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Contribution of tidal power generation system for damping inter-area oscillation

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ABSTRACT

The growing need for the clean and renewable energy has led to the fast development of grid-connected tidal stream power generation systems all over the world. These large scale tidal stream power generation systems are going to be connected to power systems and one of the important subjects that should be investigated is its impacts on power system stability. Hence, this paper investigates the possibility of tidal stream power generation system on damping inter-area oscillations, as a new contribution to earlier studies. As tidal farms are mostly installed far from conventional power plants, local signals do not include good quality to alleviate inter-area oscillations. To overcome the problem, a novel damping controller is developed by employing wide-area measurement system and added to base controllers of doubly-fed induction generator through tidal stream power generation system. The proposed wide-area damping controller includes efficient means to compensate for the incompatible performances of wide area measurement based delayed signals. Robustness of the designed damping controller has been demonstrated by facing the study system with faults leading to enough shifts in power system operating point, and tidal farm generation.

1. Introduction

As the renewable generators penetration continually increases in the power systems, it is of paramount importance to study the effect of these renewable generator integrated power systems on overall system stability. For example, application of Double Feed Induction Generator (DFIG) based wind farms in mitigating inter-area oscillations have been studied in the literature [1]. Or in [2] a novel approach for SSR mitigation with DFIG has been addressed.

Transmission voltage-level photovoltaic (PV) plants are another kind of renewable power plants that has been used for power system dynamic improvement.

For example, recently Shah et al. [3] have proposed a mini max linear quadratic Gaussian-based damping controller for a large-scale PV plant to inter area oscillation damping or in [4] the impact of large-scale PV on rotor angle stability, particularly on inter-area oscillation is analysed as compared to the synchronous generator of same MVA rating at PV location.

In addition to the widespread installation of large-scale wind farms and PV plants, worldwide capacity of grid-connected tidal power generation system (TPGS) is growing rapidly [5]. There are two scenarios in which tides can be tapped for energy. The first is in changing sea levels. This phenomenon is responsible for the advancing and receding tides on shorelines. With the help of turbines, incoming tides can be manipulated to generate electricity. This scenario is called tidal barrage power generation system. The second way to exploit tidal energy is by sinking turbines to the sea floor. In this kind of TPGS fast-flowing currents turn generator blades much like the wind does with a wind turbine. This scenario is called tidal stream power generation system [6].

In the past, large-scale barrage systems dominated the tidal power scene. But because of increasingly evident unfavourable environmental and economic drawbacks with this technology, research into the field of tidal power shifted from barrage systems to tidal current turbines in the last few decades. This new technology leaves a smaller environmental footprint than tidal barrages.

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Since turbines are placed in offshore currents avoiding the need to construct dams to capture the tides along ecologically fragile coastlines. Tidal stream generators draw energy from water currents in much the same way as wind turbines draw energy from air currents. However, the potential for power generation by an individual tidal turbine can be greater than that of similarly rated wind energy turbine. The higher density of water relative to air (water is about 800 times the density of air) means that a single generator can provide significant power at low tidal flow velocities compared with similar wind speed [7]. With growing installation of the DFIG based stream TPGS over the world, the question that arises is: Can the power converters used DFIG based stream TPGS be used to mitigate inter area oscillation? In this paper, such possibility is investigated.

The Grid Side Converter (GSC) of the DFIG may work such a shunt Flexible Ac Transmission Systems (FACTS) device. It can be used to voltage control like an STATCOM. STATCOM's ability to damping power swings has been demonstrated [8]. In [8] it has been shown that with including the auxiliary damping controller in the core control loop of STATCOM, inter-area oscillations are considerably damped. In this article, the GSC of the DFIG based TPGS is used like an STATCOM and it is utilized to damp inter-area oscillations.

Owing to the fact that FACTS and HVDC systems are usually installed on the critical points of the power system like important transmission lines or major generation plants, locally measured feedback signals can be used for the auxiliary damping controller of these devices. But owing to the fact that TPGSs usually located far away from critical points of power systems, it seems that locally measured feedback signals cannot be a good choice for DFIG based damping controller input signal. It is well known that, if wide area feedback signals are used on damping controller design, the damping controller operation can be improved unlike the local feedback signals [9].

Recent technological progress on WAMS, phasor measurement unit (PMU) and data communication technologies, allow the utility companies to use wide area signals for efficient mitigating the controller design. The achievements are mainly because of the time-stamped synchronous measurements that can be implemented in all areas of a geographically expanded power system [10].

The time which is demanded to communicate PMU data toward the system or regional control center plus that of transferring commands to control devices is totally considered as the communication delay or latency. The amount of the latency is dependent on the data transmission loading.

In wide area control systems, it reduces the impact of the control systems and can even completely destroy the control system behavior [10]. Therefore, considering this time delay through the controller design method is an important necessity and, a lot of studies have been reported to compensate destructive impacts of communication delay on wide area controller design [10–15]. In [10], a fuzzy logic Wide-Area Damping Controller (WADC) for inter-area oscillations damping and continuous latency compensation has been presented.

In [11], an adaptive phasor power oscillations damping controller has been proposed wherein the rotating coordinates were adjusted for continuous compensation of time-varying latencies. Ref. [12] has investigated a linear control design technique that utilizes an optimization-based iterative algorithm with a set of linear matrix inequality constraints.

The method proposed in [13] is to obtain the optimal controller parameters, while efficiently considering the data transmission delay. In [14], a practical experience on the HVDC-based damping controller incorporating the communication time delay has been reported. In [15], a wide-area power system stabilizer for the small signal stability has been designed where a second order approximation has been considered for the sake of latency compensation.

The major contribution of this article is to demonstrate the applicability of DFIG-based marine farms in power system dynamic stability enhancement and mitigating of inter-area oscillations in the presence of WAMS technology. To the best knowledge of the authors, employing tidal power plants to alleviate the inter-area oscillations has not been addressed. Using high penetration of DFIG based wind farms as an effective solution for inter-area oscillations mitigation has been widely reported in the literature [1]. But the application of large scale TPGSs for alleviating inter-area oscillations has not been investigated. The main difference between wind DFIG ant tidal stream DFIG is their turbine mover fluid and their speed deviations. In most of the previous papers, the application of wind DFIG in oscillation damping has been studied so that the wind speed sticks at a constant amount during the simulation period [1,2]. However, in the current paper, it is assumed that the marine current speed is not constant and varies to lower than nominal marine speed.

The proposed WADC is a double stage conventional damping controller adjusted by Teaching-Learning-Based-Optimization (TLBO) method for inter-area oscillations mitigation and continuous coverage of time-varying delay. The suggested structure is added to a standard multi-machine power system and comprehensive nonlinear simulations are used to execute the useful performance of the suggested structure. Also, the robustness of the proposed damping controller is examined through various case studies.

The rest of the paper is organized as follows. In Section 2, material and methods including DFIG based tidal farm structure and TLBO algorithm are presented. In Section 3, simulation results are carried out in two values for marine current speed and tidal farm output active power, to assess the effectiveness of the suggested structure when the marine current speed and accordingly tidal farm active power delivered to the system varies to a lower value. Finally, Section 4 concludes the paper.

2. Material and methods

2.1. Marine current speed and marine turbine

The global scheme for a practical DFIG based tidal stream power generation system is given by Fig. 1. In the following, the detailed models for all sections of a TPGS are introduced.

Tidal stream generators draw energy from water currents similar to the way that wind turbines draw energy from air currents. Ordinary the tide speeds (i.e., spring and neap tides) move the Marine Current Turbine (MCT) [5]. Some shorelines experience a semi-diurnal tide, two nearly equal high and low tides each day. Other locations experience a diurnal tide, only one high and low tide each day. A "mixed tide"; two uneven tides a day, or one high and one low, is also possible. The marine-currents are determined to start at 6 h before high waters and to end 6 h after them. On this basis, deriving a simple and applied plan is not difficult for marine-current speeds, since tide factors can be obtained as follows:

$$V_{MR} = V_{nt} + \frac{(C_{mr} - 45)(V_{st} - V_{nt})}{95 - 45} \tag{1}$$

where V_{MR} denotes the marine speed in m/s. C_{mr} represents the marine factor, 95 and 45 denote the average factors of spring and neap tides, respectively. V_{st} and V_{nt} respectively represent the marine-current speed of the spring and neap tides (for the area between France and England) [16]. The mechanical power of the considered MCT is illustrated in Eq. (2).