New Configuration and Transient Management Control Strategy for U-VSC-HVDC with Filter

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ABSTRACT
This paper presents a novel system configuration for voltage source converter (VSC)-based high-voltage direct current (HVDC) transmission connected to a large-scale offshore wind power plant (WPP). We prove that the active power through a branch (referred to as branch active power) in a power system is a continuous function of the bifurcation parameter in the closed interval from an initial parameter value to the bifurcation-point value of a saddle-node bifurcation (SNB) or limit-induced bifurcation (LIB) of the power flow equation (PFE). These results can be used to qualitatively evaluate and classify the state of power system operation conditions in terms of voltage stability and is evaluated using MATLAB.

Keywords--- MATLAB, HVDC, VSC

I. INTRODUCTION

High-Voltage direct current (HVDC) technology has been widely applied for long-distance bulk power transfer in transmission networks. Modern HVDC systems use voltage source converters (VSCs), which are based on self-commutated switching devices. This enables a decoupled control of active and reactive power and allows the connection of weak or even passive networks. Additionally, the high switching frequencies of approximately 1–2 kHz reduce the filter size, and the IGBT valves themselves have a smaller size compared with thyristor valves in classical HVDC systems. Recently, driven by the growing installations of large-scale offshore wind farms as well as the rapid evolution of power electronics technology, the VSC-HVDC technology, also called HVDC light or HVDC plus, is gaining wide acceptance.

Power system voltage stability is a main concern for secure operation of a stressed system. Static approach is widely used for voltage stability study for the situation that the system is stressed by gradual load/generation increase, in which the voltage collapse is a saddle-node bifurcation (SNB) or limit-induced bifurcation (LIB) of the powerflow equation (PFE).

A variety of numerical methods for the calculation or estimation of these bifurcations have been developed. Usually, the computation costs are large for such calculation. Hence it is useful if we can assess voltage stability before the voltage collapse is calculated. For a branch in a power system, the static transfer stability limit (STSL) is defined as the operation state, at which the partial derivative of the branch reactive power with respect to the branch active power tends to infinity, and it is shown that

II. RELATED WORK

“Combined Local and Remote Voltage and Reactive Power Control in the Presence of Induction Machine Distributed Generation”, Viawan, F.A., Karlsson, D [12] first investigates a local voltage and reactive power control (local control) in a distribution system based on local control of on-load tap-changer (OLTC), substation capacitors, and feeder capacitors, and how the presence of induction machine based distributed generation (DG) affects it. A proper coordination among those available voltage and reactive power control equipment to minimize losses in the distribution system, with and without DG, is formulated. Secondly, a combined local and remote voltage and reactive power control (local-remote control), which is based on automated remote adjustment to the local control in order to minimize the losses even more, is proposed. The automated remote adjustment in the local-remote control is also intended to keep the operating constraints fulfilled all the time, which cannot be achieved by using the local control when DG is present in the system. The OLTC and substation capacitors are assumed to be remotely
controllable, while the feeder capacitors are not. DG with both constant power and varying power are investigated.

“Power Management Strategies for a Microgrid With Multiple Distributed Generation Units”, Katiraei, F., Iravani, M.R. , Nov. 2006 [13] addresses real and reactive power management strategies of electronically interfaced distributed generation (DG) units in the context of a multiple-DG microgrid system. The emphasis is primarily on electronically interfaced DG (EI-DG) units. DG controls and power management strategies are based on locally measured signals without communications. Based on the reactive power controls adopted, three power management strategies are identified and investigated. These strategies are based on 1) voltage-droop characteristic, 2) voltage regulation, and 3) load reactive power compensation. The real power of each DG unit is controlled based on a frequency-droop characteristic and a complimentary frequency restoration strategy. A systematic approach to develop a small-signal dynamic model of a multiple-DG microgrid, including real and reactive power management strategies, is also presented. The microgrid eigenstructure, based on the developed model, is used to 1) investigate the microgrid dynamic behavior, 2) select control parameters of DG units, and 3) incorporate power management strategies in the DG controllers. The model is also used to investigate sensitivity of the design to changes of parameters and operating point and to optimize performance of the microgrid system. The results are used to discuss applications of the proposed power management strategies under various microgrid operating conditions.

“Transient Stability Analysis of a Distribution Network With Distributed Generators”, Ishchenko, A.; Popov, February 2009, [14] describes the transient stability analysis of a 10-kV distribution network with wind generators, microturbines, and CHP plants. The network being modeled in Matlab/Simulink takes into account detailed dynamic models of the generators. Fault simulations at various locations are investigated. For the studied cases, the critical clearing times are calculated. Results obtained from several case studies are presented and discussed.

“Modelling of stalling motors during voltage stability studies”, Vournas, C.D., Manos, G.A., Aug 1998,[15] investigates the effect of induction motor stalling on power system voltage stability assessment. A new time-scale decomposition is suggested when a single motor stalls. This allows a better security margin assessment in cases where motor stalling has no serious consequences on system operation. Case studies on a two motor system and a 34-bus system demonstrate the applicability of the proposed approach.

“Short-term voltage instability: effects on synchronous and induction machines”, E.G.,Vournas, C.D., May 2006, [16] discusses a few aspects of short-term voltage instability: modeling of transient overexcitation limiters of synchronous generators; possible outcomes of instability, such as induction motor stalling, or generator loss of synchronism leading to a local blackout; eigenvalue tracking and use of eigenvector to identify and characterize the instability mode; and finally, induction motor disconnection to counteract short-term voltage instability. Results on a system with large penetration of induction wind generators, as well as on a small test system, commonly used in voltage stability studies, are included. The results are used to discuss applications of the proposed power management strategies under various microgrid operating conditions. A systematic approach to develop a small-signal dynamic model of a multiple-DG microgrid, including real and reactive power management strategies, is also presented.

III. CONVENTIONAL VSC-HVDC

Conventional VSC-HVDC systems can have several configurations such as symmetric monopole, asymmetric monopole, bipole, or multi-terminal, as described in [3]. These configurations can be connected into meshed transmission networks as in [4]–[6]. The standard IEEE-9 bus system is employed to illustrate the configuration interconnecting offshore WPP through VSC-HVDC, as shown in Fig. 1.

![Conventional Configuration of U-VSC-HVDC](image)

Fig.1.Conventional Configuration of U-VSC-HVDC connected to an IEEE-9 bus system.

In this study, the multiterminal configuration is used, where the onshore VSC station consists of two independent converters to deliver the generated power through two shunt transformers. one of these transformers should be capable to handle the total power of the HVDC system. A bus coupler; is used to allow delivering the total power through , or both of them. is the point of common coupling (PCC) between the HVDC system and the electrical grid. The wind power is transmitted through HVDC and is dispatched into the grid through . To follow the typical transmission criterion obligation, [7] both lines, and shall be capable to handle the rated power delivered from the HVDC network. The rated power of the HVDC can be handled by one converter as the offshore station or by two parallel converters sharing the rated power as the onshore station.

Without losing generality, the onshore station shown in Fig. 1 can be reconfigured so that the grid
connection accommodates both series and shunt transformers respectively, as illustrated in Fig. 2.

![Fig. 2. New configuration of U-VSC-HVDC system](image)

It is noticed that the series transformer replaces the shunt transformer. Therefore, the proposed configuration provides a practical solution without significantly changing the original network or splitting it, but supporting both series and shunt connections.

It also indicates a cost-effective solution using the existing converters without installing additional converters. The series transformer used in the new configuration is known to be of lower leakage reactance than that of the shunt transformer which may reduce the costs further. In normal operations, the series transformer is disconnected by opening switch. [8] Hence, the leakage reactance of the series transformer is considered small enough to be neglected in comparison with the transmission line reactance, therefore the voltage levels of and are equivalent, so the grid connection can be considered as one-point.

In this case, the series transformer splits the PCC point into two buses, emulating a bus coupler. However, during faults, the series transformer provides series voltage to transmit wind energy into the healthy part of the electrical system. For instance, if a fault happens at the point where is opened (i.e., is closed), the leakage reactance of the series transformer is considered very small. Therefore, the voltage of and is equivalent and the grid interconnection can be considered as one point.

Multiple operations can be achieved by opening and closing different switches according to the following states of operation.

**State 1:** When WPP is supplying rated power (i.e., 100%) and there are no grid faults, the onshore converters are connected through the shunt transformer to supply total wind power. This can be achieved by closing switches S1 and S3, while S2 and S4 are opened. When is opened (i.e., is closed), the leakage reactance of the series transformer is considered very small. Therefore, the voltage of and is equivalent and the grid interconnection can be considered as one point.

**State 2:** This can be useful to utilize the HVDC system increase power transfer capability of the electrical grid, where the series connection is used for series compensation functions and shunt connection is made to supply wind power when WPP is generating less than 60% of its rating. This state can be achieved by closing S2 and S3, while S1 and S3 are kept open.

**State 3:** The advantage of the U-VSC-HVDC configuration lies in its capability to provide fast power redirection during different grid faults through series voltage injection and therefore prevent grid propagations, which are caused by various fault impacts. For instance, if a voltage dip is detected at , series voltage is inserted through transformer to build up the voltage at . This operation can be achieved by closing switches S2 and S3 to guarantee transferring the active power of the HVDC system into the grid, while and are opened.

**State 4:** For faults at , S2 and S4 are closed, while and are opened. The series voltage is injected in the direction of to direct the active power into the healthy part of the system.

**State 5:** The voltage collapse indicated by an SNB or LIB of the PFE also implies the maximum load ability limit. [15] If the generation capacity is adequate for load needs (which is the topic of generation adequacy), then the transmission network plays an important role as the medium for power transmission from generators to loads. It is physically meaningful that some branch active powers attain maxima before voltage collapse.

**IV. PROPOSED SYSTEM**

Our studies clearly show the nonlinearity of power flows in power systems, reveal the close relation between the power transfer capability and the voltage stability, and describe the mechanism of voltage collapse as a result of cascading events defined above in the situation that the system is stressed by load/generation increase.

Moreover, [16] the studies can be used to assess power system voltage stability for power transfers based on branch active powers, which can be obtained by simple computation or from measurement. Specifically, the occurrence of critical branches and the number of critical branches provide the information for qualitative evaluation and classification of the state of power system operation conditions in terms of voltage stability. [14] In addition, the studies well explain the limitation of DC power flow methods.

![Fig.3. π equivalent circuit of a branch](image)
We use mathematical analysis and bifurcation theory to derive the analytical results. Consider the parameter-dependent PFE as follows:

$$h(z, \xi) = 0, \quad z \in \mathbb{R}^n, \xi \in \mathbb{R}^1$$

Where $Z$ and $\xi$ are respectively the unknown variables and the bifurcation parameter. Since both SNB and LI Bare co-dimension-one bifurcations, we assume that the parameter is a scalar one. The load/generation increase can be described by the increase of the parameter. For instance, a general form to describe the load/generation increase is given by

$$P_{Gi} = P_{Gi0} + \xi \Delta P_{Gi}, \quad P_{Li} = P_{Li0} - \xi \Delta P_{Li}, \quad Q_{Li} = Q_{Li0} + \xi \Delta Q_{Li}$$

where $P_{Gi}$, $P_{Li}$, and $Q_{Li}$ respectively represent the active power supplied by the generator, the active, and reactive powers consumed by the load at bus $i$. Their initial values are respectively $P_{Gi0}$, $P_{Li0}$, and $Q_{Li0}; \Delta P_{Gi0}, \Delta P_{Li0},$ and $\Delta Q_{Li0}$ represent the direction of the load/generation increase.

We present our analytical results in the following theorem.

**Theorem (Necessary Condition for Power System Voltage Collapse):** Consider a power system that is stressed by gradual load/generation increase described by the increase of a scalar bifurcation parameter. Then the system has the following properties:

1. The branch active powers are defined implicitly by the PFE as continuous functions of the bifurcation parameter in the closed interval from an initial parameter value (denoted as $z_0$) to the bifurcation-point value (denoted as $z_c$) of an SNB or LIB. Thus each branch active power attains at least one local maximum and a global one in the closed interval.
2. Generally, there is a sequence of branch active powers meeting local or global maxima before the voltage collapse, which provides useful information for power system voltage stability assessment.

The operation sequences of the four switches $S_1$, $S_2$, $S_3$, and $S_4$, switching from one state to another. The converters should be blocked before opening or closing any of the switches. These switches are GTO based switches to minimize the switching delays. The nominal switch-off delay is estimated to be several to hundreds of microseconds including the blocking time of the converters.

V. CONCLUSION

A double-ended universal power flow controller is configured for VSC-HVDC system in connecting offshore WPPs. The configuration is realized at the onshore VSC station to achieve shunt and series compensation, which is named as a U-VSC-HVDC system. The novel configuration allows the smooth power transfer from WPPs during symmetrical and asymmetrical faults in ac power system networks. It also reduces the possibilities of severe power network propagations that may occur due to sudden power reduction. The states of operations for the new U-VSC-HVDC are presented and realized to handle various fault location and types of compensation. Positive and negative sequence controllers are developed to handle symmetrical and asymmetrical faults. In addition, the paper shows the concept to control the negative sequence voltage component of the series transformer in order to mitigate power oscillations and DC link voltage ripples caused by asymmetrical faults. Hence, this prevents damage to the dc
link and WPP components. A comprehensive simulation study proves the concept and demonstrates the proposed advantages.

REFERENCES

[14] Ishchenko, A. ; Popov, “Transient Stability Analysis of a Distribution Network With Distributed Generators”, February 2009,