variables while the data used for IPDT is post fault mechanical variables of generator like angle, speed and acceleration of rotor. The proposed algorithm can be used as an out of step relay which could be trained and designed for each specific generator with respect to any fault or abnormal condition which threat generator stability. The proposed algorithm is demonstrated on generators of IEEE 39bus test system with promising result.

1. Introduction

Rotor angle instability of synchronous generators following large disturbances is regarded as a major threat for system dynamic security. In the case of transient instability, generator experiences out of step condition which can cause mechanical and thermal damages for it. In order to avoid any damage to unstable generator, it should be disconnected from the network as soon as the out of step condition is recognized. Therefore, fast recognition and detection of out of step condition for an unstable generator is a vital requirement for its safety. For this purpose, all synchronous generators are equipped with an out of step relay which is responsible for detection of out of step condition and quick disconnection of the generator from the grid. In this regards, early prediction of generator instability is very essential for which utilizing new intelligent techniques such as SVM, ANN and DT can improve the prediction ability compared to analytical methods.

Regarding generator protection against instability condition, the literatures can be categorized into two fields namely detection and prediction of out of step condition for a generator. Assessment, detection and prediction of transient angle stability have drawn considerable attentions for several years in the literature and industry [1]. In [2], an energy based evaluation method is used to determine stability region of generator based on the power system post-fault data. In [3], fuzzy logic theory is used for developing a protection scheme to recognize out-of-step condition for generators. In [4], by improving Prony analysis method and based on the application of rotor angle measurement, an algorithm is proposed for online monitoring and predicting out-of-step condition of the interconnected power systems. In [5], for transient instability detection, a scheme based on recurrent radial basis function (RBF) and multilayer perceptron (MLP) artificial neural networks is proposed in which by predicting generators' angles and angular velocities, transient stability can be assessed. In [6], the application of a learning-based nonlinear classifier, the support vector machine (SVM) for transient instability detection of a real power system with high dimensionality is presented. In [7], based on the voltage and current measurements in a line, for online detection of loss of synchronism an approach is presented in which the instability conditions are derived from energy function analysis. In [8], for rapid stability assessment, fuzzy rule-based classifiers is proposed which in real time operation works based on the wide-area response signals captured from strategic monitoring buses. In [9], for detecting inter-area instability, a decision tree based approach is proposed in which by means of wide area data

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including voltage and angle measurements acquired by PMU, the unstable condition can be detected. In [10], based on the wide area measurements, a fast and accurate real time detection algorithm for transient instability is presented in which trajectory characteristic and transient energy are synthesized to improve the detection accuracy. In [11], by using phasor measurements and decision trees for large-scale interconnected power systems an online dynamic security assessment scheme is proposed in which by using real-time measurements, DTs provide online security assessment and preventive control guidelines. In [12], critical clearing time (CCT) and transient stability time margin (TM) are used as criterions for transient stability assessment and two multi-layered perceptron (MLP) neural networks (NN) is proposed for assessing stability status of generator by estimating CCT and MT with respect to a specific contingency. In [13], for estimating transient stability status of a generator with respect to a particular contingency, a normalized power system transient stability margin is proposed which is estimated by a multi-layered perceptron (MLP) neural network. The proposed NN uses pre-fault operational data to estimate stability status of the generator. In [14], a binary support vector machine (SVM) classifier is used to predict stability status of a generator based on dynamic generator trajectories of rotor angle, speed, voltage, electromagnetic power and imbalance power. In [15], a real time clustering identification-predicting algorithm without relying on the prior knowledge of the network model is developed in which by classifying generators into coherent groups the unstable group can be detected. In [16], for online monitoring of rotor angle stability, by using PMU data and based on the Lyapunov exponents a technique is proposed for determining power swing leading to system instability. In [17], based upon the autoregressive model (AR model) a new out-of-step prediction logic which is a kind of time-series analysis is proposed in which by using the phase difference of the voltage between substations as input data the oscillation after the clearance of a severe fault is modeled using the mth-order of the AR model. In [18], for predicting transient instability status of power system following a disturbance, a hybrid classifier is proposed in which by using relative rotor angles of the generators in the COI framework a new synchronism status index is constructed as input data for classifier. In [19], based on the trajectories of synchronously measured post-disturbance bus voltage magnitudes following a large disturbance, a predictor for angular instability is proposed. In [20], by using the post-fault voltage variations measured at the high voltage generation buses of a multi-machine power system and based on the SVM classifier a technique for predicting the transient stability status after a fault is proposed in which the algorithm is triggered by the voltage dip due to a fault. In [21], an intelligent wide area synchrophasor based system (IWAS) incorporating artificial neural networks (ANN) is proposed for real time predicting and mitigating transient instabilities. In [22], by using an adaptive artificial neural network, a predictor for rotor angle instability of generator under contingency is proposed. In [23], for predicting out-of-step of synchronous generators a decision tree based method is proposed which is able to distinguish between stable and out-of-step conditions based on the input features measured at the relay location well before the instant of out-of-step. In [24], for predicting out-of-step condition of generator by using rotor speed–acceleration data obtained from PMU measurements and based on the rate of change of speed–acceleration a new algorithm is proposed. All proposed methods mainly rely on post fault data based on the assumption that fault occurrence and clearance have been already detected. Some methods only predict instability for group of machines rather than an individual unit and their performance with respect to noise, bad data, change in network configuration and unsymmetrical fault remain questionable.

In this paper, for early prediction of out of step condition of an unstable generator, an intelligent out of step predictor scheme consisting of a Fault Detector DT (FDDT), a clearance detector DT (CDDT) and an Instability Predictor DT (IPDT) is presented. In the proposed scheme, by using on line local data acquired by PMU at the terminal of the generator under protection, at the first and second stages, FDDT and CDDT detect the occurrence and clearance of the fault respectively and finally, at the third stage, IPDT predicts out of step condition of the generator. The input vector data for all DTs is a moving time window consisting of a number of sampling vector data (SVD) which are measured in consecutive time steps. Each sampling vector data may include active power, reactive power, voltage magnitude, voltage phase angle, current phase angle and speed and rotor angle of the generator. In this approach, by using electrical operating data of the generator the occurrence and clearance of the fault are first recognized based which IPDT predicts out of step status of the generator using post fault electromechanical oscillation data.

2. Overview of the proposed approach

In this paper, for predicting out of step condition of a specific generator, an intelligent predictor consisting of three stages of decision tree is proposed in which the occurrence and clearance of fault are detected and then instability of generator is predicted using post fault local data of the generator oscillation. The main philosophy behind the proposed approach is based on this fact that the instability trend of a generator can be identified from its transient behavior at the post fault condition. It is worth noting that based on the dynamic characteristic of a generator its stability feature is mainly reflected in its post-fault behavior by which generator behavior starts to discriminate between stable and unstable conditions. In other words, post fault electromechanical behavior of the generator contains rich information about the nature of its stability which can be used for predicting unstable status. This fact is illustrated in Fig. 1 which shows typical trend of generator rotor angle behaviors with respect to a fault with the associated critical clearing time equal to CCT = 317 ms. In this figure, the rotor angle variation for four scenarios including two stable scenarios (t_{clear1} = 310 ms < CCT, t_{clear2} = 315 ms < CCT) and two unstable scenarios (t_{clear3} = 320 ms > CCT, t_{clear4} = 325 ms > CCT) are investigated. As it can be seen until the time of fault clearance the variation of generator rotor angle for stable and unstable scenarios are relatively similar with very low discrimination. However, after fault clearance, generator rotor angle starts to differentiate between stable and unstable scenarios with high discrimination which makes it more suitable for discriminating and recognizing unstable cases from stable cases. It is worth noting that most of the previous works are based on this assumption that fault occurrence and clearance have been recognized by the generator and instability predictor starts to work using post-fault generator data. However, it is obvious that in real time operational environment, the occurrence and clearance of all faults affecting generator stability cannot be recognized by the local protection of generator. For example, the occurrence and clearance of the faults occurring out of the protection zone of generator cannot be informed to the generator for activating the intelligent out of step relay which should work based on the post fault data. Therefore, for an intelligent

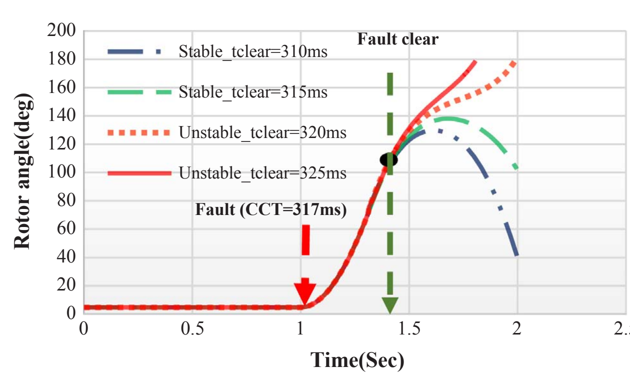

Fig. 1. Rotor angle variation for different stable and unstable scenarios.