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Reactive power management in an offshore AC network having multiple voltage source converters

Muhammad Raza*, Carlos Collados, Oriol Gomis-Bellmunt

Centre d'Innovació Tecnològica en Convertidors Estàtics i Accionaments, Departament d'Enginyeria Elèctrica, Universitat Politècnica de Catalunya, Barcelona, Spain

HIGHLIGHTS

- Presents a concept of an offshore AC hub to integrate future offshore wind farms with different onshore grids.
- Presents the control VSC-HVDC system for an offshore AC hub.
- Introduce a method of multi-objective optimization of an offshore AC hub.
- Provide a methodology to manage the reactive power in an offshore AC hub.

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ABSTRACT

Many offshore wind power plants are being developed every year at North and Baltic Sea. From the prospective of environment and integrated European power, combined power transmission from several offshore wind power plants using VSC-HVDC transmission system to different onshore grids are suitable instead of connecting each wind power plants individually. Offshore AC hub is beneficial for the wind power plants that are far from shore but close to each other within the vicinity of 20 km. This paper presents a method of controlling reactive power flow in the offshore AC grid to minimize the power losses and voltage deviation. In the proposed scheme, offshore grid frequency and voltage are controlled through more than one converter. Using frequency and voltage droop schemes, the active and reactive power sharing is achieved among converters. Furthermore, the optimization algorithm is developed to acquire the set points for the wind power plants and VSC-HVDC droop gains for the optimum operation of the network.

1. Introduction

Renewable generations are becoming universally adopted primary source of energy. A breakthrough in advanced power transmission technology, specially in the power electronics devices, has enabled the installation of renewable generation units at remote locations. The wind energy has been a main focus in the last decade particularly at offshore comparatively to other renewable sources. Up to the mid of 2016, 3344 offshore wind turbines with a combined capacity of 11,538 MW have been installed in European waters [1,2].

The most common export system for the offshore wind energy to onshore grid is the high voltage alternating current (HVAC) cable system, typically at the voltage level of 150 kV. The HVAC export system is a well established technology. However, the HVAC cables have high effective capacitance that limits the transmission of large active power over the long distance, typically limited up to 90 km for 100 MW [3]. A voltage source converter (VSC) based high voltage direct current (HVDC) transmission system has eliminated the power export limitation imposed by cable capacitive effect, and it has the ability to create the offshore grid [4–6]. Many experts are foreseeing the need of having offshore grid for better trade and integration of large offshore wind energy generation in Europe [7,8]. An offshore grid would link several offshore wind power plants with different countries. In [9], the impact of an offshore grid on the European energy market has been studied considering several technical concepts for grid connection. A new concept of 'hub and spoke' transmission system for the interconnected North Sea is proposed by Tennets [10]. In this concept, an artificial island called 'hub' will be build in center of different offshore wind power plants that are far from the shore. Offshore wind power plants and onshore grids will be connected with export system called as 'spoke'. For wind power plants connection with the hub, the export system will be high voltage alternating current (HVAC) cables system since the distance will be short, and the installation is simple and cheap. For onshore connection with the hub, the export system will

* Corresponding author.
E-mail addresses: muhammad.raza@citcea.upc.edu (M. Raza), carlos.collados@citcea.upc.edu (C. Collados), oriol.gomis@citcea.upc.edu (O. Gomis-Bellmunt).

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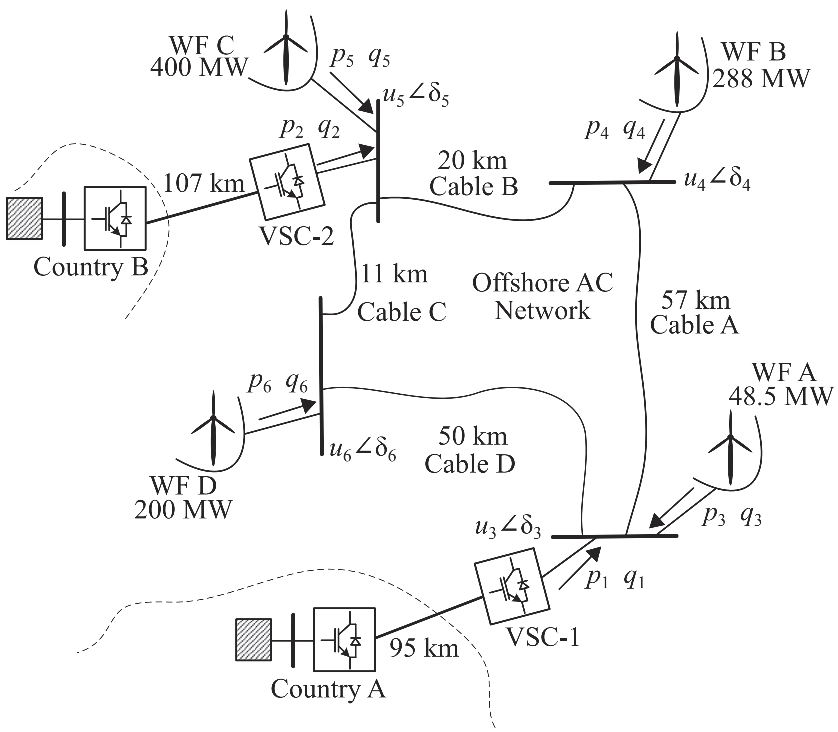

Fig. 1. Configuration of offshore AC network interconnecting two onshore grid using VSC-HVDC system.

be VSC-HVDC transmission system as the distances of countries from the island are longer. Once build, up to 100 GW or more of offshore wind energy is expected to be connected via this island.

There are several options under investigation for the formation of the offshore grid [11]. The interconnection between onshore grids via multi-terminal (MT) HVDC system requires the DC circuit breaker which may increases the overall system development cost [12,13]. Further, the mesh DC network may also need the selectivity and reliability at the level similar to distribution network at onshore. The DC protection system is complex compare to AC since the require fault interruption time is less in the DC network and there is no zero crossing in the DC current. Another approach to interconnects onshore grids is through offshore AC hub using point-to-point VSC-HVDC transmission topology. In this way, the DC circuit breaker is not required, and the DC fault protection can be achieved using AC circuit breakers and by opening IGBTs valves. Offshore AC hub is the network of medium or high voltage AC cables that interconnects several offshore wind power plants with each other [14]. Wind power plant distance up to 20 km from the offshore AC hub is considered economical [15]. To operate the offshore AC network or hub, the VSCs of HVDC transmission system controls the voltage and frequency as the primary sources and they behave as slack sources in the network [16–18]. The distribution of the total power in the network among the HVDC transmission system can be controlled by applying frequency and voltage droop schemes in the VSCs [14]. The advantage of droop scheme is to have multiple distributed slack sources in the network, and communication between VSC-HVDC transmission system is not required for power sharing during normal operation as well as in the failure of any transmission system. However, the parallel operation of the VSCs require the impose frequencies to converge at the same equilibrium point to achieve stability in the system. The dynamic and stability aspects of parallel operating VSC to control offshore AC network are discussed in [19]. The study perform in [19] provide the boundaries limits of frequency and voltage droop gains for stable operation which can be applied to determine the optimum steady-state operating points.

Reactive power management is an important factor in minimizing losses in the network with respect to the active power dispatch by the wind turbines [20]. Traditionally, reactive power management is addressed as an optimization problem and the solution is found by solving an optimal power flow algorithm (OPF) [21,22]. The solution of OPF algorithm provides the reactive power set-points for wind turbines with respect to wind active power in-feed based on minimization criteria define as an objective function in the algorithm, such as active power loss, voltage deviation, and cost. Multi-objective optimization technique compared to single objective offer advantage in term of providing solution with respect to the weight of multiple loss function criteria in order to operate the network more effectively [21,23–26]. At present, most of the offshore wind power plants are connected to a single onshore grid. In future projects such as Kriegers flak, there will be several wind power plants connected to different onshore grids [27]. This will require diverse approach to optimize the network operation. Optimal network operation through only wind turbines reactive power dispatch will not be sufficient due to the active power trade operation among onshore grids. This has introduced the additional constraints compare to traditional offshore wind farm network in which all produce wind power received at single onshore grid. For the offshore AC network having multiple wind power plants interconnection, the VSC based HVDC transmission system will be suitable as an export system due to its ability to control the distribution of power flow in the offshore network [28]. The frequency and voltage droop schemes provide additional degree of freedom to control the active and reactive power flow. This further allows to optimize the network operation according to the wind dispatch and trade requirement.

Currently, no such study is performed for the optimization of the offshore AC network that have parallel connected VSC systems. In this paper, a method of reactive power management has been proposed for an offshore AC network using multi-objective optimization technique. This paper is an extension of a research work presented in [29]. The optimization problem is solved using interior point method. The solution of the algorithm provides the reactive power set points of each wind power plant and reactive power contribution from each VSC-HVDC transmission system according to the net wind power generation. The paper also address the droop gains selection method considering the network long-term voltage stability. The rest of the paper is organized as follows: Section 2 explains the configuration of the offshore AC network and the operation of the VSC-HVDC transmission system, in