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Online emergency damping controller to suppress power system inter-area oscillation using load-generation tripping

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ABSTRACT

Emergency damping controller (EDC) is regarded as the final defense against inter-area oscillation for preventing power system splitting into islands. EDC can be applied in power systems based on the utilization of different strategies. In this paper, a new strategy of EDC based on the utilization of emergency action of load-generation tripping is proposed for damping inter-area oscillation. In this approach, by using correlation characteristic of buses phase angle, coherent groups of generators which are the source of inter-area oscillation are identified. In order to detect an emergency situation for power system dynamic which dictates application of EDC, a new index denoted as system brittleness index (SBI) is proposed. The system brittleness index can be evaluated based on the online data measured by WAMS at the consecutive time intervals. By tracing the trend of SBI variation, it is possible to predict system potential for splitting into uncontrolled islands. Once the trend of SBI alarms an emergency condition, it will be imperative to apply EDC strategy. In order to effectively utilize the emergency action of load-generation tripping as an EDC strategy, based on the inertia and damping coefficient of oscillating groups of generators, a new damping index (DI) is proposed. By evaluating the damping indices for two oscillating areas, they can be verified as low damping and high damping areas. Based on the damping criterion, the direction of increase in power exchange between two areas should be from low damping (sending area) to high damping area (receiving area). Therefore, it means that in the high damping and low damping areas, generation tripping and load tripping should be applied respectively. In the receiving area, the location of generation tripping is determined based on the mode shape characteristic of inter-area mode with respect to generators speed. Also, the sensitivity of the inter-area mode with respect to active power of load buses is employed as criterion for determining the location of load tripping in the sending area. The proposed approach has been examined on the IEEE 39-bus test system and Iran power system as a realistic large scale power system with promising results.

1. Introduction

Inter-area oscillations typically ranging from 0.1 to 1 Hz is inherent to power systems and considered as a serious concern for secure operation of power systems. Inter-area oscillations can be caused when two coherent groups of generators with weak connection start to oscillate against each other. These oscillations usually are excited by events such as random variation of load demand, fault or network switching. As electrical power systems are being operated closer to their limits, poorly damped oscillations can pose various problems such as limiting transfer capacities and in more severe cases with negative damping these oscillations may propel the power system toward uncontrolled islanding causing a wide-scale blackout [1] such as the 10 August 1996 western blackout [2]. Power system experiences with respect to inter-area oscillations give us a lesson that effective measures of emergency control to damp inter-area oscillations should be implemented when sever oscillations occurred [3]. Damping inter-area oscillations is one of the major challenges to the electric power system operators. The conventional method to deal with inter-area oscillations problem is to add damping controllers, such as Power System Stabilizers (PSS), HVDC and FACTS modulation controls. These devices indeed provide effective long-term solutions and have been widely used [4]. These damping controllers which conventionally use the local signals as feedback inputs have limitation for improving damping of some inter-area modes due to the lack of the observability of the inter-area mode from the local signals [5]. Basically, the damping

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control methods for inter-area oscillations can be classified into the following two general categories [6].

1. Device based methods using controlling equipments such as Power System Stabilizers (PSSs) and Flexible AC Transmission Systems (FACTS) devices.
2. Operation based methods changing system operating conditions such as generation rescheduling (GR), load shedding (LS) and changing network structure.

In [7], by proper adjustment of the PSSs and reactive power compensators, increasing the damping ratio of inter-area modes in the Iranian interconnected power system were obtained which resulted in the improvement of stability and effective reduction in amplitude of power oscillations. In [8], a detailed analysis of low-frequency inter-area oscillations of the South China interconnected power system based on the eigen analysis, participation factors and mode shape of the generators is presented in which by optimum allocations and parameter setting of PSS besides HVDC small signal modulation, the inter-area oscillation are improved. In [5], by introducing the delay margin as an additional performance index and combining it with conventional design techniques to deal with communication delays, a systematic approach for designing a Wide Area Damping Controller is introduced which applied to the design of a WADC for FACTS devices in a multi-machine power system. The application of multiple WAMS-based HVDC and FACTS wide-area stabilizing controllers for providing efficient damping against multiple inter-area oscillation modes under various operating conditions has been studied in [9]. In [10], wide-area signals are used to design an adaptive damping controller based on the classification and regression tree (CART). A fuzzy logic wide-area damping controller (FLWADC) for inter-area oscillations damping is designed and embedded in a static synchronous series compensator (SSSC) located in a standard four-machine two-area power system [11]. By driving an explicit formula for evaluating modal damping coefficient, an inter-area oscillation damping controller based on modulation of active and reactive power of HVDC terminals is designed [12].

However, the effectiveness of the device based controllers to damp inter-area oscillations is limited because inter-area modes are not always controllable or observable or both from the local signals. With the development of wide-area measurement system (WAMS) and deployment of synchronized phasor measurement units, wide-area damping controllers (WADCs) based on remote signals have been proposed to enhance the damping of the inter-area oscillations [13].

From the system operating point of view, device-based damping controllers may not provide adequate damping to mitigate low frequency oscillation in all situations. Also because of long time manufacturing and economic considerations, such methods cannot be implemented as well [4]. In [4], a generation rescheduling method based on offline sensitivity analysis is used to maximize power transfer subject to the small-signal stability constraint under a set of contingencies. In [6], based on the wide area measurement system (WAMS) and using generation rescheduling, a new approach for damping inter-area oscillation is proposed in which a non-model based method is adopted for estimating mode shape from the measured data like generator rotor speeds. The proposed approach is applied on a two area small system and IEEE 39-bus test system. By using load shedding and generation rescheduling, an emergency damping control is presented in [3] to suppress anticipated inter-area oscillations in system contingency to obtain the optimal locations and amounts of emergency control strategy. In [13], a new Wide Area Damping Controller (WADC) for a selected generator exciter based on networked predictive control (NPC) is introduced to improve the damping of inter-area oscillations.

In this paper, for suppressing low frequency inter-area oscillation and preventing power system from uncontrolled islanding, a new approach for online emergency load-generation tripping (OELGT) based on online PMU measurements is proposed. In this approach, for each oscillating area a damping index is proposed and evaluated based on the measured data from which the proper location for generation and load tripping can be identified. Also estimated mode shape from measured data is used for determining the proper generator for tripping. Proper load bus for tripping is determined based on the sensitivity of inter-area mode with respect to load power. In Section 2, the overview of the proposed approach is presented. The principle of the proposed approach is presented in Section 3. The simulation results are explained in Section 4. Finally, Section 5 comes with conclusion.

2. Overview of the proposed approach

The structural concept of the proposed approach denoted as emergency damping controller (EDC) is shown in Fig. 1. EDC strategy which consists of emergency actions including load and generation tripping acts as the final defense strategy for preventing system blackout. In this approach, at each time instant, all system operating data including all generators and load buses are gathered and analyzed via WAMS from which excited inter-area mode and system brittleness index (SBI) indicating system tendency for separation are evaluated. The system will be at risk of splitting if the value of SBI becomes negative. It means that the controlling actions of all existing conventional damping controllers are not sufficient for suppressing the excited inter-area mode and system tends to

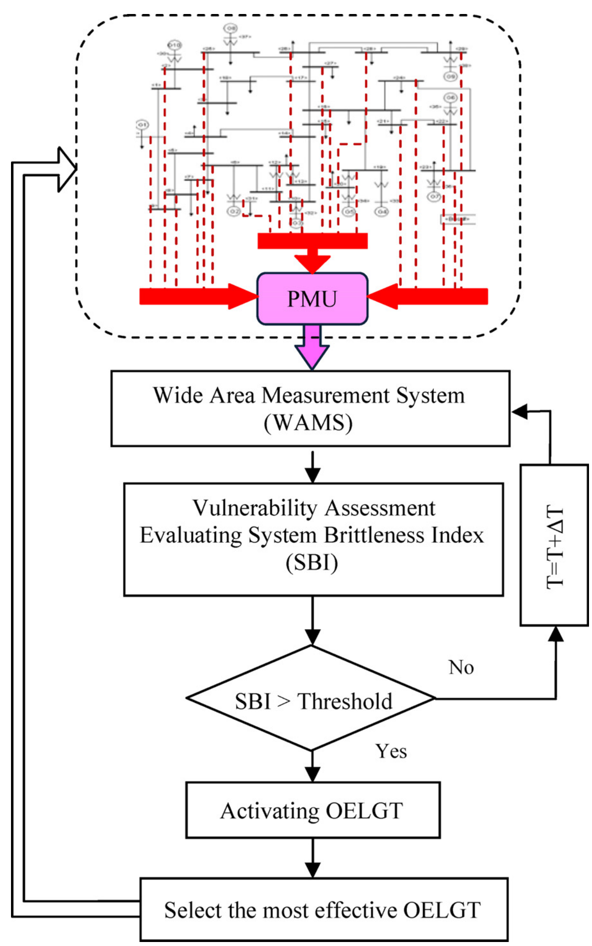

Fig. 1. Conceptual structure of the proposed approach of EDC.

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