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A decision support tool for transient stability preventive control

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ABSTRACT

The paper presents a decision support tool for transient stability preventive control contributing to increased situation awareness of control room operators by providing additional information about the state of the power system in terms of transient stability. A time-domain approach is used to assess the transient stability for potentially critical faults. Potential critical fault locations are identified by a critical bus screening through analysis of pre-disturbance steady-state conditions. The identified buses are subject to a fast critical contingency screening determining the actual critical contingencies/buses. These two screenings aim at reducing the computational burden of the assessment, since only contingencies considered as critical are taken into account. The critical clearing times for the critical contingencies are determined. A preventive re-dispatch of generators to ensure a predefined minimum critical clearing time for faults at all buses is proposed, while costs are minimized. The results of the assessment are presented to the control room operator, who decides to accept the suggested dispatch or to repeat the assessment considering additional user-specific constraints. The effectiveness of the proposed method is demonstrated on a standard nine-bus and the New England test system.

1. Introduction

Observability of power systems has to be increased to improve the situation awareness of control room operators. Situation awareness is a key aspect in maintaining power system security, because it enables anticipation of critical conditions and effectively set preventive actions to mitigate them [1,2]. Lack of situation awareness was several times identified as one of the major causes for large power system blackouts [3,4]. Various problems with situation awareness are related to missing information, i.e. the control room operator is not provided with the needed information [5–7]. Therefore, appropriate monitoring, visualization and decision support tools have to be developed to support the decision making process and to prevent or properly respond to electrical incidents in order to maintain power system stability [8,9]. Dedicated decision support tools are needed to facilitate the incorporation of high shares of renewable energy sources (RES) while keeping the power system operative and stable [10]. However, in this work, RES are not included in the analysis intentionally, as the work is mainly concerned with improving the calculation methods for a required re-dispatch. Since a considerable amount of the RES are converter driven (e.g., photovoltaic and wind turbines), they cannot lose synchronism as they are usually synchronized to the grid by a phase-locked loop. Moreover, due to advanced capabilities, such as voltage support during fault-ride-through situations, RES can contribute positively to maintain transient stability.

Transient stability is an important aspect of power system stability since it describes the ability of a power system to withstand large disturbances and keep synchronism [11]. Maintaining synchronism means that all synchronous generators (SGs) in a system operate at the same rotor speed and none of them falls out-of-step by accelerating or decelerating with respect to the other SGs. Transient instability can lead to widespread outages due to unintended tripping of protection devices which could trigger a cascaded breakdown of the power system [12]. Hence, it is crucial to assess the transient stability of power systems online on a grid-wide basis and set preventive actions if issues are identified [13,14].

The paper presents a novel online decision support tool for transient stability preventive control, building on experiences of previous tools. The proposed tool takes into account the current grid state and analyzes the grid's capability to withstand three-phase faults for a user-specified duration (desired limit, minimum critical clearing time (CCT), further called CCT_{lim}) at the most severe locations (buses) of the grid. A time-domain (TD) approach is used to assess transient stability on a grid-wide basis. To reduce the

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computational burden of the TD simulations, a critical bus screening (CBS) and fast critical contingency screening (FCCS) are carried out prior to the assessment. The CBS identifies potentially critical buses with regard to three-phase faults, by means of pre-disturbance conditions without the need for TD simulations. The FCCS determines the actual critical buses within the set of potentially critical buses by checking whether the system can withstand a three-phase fault for user-specified limit without any SG losing synchronism. This results in a yes/no decision, which eventually determines the critical buses. To achieve the desired minimum CCT for all critical buses, the needed dispatch of SGs is determined. The power is dispatched by means of an optimal power flow (OPF) calculation minimizing the generation costs while respecting technical constraints, such as generators' capacity, maximum line flows and bus voltage limits. Since the method aims at proposing a preventive generation re-dispatch, which ensures that the stability margins in the current operating point are sufficient, the ramp rates of generators are not considered in the OPF. As the preventive control is applied before a contingency occurs, the consideration of costs is an important factor in the assessment. The results of the assessment in terms of needed re-dispatch and associated costs are presented to the control room operator who has to decide whether the proposed re-dispatch is applied or not. The operator may also introduce additional constraints, e.g. the unavailability of generators to take over the dispatched power. The dispatch procedure is re-run, takes into account the additional introduced constraints and delivers a new dispatch proposal. The approach guarantees a minimum CCT for all buses of the power system and, thus, a sufficient transient stability margin.

The main scientific contribution of the paper is twofold. Firstly, a novel fast converging technique to determine the needed dispatch for re-establishing a predefined stability level is presented. Secondly, the paper elaborates on the combination of the transient stability assessment, the dispatch determination and the critical contingency analysis to enable an online application of the approach.

2. Transient stability preventive control – brief summary and relation to the paper

This section intends to summarize preventive transient stability approaches found in the literature. Moreover, the relation between transient stability assessment and OPF calculation are discussed as both items appear in this work. At this point, only re-dispatch of SGs is discussed as a possible counteraction, whereas many other actions can be applied to enhance transient stability, e.g. load shedding, increase of bus voltage and transmission impedance reduction.

Numerous approaches to determine the needed dispatch can be found in the literature. They can be classified into two categories: (a) determining the dispatch within the multi-machine system and (b) converting the multi-machine system in a single-machine equivalent (SIME) and analyzing it as an one-machine against infinite bus (OMIB) system.

Regarding the first category, several approaches have been introduced. An approach which uses the virtually linear relationship between rotor angle and CCT of the SGs is proposed in [15,16]. Since the relationship is not exactly linear, several TD simulations are necessary to obtain accurate results. Moreover, the estimation of the rotor angles introduces additional uncertainties. In [17], the authors propose to use the almost linear relationship between CCT and active power output of the generator. Several TD simulations are needed to determine the relationship. Specifically, seven CCTs associated with the SG power output were calculated in the paper, which implies a high computational burden.

Transient stability analysis using SIME, where the system is transformed into an OMIB equivalent, is very well covered in the literature [18–24]. The SIME approach transforms a multi-machine system to an OMIB equivalent, based on the fact that a loss of synchronism originates from the separation of one machine against another machine (or groups of machines). Considering that, the machines are separated into two groups: the non-critical and the critical machines which are responsible for the loss of synchronism. After the transformation into an OMIB system, transient stability is assessed by using the equal area criterion (EAC). The SIME parameters have to be updated continuously in every time step in order to achieve accurate results while the source for the parameters is provided by a simultaneously running TD simulation.

Regardless of which approach is used to determine the dispatch, power has to be re-distributed between the SGs. In order to do that in a transparent and appropriate way, OPF calculations are used to find a good trade-off between security and economics.

In general, transient stability-constrained OPF can be grouped into two different approaches, called *Global Approach* and *Sequential Approach*. The authors of [18] propose the mentioned grouping and give a comprehensive and up-to-date summary about transient stability in OPF calculations and about real-time stability in power systems in general. In the global approach [25–27,22,28], transient stability models are converted into algebraic equations at each time step of the simulation. This non-linear set of equations is then included in the OPF as a stability constraint, which results generally in a large single non-linear programming problem. In the sequential approach, transient stability constraints are derived from TD simulations and directly converted into conventional constraints of standard OPF calculations, e.g. maximum active power setpoints of the generators. The advantages of the sequential approach are that the OPF can be solved with a standard OPF solver and the flexibility of choice of the receiving generators for the dispatch. Opposed to these advantages, however, the sequential approach does not guarantee optimality which, therefore, makes the global approach more appealing from a conceptual perspective [18].

Since this paper aims at providing a tool for transient stability preventive control from the operator's perspective, the problem is seen from a different angle. The tool should inform the operator about insufficient transient stability margins and support the operator's decision making by suggesting an appropriate dispatch to achieve the defined stability margin. An interesting transient stability assessment approach for preventive control, that incorporates the critical contingency filtering and ranking method from [29], was proposed in [19,24]. A sequential approach, based on SIME, has been developed in the mentioned work. Opposed to that, the approach proposed in this manuscript takes into account the full multi-machine system without the need to transform it into an OMIB system. Moreover, in the proposed approach only 2–3 CCTs need to be calculated to determine the dispatch of a generator.

3. Description of the transient stability preventive control approach

In emergency control, the incident already occurred and the main aim is to safe the system. Opposed to that, the objective of preventive control is to prepare the power system for future uncertain events which may occur. The system has to be operated and maintained in a state, where it is able to withstand and handle disturbances satisfactorily. Therefore, in preventive control economic aspects have to be taken into account. The system operator would usually refuse to take expensive countermeasures against contingencies that may occur [30] and, thus, a trade-off solution between costs and security has to be found.