Using Operation Data from Digital Fault Recorder to Validate STATCOM's Performance

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Abstract

To control voltage and enhance system stability, Dominion Energy has employed several Static Synchronous Compensators (STATCOMs). With the complexity of the system controller and modes of operation, ensuring STATCOMs' correct response to different dynamic events such throughout the grid become a challenge. Therefore, STATCOM's performance validation would be an essential analysis to be conducted. This procedure brings benefits to device management by identifying potential devices failure, improving dynamic model for simulation, and studying control interaction between STATCOMs. The proposed framework utilizes operation data saved in Digital Fault Recorder (DFR) during dynamic event and STATCOM's EMT-type model to validate STATCOM's response. This framework is able to get the accurate model response coming from STATCOMs with automatic gain change feature. This is achieved by estimating the external system's Thevenin impedance and accordingly changing the STATCOM gain. This paper presents how these issues have been solved in order to automate STATCOM's performance validation. Finally, the framework is validated based on three STATCOMs' actual events response.

***Key Words*—STATCOM, FACTS, PSCAD, DFR, Performance Validation, Model Validation**

I. Introduction

The uses of high speed switching devices such as IGBTs and GTOs has significantly increased thanks to the progress achieved in semiconductor technology in recent decade [1]. The IGBTs based Flexible AC Transmission System (FACTS) devices based on have been widely deployed across power network to increase power transfer capacity and system reliability [2][3]. Since the first Static Synchronous Compensator (STATCOM) came in service in 1991 Japan [4], STATCOMs have been deployed in commercial operation to provide voltage stability control. Compared with fixed switched capacitor bank (FSC), STATCOM provides more faster reactive power support to prevent overvoltage and undervoltage. In addition, STATCOM requires less space when comparing with thyristor based Static VAR Compensator (SVC). This is because STATCOM provides both inductive and capacitive power with Modular Multilevel Converter (MMC) such that Thyristor Switched Capbank (TSC) and harmonics filter would not be needed [5].

After commissioning or controller update, validate STATCOM's performance against models provided by vendors is mandatory to guarantee the reliability and accuracy of STATCOMs' performance [6][7]. However, it is challenging for operators and field engineers to verify devices' behavior due to the complexity of controllers. Besides, most of the control functions such internal current control loop and current modulation are "black-boxed" due to the protection of vendor's IP right. Hence, it is essential to find a solution that can validate FACTS devices performance to ensure their correct response. In recent decades, researchers and engineers have proposed several methods to validate FACTS devices' performance using average model or electromagnetic transient analysis tools (EMT-type) model. One of the commonly used method is to compare field measurement against RTDS model's response during STATCOM's start-up sequence to ensure devices' reliability and accuracy [8].

However, FACTS devices' performances during start-up/shut-down sequence could not represent their behavior under disturbances. Engineers and researchers are more interested about devices' response to dynamic events e.g., line faults, generator tripping, and load rejection. Very few researches are conducted using operation data to provide FACTS devices' performance assessment and model validation. One of the challenges is the difficulty of reproducing external system condition or short circuit level during the event. Without knowing its external system condition, it would be difficult to reproduce response from FACTS device with automatic parameter adjustment.

This paper proposed a systematic scheme to validate STATCOM's performance during dynamic events. This method utilized STATCOM's three phases EMT-type model in PSCAD and field operation data recorded in DFR. To automate the validation process, an automation framework is developed configure STATCOM with system's EMS settings. The proposed framework is able to replicate external AC system's short circuit ratio so that Auto-Gain change (AGC) can adjust STATCOM's gain accordingly.

II. STATCOM System Configuration

The diagram of STATCOM system including transformer and AC grid is shown in Fig.1. This simplified model shows a voltage source converter (VSC) for AC voltage/reactive power control and DC Capacitor that has a relatively constant DC voltage with minimum ripple. In the modern STATCOM designed, MMC based STATCOM contains multiple individual submodules. A small DC Capacitor is connected with each of these submodules.

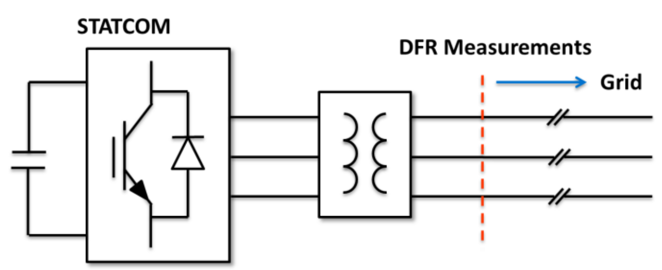

Figure 1 STATCOM configuration

A. *STATCOM Control Schemes*

There are two major control modes for modern STATCOMs' operation: voltage control mode (VCM) and Q control mode (QCM). By referring to voltage set point, VCM provides reactive power to maintain voltage. The control can be represented as the following equation.

$$V_{act} = V_{ref}\text{-slope} \cdot \frac{Q_{act}}{Q_{nominal}} \qquad (1)$$

where V_{act} denotes actual measured voltage and V_{ref} represents reference voltage. *slope* indicates STATCOM's droop control slope. Q_{act} represents actual reactive power output, while Q_{nomial} denotes its nominal reactive power value. According to Figure 2, the blue curve indicates that STATCOM is providing capacitive power if operating point is at the left hand side of the y-axis. When the operating point is at the right hand side, STATCOM provides inductive power to recover voltage.

If both VCM and QCM are applied at the same time, STATCOM will operate along the blue curve in within couple milliseconds when disturbance occurs. As soon as it reaches the intersected point with system load line (green), STATCOM starts bringing back the operating point to the Q set point Q_{ref}. Generally, the operation of QCM takes longer time (more than 10 seconds) than VCM; therefore, VCM is playing a key role during transient disturbance.

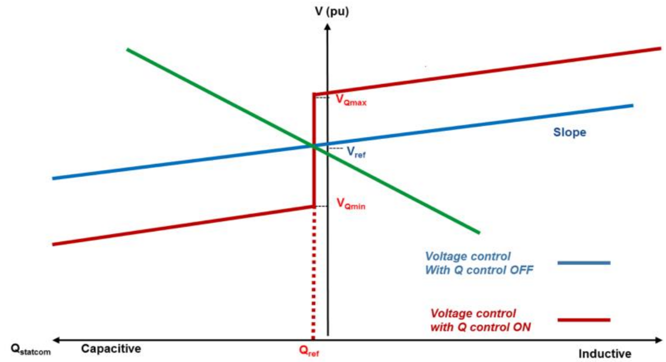

Figure 2 STATCOM's QV Control Mode

The gain adjustment function is required for STATCOM at the network system with risk of large short circuit level (SCL) change. The higher the SCL, the stronger the AC system is. When system is strong, STATCOM's gain can be set as a larger value. A lower SCL indicates a weaker AC system. To prevent overshoot and system instability condition when system is week, STATCOM gain will be adjusted to a lower value. To provide gain adjustment, there are two different methods: passive and automatic.

When controller detects multiple consecutive changes in control current signal, the passive gain adjustment method will reduce the gain in stepwise with a certain percentage until the system stability is reached. The gain will be automatically adjusted to its initial setting after disturbance is cleared. One of the drawbacks of this method is that the passive method can only reduce gain, but when SCL changes from low to high before the gain recovery at the end of the day, the gain setting cannot increase by itself. That means system will be running in a low gain setting even though the system strength is high. In order to solve this problem, the automatic gain change (AGC) is introduced. Figure 3 shows a field measurement of reactive power and gain change when ACG is activated. According to this figure, STATCOM injects reactive power to AC grid and measures its SCL by calculating dQ/dV. Based on the computed dQ/dV, STATCOM can adjust its gain accordingly. AGC can be activated cyclically several times a day.

In this paper, the AGC function is deployed in the STATCOM under study. The same function is also implemented in its PSCAD model and therefore its gain in

PSCAD cannot be adjusted manually by utility users. In order to set the gain to its pre-fault value, a scheme is introduced in this paper to provide pre-fault system SCL estimation such that the PSCAD model can automatically adjust its gain.

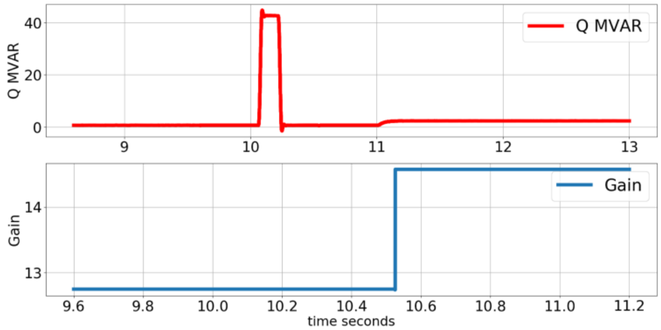

Figure 3 STATCOM Auto-Gain Control

B. *Measurements of STATCOM*

Dominion Energy's STATCOMs HMI information includes reference voltage, reactive power reference, gain, slope, etc. They are all stored in the EMS system.

When disturbance occurs, the disturbance will trigger STATCOM's DFR. In Dominion Energy, STATCOM's DFR is able to capture voltage/current transient with sampling rate of 9600 samples per second. As shown in Figure 1, the voltage and currents used for voltage and Q control are measured at the point of interconnection. The reactive power output of STATCOM is computed based on the transformer's primary side voltage/current. Besides AC voltage and current signals, DC voltage measurements and STATCOM's control currents are also stored in DFRs.

III. PERFORMANCE VALIDATIION SETUP

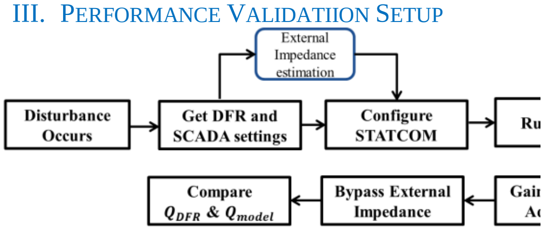

Figure 4. As it can be seen, as soon as disturbance occurs, STATCOM's DFR is triggered automatically. Then the automatic system starts extracting DFR measurements and STATCOM's EMS pre-event settings. The pre-fault SCL (external impedance) is estimated based on the given EMS gain value. The external impedance will be connected between the voltage source and STATCOM transformer. When the STATCOM's PSCAD model is finally configured based the pre-fault EMS settings, PSCAD starts running. Simultaneously, the DFR primary side voltage at the point of interconnection is replayed as a voltage source. The STATCOM gain is adjusted through the automatic adjustment system. When the gain adjustment is completed, the estimated external impedance is bypassed. Finally, the simulated reactive power output and reactive power computed based on voltages/currents stored in DFR are compared to provide performance validation report.

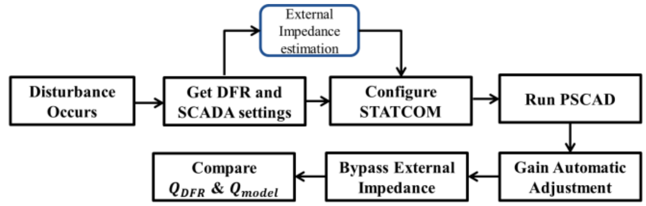

Figure 4 Workflow of Performance Validation

A. *Estimating the External Impedance*

In order to let the STATCOM automatically adjust its gain to a desire value, an estimated external impedance representing the actual system condition should be assigned to the model. To get the accurate impedance value, the relationship between gain and external impedance should be found.

By varying the external impedance with fixed slope of droop control in STATCOM's PSCAD model under nominal voltage, different gain values can be yielded. Finally, a polynomial regression model can be formulated based upon the gain and impedance values.

Figure 5 indicates that the polynomial model is able to portrait the actual relationship between gain and external reactance. Based on the polynomial model, we can estimate the external impedance given the gain from EMS.

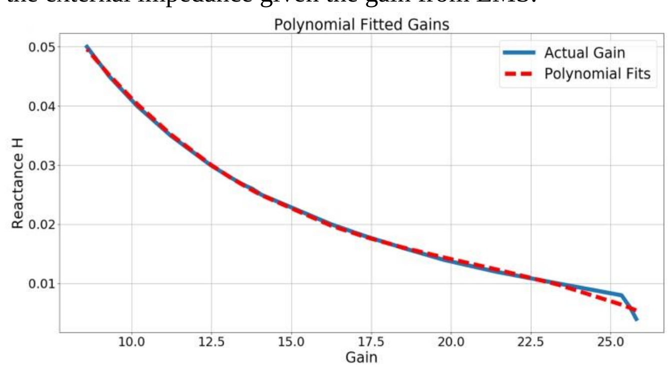

Figure 5 Actual Gain and Polynomial Fits

B. *Bypass the Estimated External Impedance*

The estimated external reactance is used for AGC only. When AGC is completed, the estimated external reactance will be bypassed. This is because the collected DFR voltage/current measurement has included the impact of external impedance already. STATCOM model will respond to the external impedance bypassing, however, the response has negligible impact. This is because changing the external impedance will only impact the load curve, but the

STATCOM work on the operating condition decided by the load curve.

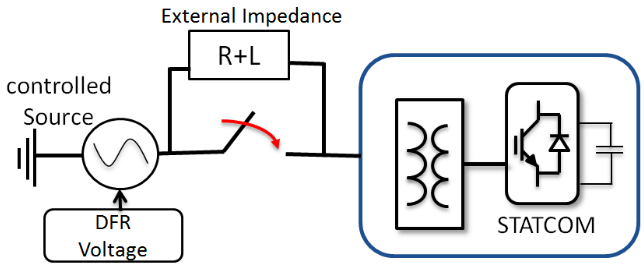

Figure 6 Bypassing External Impedance

IV. STATCOM Performance Validation

A. System Setup

The STATCOM under study is connected at Dominion's 230 kV bus. The reactive power output of STATCOM is within +/- 125 MVAR. The STATCOM is operating under VCM and QCM at the same time. To provide better reactive power margin, the STATCOM's reference reactive power Q_{ref} is set as 0 MVAR. The slope of droop control is set as 1%. In this study, three Dominion STATCOMs are validated with the same dynamic event.

The performance validation framework is written in Python which can be integrated with PSCAD where the STATCOM model is built upon. The framework is running on a server with 16 GB RAM and an Intel(R) i7-6820HQ CPU @ 2.7 GHz.

B. Performance Validation Results

A single line to ground fault disturbance occurred in Dominion system network on early 2019. Figure 7 shows the response of STATCOM No.1 recorded in one of the connected DFRs. According to this figure, the voltage measurement has a significant drop. The STATCOM quickly supplied a large amount of capacitive reactive power to maintain the voltage. When the fault is cleared, the reactive power supply of STATCOM is reduced to mitigate overvoltage.

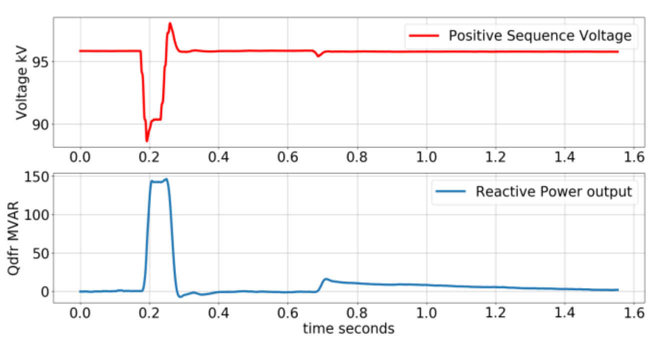

Figure 7 DFR voltage and reactive power

The EMS pre-fault gain settings for all STATCOMs are shown in Table 1.

Table 1 STATCOM Gain Settings

STATCOMs	EMS Gains	PSCAD Gains
No.1	13.5	13.6
No.2	9.3	9.7
No.3	12.4	13.0

The external reactance can be found by the given gain value and the pre-estimated polynomial model. With gain equals to 13.5, the external reactance L is set as 0.0265 H. The PSCAD model's gain value changed from default 12.75 to 13.65 when automatic gain adjustment is activated. It has to mention that the polynomial curve and **Error! Reference source not found.** only apply to the STATCOMs under studied in this paper only.

The performance validation result shown in Figure 8 indicates that the STATCOM is providing the same performance as what it is expected to be. As can be seen, the trend of the simulated reactive power response is close to the reactive power output stored in DFR.

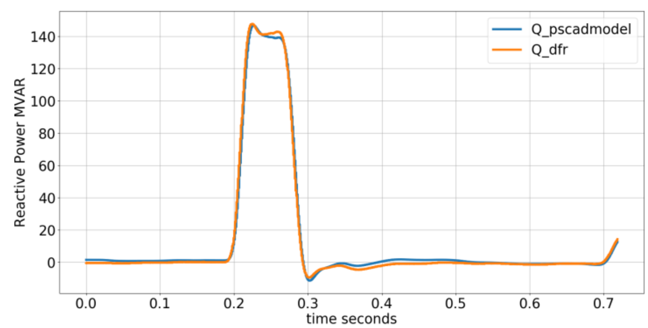

Figure 8 Performance validation result of STATCOM No.1

The results of STATCOM No.2 and 3 are shown in Figure 9 and Figure 10

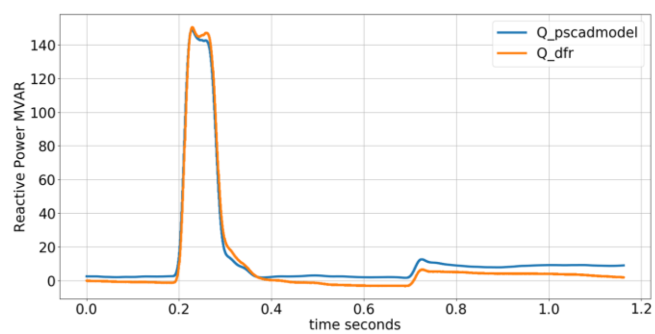

Figure 9 Performance validation result of STATCOM No.2

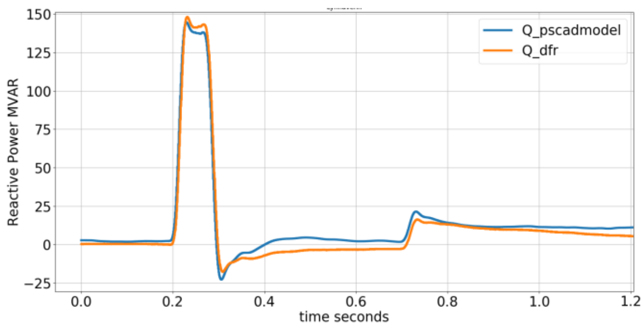

Figure 10 Performance validation result of STATCOM No.3

V. Conclusion

This paper proposed a systematical approach for STATCOM performance by evaluating vendor's validated model response against STATCOM's field measurements. An automation framework is developed based on the proposed methodology. This framework is able to automatically estimate external system's SCL and adjust STATCOM model in PSCAD based on EMS settings.

The test results based on 3 STATCOMS indicate that the proposed solution is able to provide reactive power response which closely matches the DFR reactive power measurements from the field. This study demonstrates that utilities can utilize this framework to provide STATCOM devices performance validation.

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About the Authors

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Robert Orndorff has worked at Dominion Virginia Power since 1984. He earned an A.A.S degree in Electronics in 1986 and spent 11 years as a field relay technician and in 1997 transferred to the Fault Analysis department where he currently works. His current responsibilities include maintaining and configuring Dominion's Digital fault recorders, event retrieval and analysis from smart relays and DFRs. Robert is an IEEE member and has been a member of the Transient Recorder's User Council (TRUC) since 2002.

Sergey Kynev received the B.Sc degree in Electrical Engineering and the M.Sc in Power Transmission Systems from St. Petersburg Polytechnical University, Russia in 2008 and 2010 respectively. He worked for HVDC Research Institute in Russia prior to joining Siemens Germany in 2011. He is currently a lead engineer for FACTS and synchronous condenser with Siemens in Raleigh, NC.

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