Dynamic Performance Study of a HVDC Grid Using Real-Time Digital Simulator

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Abstract—**The dynamic performance study of a three-terminal high-voltage direct current (HVDC) grid has been presented in this paper. The study has been carried out in real-time digital simulator (RTDS) platform. In order to standardize the internal controllers developed in RTDS, the results from the dynamic performance study are validated by comparing with the PSCAD results.**

Keywords-control; converter; dc grid, HVDC; real-time digital simulator

I. Introduction

The electricity consumption all over the world is increasing very rapidly in recent years. In Europe alone, the total electricity consumption has increased by 32.8% during 1990 to 2007 [1]. As a result, the European high-voltage alternating-current (HVAC) grid is operating very close to its limits. Moreover, the increased penetration of renewable energy resources, especially the wind energy, has given rise to several new challenges for the existing HVAC grid. Severe intermittency of these renewable sources actually demands the existence of a sufficiently strong grid spread over a large geographical area. In this perspective, the concept of a high-voltage direct-current (HVDC) grid is emerging, which can provide a strong backbone to the existing AC networks and can facilitate the integration of bulk amount of renewable energy.

Point-to-point HVDC links have already proven their effectiveness over the HVAC systems for long distance power transmission mainly because of the lower losses in the DC cables. For offshore wind connection, the additional advantage of HVDC is that it acts as a firewall between the offshore and onshore networks. There are two broad classifications of HVDC technology. One comprises of thyristor based line-commutated converters (LCC) and the other relies on insulated gate bipolar transistor (IGBT) based voltage-source converters (VSC). One of the main problems with LCC is that for a power reversal, LCC needs a reversal of the DC voltage. Whereas, VSCs are capable of changing the direction of power flow by reversing the current. This characteristic, along with some other advantages such as no need of additional reactive power support and the presence of a strong AC grid make VSCs the most suitable candidate for the formation of a multi-terminal HVDC grid and connections to offshore wind farms.

A VSC based multi-terminal HVDC grid, where several converter terminals are connected in parallel with the DC buses can be termed as a DC grid in a more generic sense [2]. However, an actual DC grid could be much more complex with a meshed structure, having multiple power flow paths between two points and with more than one DC voltage levels [3]. Such a DC grid can provide many advantages as follows: a) it can drastically reduce the number of converters compared to several point-to-point HVDC connections [4, 5], b) increase the flexibility in power flow control and energy trading [4], c) for offshore DC grid, it can reduce the effect of intermittency of the wind power and provide redundancy in case of transmission system failures [5].

With the advent of the DC grid concepts, it has become very essential to verify the emerging ideas through real-time simulations, because at present no such DC grid exists in reality, where the actual tests could be performed. With this purpose, ABB has developed a state-of-the-art real-time hardware-in-loop simulation resource for verification of DC grid control and protection. This paper reports some preliminary studies on a three-terminal DC grid simulated in real time digital simulation (RTDS), which will serve as a building block of the future research on DC grid. The important feature of this RTDS implementation is that in principal all basic features of ABB's control strategy for the VSC-HVDC stations, which are normally carried out in MACH-2 platform, have been incorporated inside the RTDS internal controllers. In order to benchmark the RTDS model and its internal controllers, all the simulation results are compared with the corresponding PSCAD results, where the PSCAD models employ a full-scale version of ABB's control functions.

II. Description of the Test System

A. General Description

The objective of the DC grid simulation centre is to develop a simulation setup for a multi-terminal HVDC system interconnected to several unsynchronized HVAC grids and offshore wind farm nodes. As a preliminary step towards that objective, a three-terminal DC grid is first modeled in RTDS platform. The AC side for each of the three stations is represented by 400 kV three-phase ideal voltage source behind

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small impedance as shown in Fig. 1. The DC side pole-to-ground voltage of the system is kept at 320 kV. Each converter station consists of a two-level VSC based on IGBT and anti-parallel diode, phase reactor and the DC link capacitor. The AC side of the converter is connected to the grid through a 425kV/400kV transformer with tap changer. All the converter stations have active and reactive power capabilities of +/-600 MW and +/-250 MVAR respectively.

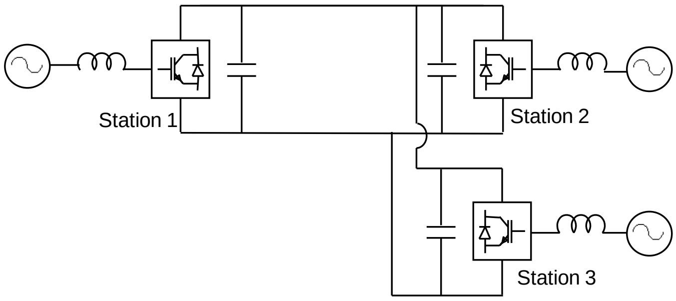

Figure 1. Three-terminal test system

B. RTDS Hardware Description

The entire test system is modeled in three PB5 processor cards in RTDS. PB5 cards are the latest generation processor cards having two PowerPC RISC processors (Freescale MC7448 RISC) operating at a clock frequency of 1.7 GHz. Compared to the earlier generation GPC processor cards, the PB5 cards have much higher computing capacity and higher number of communicating fiber ports with the other PB5 cards.

In the test system, the converter stations are modeled inside three separate small-time step subnetworks. The small-time step subnetwork has been developed in RTDS in order to model the VSC based systems more accurately. A dual time step technique is adopted, where the large scale network simulations run with a time step of 50 µs, and simultaneously the small-time step VSC models can be simulated with a time step of 1-3 µs [6]. With this arrangement, the high frequency PWM switching (in the range of 1.5 to 2 kHz) can be achieved with sufficient accuracy and with optimal allocation of hardware resources. In the simulated test system, three AC grids are modeled in large time step. The small time step VSC subnetworks are interfaced with the large time step AC systems through interfacing transformers. On the DC side, the small time step VSC subnetworks are connected through travelling wave models of transmission lines. In order to physically realize this interconnection, the PB5 cards are connected by fiber optic cables through the communicating fiber ports.

III. CONTROL STRATEGY

The schematic diagram of the control strategy of a point-to-point VSC-HVDC converter has been presented in Fig. 3. In a point-to-point scenario, one of the converter stations works in DC voltage control mode and the other station works in active power control mode. In case of a multi-terminal DC grid, only one station takes the responsibility of DC voltage control under normal condition. The remaining stations can be in active power control mode. However, it is better to incorporate additional DC voltage control loop in the active power controlling stations, so that during faults in the DC voltage controlling station, the other stations can take up the responsibility of controlling the DC voltage. Apart from that, all the converter stations can be in either reactive power or AC voltage control mode. For the three-terminal case study presented in this paper, station 3 is working as the DC voltage controlling station and stations 1 and 2 are in active power control mode. Since all the stations are connected to strong AC grids, instead of AC voltage control, the stations are kept in reactive power control mode.

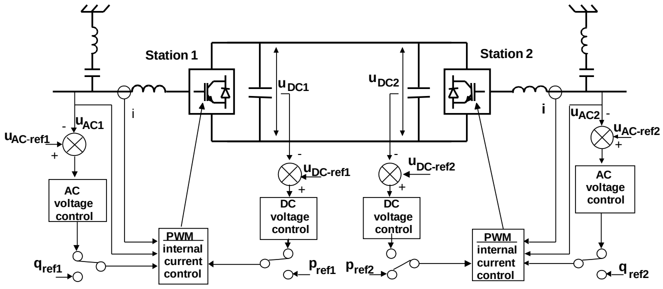

Figure 2. The control strategy of a point-to-point VSC-HVDC link

IV. PRELIMINARY RESULTS

A. Point-to-point scenario

In order to validate the performance of the RTDS internal controller, first a point-to-point VSC-HVDC model has been prepared in RTDS and the results are compared with the PSCAD-EMTDC results. A case study, where a 100 ms three-phase to ground fault is applied at the point of common coupling (PCC) of the DC voltage controlling station (station 2 for the two-terminal case), is presented in Figs. 4 and 5. In this case study, station 1 is acting as a rectifier carrying 600 MW (100%) of active power. The DC voltage is maintained at 1.0 p.u. (640 kV pole-to-pole) and the modulation index of both the converters are maintained approximately at 0.85 through the transformer tap changers. The reactive power command is set to zero for both the stations. As soon as the fault occurs, the power transfer from station 2 to the AC side comes to zero and the power coming from the AC side of station 1 starts charging the DC capacitor making the DC voltage to rise. However, during this period, station 1 takes the responsibility of controlling the DC voltage which does not allow the DC voltage to rise beyond a tolerable range. As the fault is cleared, the DC voltage control is transferred back to station 2 again and the power flow in the system is restored to the pre-fault values quite smoothly. It is also observed that the PSCAD and RSCAD results are almost the same which validates the correctness of the RTDS internal controller.

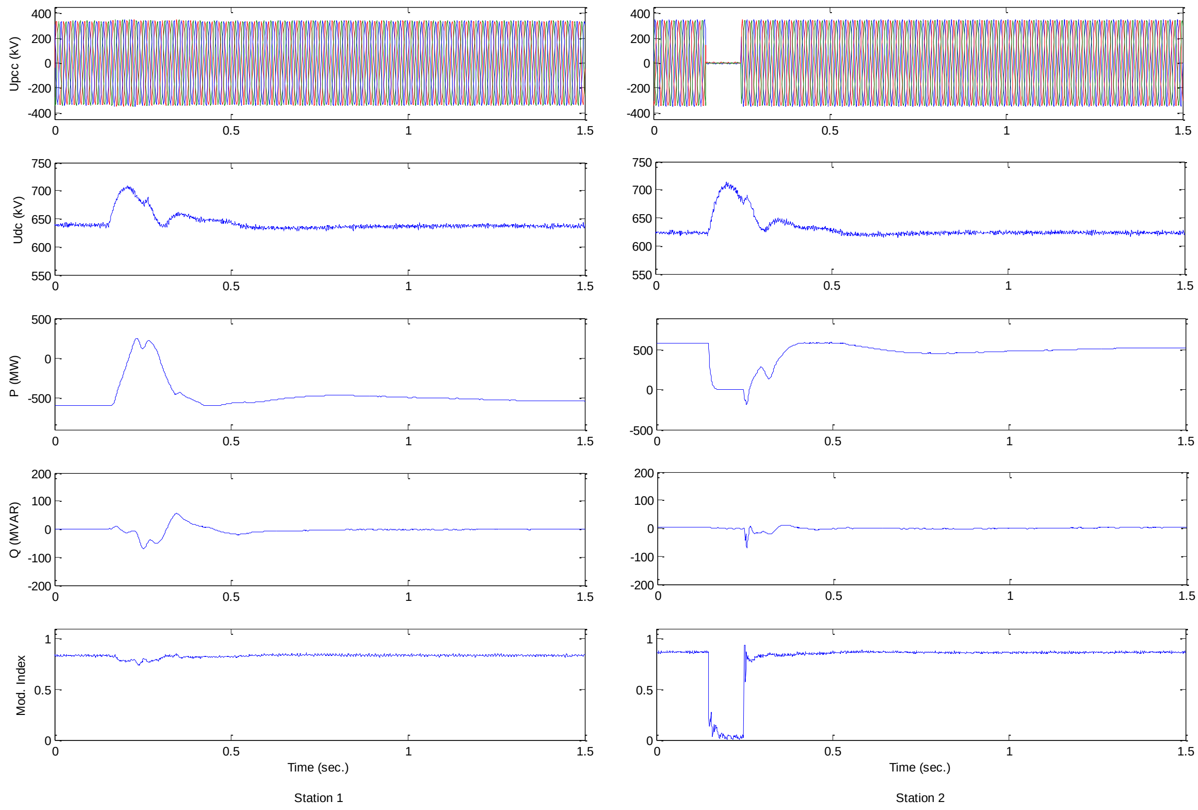

Figure 3. PSCAD results for a 100 ms three-phase fault at station 2

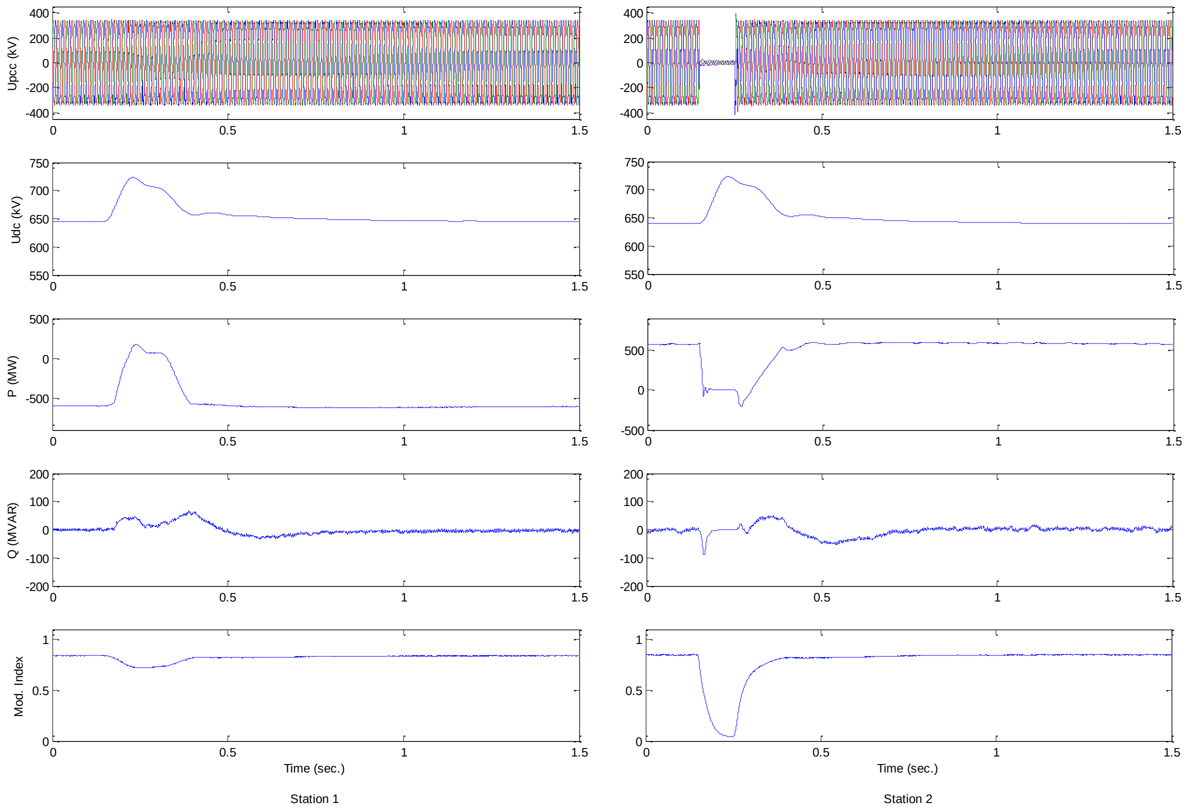

Figure 4. RSCAD results for a 100 ms three-phase fault at station 2

B. *Three-terminal scenario*

Once the RTDS internal controller performance is verified, the same controller is now applied for the RTDS model of the three-terminal DC grid. A case study is presented in this paper (Fig. 6), where stations 1 and 2 are working as rectifiers carrying 400 MW and 200 MW of active power respectively. As a consequence station 3, the DC voltage controlling station, works as an inverter transferring almost 600 MW of power. The reactive power command is as usual set to zero. A 100 ms three-phase to ground fault is now applied at the PCC of station 1. It is observed that the DC voltage variation is below 5% during the fault. The fault-ride-through is quite fast and smooth which establishes the effectiveness of the RTDS internal controller.

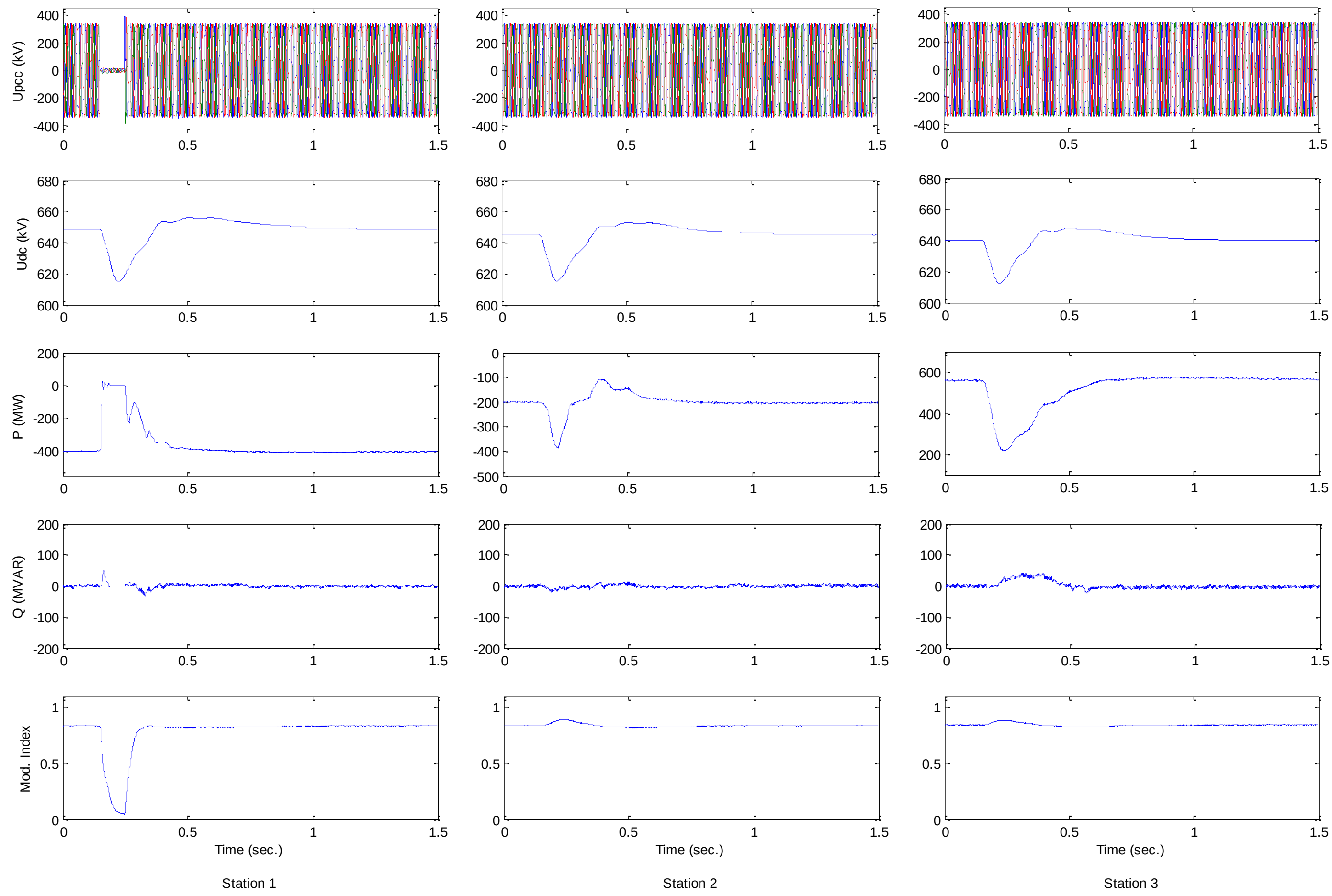

Figure 5. RSCAD results for a 100 ms three-phase faults at station 1

V. CONCLUSION AND FUTURE WORKS

The paper presents the dynamic performance study of a three-terminal DC grid simulated in RTDS. This three-terminal model will serve as the building block for the future studies on DC grid. The performance of the RTDS internal controller for the VSC-HVDC stations has been validated with PSCAD results. Few more case studies for the DC grid and more detailed analysis of the results will be included in the final paper.

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