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Review of Power System Stability in HVDC Transmission Links

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ABSTRACT: The increasing number of high-voltage DC (HVDC) transmission links, imposes the serious challenges on power system control and stability analysis. While some of HVDC systems offer better controllability and improvement of global power-system stability, there is also an increased risk for local instabilities which can either start as parasitic small signal oscillations, or concurrent commutation failure of converters consequently impair voltage quality or cause high over-voltage at the converter ac buses. To analyze the nature and causes of these instabilities, appropriate analytical models of power systems and HVDC links are required. This paper reviews of the power system stability in HVDC transmission links.

KEYWORDS: HVDC, Transmission links, power system, Stability.

I. INTRODUCTION

The number of HVDC converters (and/or other power-electronic devices) is increased; the high-frequency interaction between different devices will be so complicated that local analysis may not result in a reliable conclusion. Moreover, that the HVDC controller design might suffer from lack of an accurate power system model if only the dynamics of a small portion of it is regarded. On the one hand, considering dynamics of all power components and ac system results in a huge number of state variables, of which most of are in essential. On the other hand, all of the electrical network dynamics cannot be neglected while analyzing the interactions among HVDC converters (otherwise, the TSPs could have been used for the same purpose).

In a hybrid model of power system has been proposed to overcome this problem; in fact, the areas of power system which consist of HVDC converters are modeled including ac network dynamics, and the remaining parts are modeled using the power frequency admittance matrix. Although this model reflects the nature of oscillations in power systems, but still it is not the best tool when the proportional gain of a controller causes instability. Also, the small-signal stability cannot be analyzed in the frequency domain to obtain gain and phase margins of stability, which are crucial in controller design. The JTM not only can analyze the stability issues but it also regards the ac network model in a feedback loop which is ideal for VSC controller design. The stability analysis by JTM is based on monitoring the zeros of network transfer function, therefore, it is limited to a small power system.

Moreover, the LCC-HVDC model has not been included in JTM-based model. The state-space models of all HVDC controllers and mechanical parts of electrical machines are placed in block. The models of HVDC converters, dc-links, loads, and electrical parts of machines are included in block, and the ac network model is considered in block. By eigenvalue analysis of the closed-loop FCS model and by analyzing the frequency response of FCS open-loop transfer functions, the small-signal and high-frequency interactions can be implemented.

The voltage stability and steady-state interactions are investigated by modal and/or nodal analysis of the block N model in quasi-static form which resembles the load-flow Jacobian matrix that can be used for the same purpose. The main advantage of the FCS model over conventional stability analysis tools is its feedback structure which makes all stability analyses, associated with multivariable control systems, can be applicable to a power system. For instance, by providing the plant model the input–output interactions between devices, ill-conditioning, and non-minimum phase phenomena can all be analyzed, or by providing the open-loop model of the system, robustness of small-signal stability can be indicated in terms of phase and gain margins. However, as the same as conventional approach to analyze the small-signal stability, the eigenvalue analysis of FCS closed-loop model detects all unstable modes and their associated participation factors. Moreover, by the FCS model both dynamic and static stabilities are investigated in a single platform and their relationships are clear; this feature provides more authentic understanding about the stability limits and also forecasts which instability may occur first. Another benefit of FCS structure is the development of the plant model as a stand-alone model which can be used to design multivariable controllers for converters with high interactions.

II. LITERATURE SURVEY

M. Q. Khan et al.,[1] Recent advances in data sensing and processing technologies enable data-driven control of high-voltage direct-current (HVDC) systems for improving the operational stability of interfacing power grids. This work proposes an optimal data-driven control strategy for an HVDC system with line-commutated converters (LCCs), wherein the dc-link voltage and current are optimally regulated at distinct HVDC terminals to improve frequency regulation (FR) in both rectifier- and inverter-side grids. Each HVDC converter is integrated with feedback loops for regulation of grid frequency and dc-link voltage in a localized manner. For optimal FR in both-side grids, a data-driven model of the HVDC-linked grids is then developed to design a data-driven linear quadratic Gaussian (LQG) regulator, which is incorporated with the converter feedback loops. Case studies on two different LCC HVDC systems are performed using the data-driven models, which are validated via comparisons with physics-based models and comprehensive Matlab/Simulink models.

P. Agnihotri et al.,[2] Control strategies for power swing damping which use wide-area feedback signals need to be robust to partial/complete loss of communication and changes in operating points and topology. In addition, they should have a positive effect on all controllable swing modes and ensure adequate stability margins to avoid destabilization of untargeted modes. This work proposes a control strategy for multiple embedded dc links (multi-terminal or multi-infeed), which has all these attributes and is inherently able to provide wide band damping.

T. N. Pham et al.,[3] This work considers high voltage direct current (HVDC) links for the primary frequency control of interconnected time-delay power systems with electric vehicles (EVs). Novel distributed control of HVDC links is proposed to minimize the differences in the frequency deviations between the connected power areas. A power system with EVs, HVDC links and multiple time delays is first presented. Then, we propose a new robust distributed HVDC controllers design method to stabilize the closed-loop system with a guaranteed H_∞ performance. The design method can be flexibly extended to design static output feedback controllers of various structures to cater for different power system topologies.

A. Elahidoost et al.,[4] This work analyzes the problem of the expansion of an offshore HVDC network. We assess which new HVDC link deployment ensures the highest stabilization of the DC voltage under transient conditions, in the worst-case scenario and for a given grid topology. A linear feedback controller is also designed to guarantee the minimization of the DC grid voltage deviations, while ensuring input constraints. The operation of this controller is compared to that of a standard droop regulator commonly applied in multiterminal Voltage Source Converter (VSC)-based HVDC networks.

F. E. Alfaris et al.,[5] This work proposes an electromagnetic transient model of the Convertible Static Transmission Controller (CSTC) system in shunt-shunt operation mode. This proposed transient model is used for dynamic analysis and system design. Two recently proposed control structures, which aim to suppress the DC link voltage oscillations under unbalanced AC grid, are applied and compared to the conventional state feedback control method. The simulation tests for a CSTC transmission system connect two active networks are adopted by PSCAD-EMTDC and MATLAB/Simulink.

R. Vaid et al.,[6] This work investigates a Wide Area Measurement based robust damping control for multi-infeed VSC HVDC links embedded in the ac system. The feedback signal for the controller design is synthesized from the local and remote signals which results in a good pole-zero separation, which results in improved damping of the swing modes. Furthermore, the work demonstrates utilization of additional degrees of freedom available due to multi-infeed HVDC links over single HVDC/FACTS device, embedded in ac system for preferential damping of selective swing modes. The proposed damping control is robust towards the loss of communication and changes in the operating point, and network conditions.

P. Agnihotri et al.,[7] Control strategies for power swing damping which use wide-area feedback signals need to be robust to partial/complete loss of communication and changes in operating points and topology. In addition, they should have a positive effect on all controllable swing modes and ensure adequate stability margins to avoid destabilization of untargeted modes. This work proposes a control strategy for multiple embedded dc links (multiterminal or multiinfeed), which has all these attributes and is inherently able to provide wideband damping. The strategy uses only a limited set of nonlocal signals.

S. Ahmad et al.,[8] This research work proposes an application of conjugate gradient algorithm for optimization of adaptive Feedback Linearization Control (FBLC) strategy for damping power system oscillations through HVDC link. The nonlinear supplementary control scheme is based on real-time optimized NeuroFuzzy identification of the power system dynamics. A self-tuned (FBLC) is employed to derive appropriate control law to modulate the real power flow through HVDC system and improve its damping. Validation of the performance of control scheme is carried out through different fault situations of two-area test power system and bench-marked against the gradient descent based FBLC.

T. N. Pham et al.,[9] This work presents a load frequency control scheme using electric vehicles (EVs) to help thermal turbine units to provide the stability fluctuated by load demands. First, a general framework for deriving a state-space model for general power system topologies is given. Then, a detailed model of a four-area power system incorporating a smart and renewable discharged EVs system is presented. The areas within the system are interconnected via a combination of alternating current/high voltage direct current links and thyristor controlled phase shifters. Based on some recent development on functional observers, novel distributed functional observers are designed, one at each local area, to implement any given global state feedback controller.

A. Bidadfar et al.,[10] A general platform is introduced to study the dynamics of power systems with high voltage dc (HVDC) transmission links. Small-signal stability, voltage stability, and interaction phenomena of power systems with both line-commutated-converter HVDC (LCC-HVDC) and voltage-source-converter HVDC (VSC-HVDC) are addressed using the proposed platform. In this platform, the entire power system is modeled as a multivariable feedback control system (FCS) which consists of three interconnected blocks. The contents as well as the inputs and outputs of the blocks are selected such that the conventional analysis tools for power system stability are applicable, both in the time and frequency domains.

III. CHALLENGES FOR PROTECTION OF FUTURE HVDC GRIDS

Nowadays, High Voltage Direct Current (HVDC) transmissions are gaining relevance in long distance and renewable energy integration projects over the conventional Alternating Current (AC) transmissions due to several advantages as improved flexibility and independent active and reactive power controllability. Despite that, the high currents and voltage collapses generated by fault conditions in HVDC systems imply some unresolved technical challenges regarding the detection, location and clearance of faults. Faults have to be cleared in a very short time range in order to minimize their impact on the system. For this objective, very fast protection algorithms and reliable HVDC circuit breakers are required.

- Accuracy: the protection system only operates when the fault condition is located inside its protection zone.
- Speed: fast operation in order to avoid damage on equipment and to minimize the fault impact on the system. This time covers the detection and identification times of the protection algorithm and the operation time of the CBs.
- Sensitivity: all relevant fault conditions must be detected.
- Selectivity: internal and external fault conditions must be properly differentiated and the isolated zone should be as small as possible.
- Recoverability: the system must reach a stable state after fault clearance.

These components are mainly measurement devices, protection algorithms, circuit breakers and fault-clearing strategies. Measurement devices are in charge of adapting the signals needed by the relays to operate properly. Protection algorithms use these measurements in order to discriminate between normal and fault conditions. Circuit breakers isolate the faulty part of the system, interrupting the current. The adopted fault-clearing strategy determines the impact of a fault condition on the system.

IV. CONCLUSION

Power systems contain protective devices to prevent injury or damage during failures. The quintessential protective device is the fuse. When the current through a fuse exceeds a certain threshold, the fuse element melts, producing an arc across the resulting gap that is then extinguished, interrupting the circuit. However, when the number of HVDC converters (and/or other power-electronic devices) is increased, the high-frequency interaction between different devices will be so complicated that local analysis may not result.

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