ON A MATLAB/SIMULINK COMPARATIVE SIMULATION OF VOLTAGE SAG MITIGATION IN IEEE 13-BUS DISTRIBUTION TEST FEEDER BY DVR AND D-STATCOM

MÔ PHỎNG SO SÁNH HIỆU QUẢ KHẮC PHỤC SỤT GIẢM ĐIỆN ÁP NGẮN HẠN TRÊN LƯỚI PHÂN PHỐI MẪU 13 NÚT CỦA IEEE BỞI DVR VÀ D-STATCOM

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ABSTRACT

This paper presents the comparative improvement of the voltage profile of the distribution system using a Dynamic Voltage Restorer (DVR) and a Distribution Static Synchronous Compensator (D-STATCOM). The IEEE 13-bus test system is used as a case study to show the effectiveness of DVR and D-STATCOM on mitigating voltage sags in distribution networks. In the simulation, a DVR is coupled on the branch connected to bus 632 or a D-STATCOM is supposed to be connected in parallel with bus 632. Comparative simulation results of the system with DVR and D-STATCOM are performed by using MATLAB/Simulink. The power quality event is simulated as the result of a three-phase fault at the downstream of the feeder. It's possible to conclude from the simulation results that DVR is more suitable to mitigate the voltage sag of the load side behind the DVR coupling position while D-STATCOM can enhance the voltage quality of a number of buses of the test system near the bus connected with D-STATCOM.

Keywords: *Distribution System, Dynamic Voltage Restorer (DVR), Distribution Static Synchronous Compensator (D-STATCOM), Voltage Quality, Voltage Sag.*

TÓM TẮT

Bài báo này trình bày về hiệu quả nâng cao chất lượng điện áp trên lưới phân phối điện bằng cách sử dụng thiết bị điều áp động (Dynamic Voltage Restorer - DVR) và thiết bị bù đồng bộ tĩnh trong lưới phân phối (Distribution Static Synchronous Compensator - D-STATCOM). Lưới phân phối mẫu 13 nút của IEEE sẽ được sử dụng như một trường hợp để minh họa cho hiệu quả định lượng việc cải thiện sụt giảm điện áp ngắn hạn trên lưới phân phối của DVR và D-STATCOM. Trong mô phỏng này, phương án một DVR được kết nối trên nhánh nối với nút 632 sẽ được so sánh với phương án một D-STATCOM được nối song song với phụ tải nối vào nút 632. Việc mô phỏng hệ thống có DVR và D-STATCOM được thực hiện trên MATLAB/Simulink. Sự kiện chất lượng điện năng được xem xét là sụt giảm điện áp ngắn hạn do ngắn mạch xảy ra ở phía cuối lưới mẫu. Có thể kết luận là việc sử dụng DVR sẽ phụ hợp hơn để cải thiện chất lượng điện năng cho các phụ tải phía sau điểm đặt DVR trong khí D-STATCOM sẽ cải thiện được chất lượng điện năng cho nhiều phụ tải ở gần điểm kết nối D-STATCOM.

Từ khóa: *Lưới phân phối, thiết bị điều áp động (DVR), thiết bị bù đồng bộ tĩnh D-STATCOM, chất lượng điện áp, sụt giảm điện áp ngắn hạn.*

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1. INTRODUCTION

With the presence of increasingly number of sensitive loads (e.g. electronics appliances, PC and variable speed drivers…) the customer's power quality requirement have become higher recently in Vietnam that pushes the utilities under the pressure for supplying a better power quality such as low power uninterruption rate, low harmonics distortion, stable voltage and frequency [1]. However, distribution systems are also the areas numerous nonlinear loads are directly connected, which significantly affect the quality of power supplies. Power quality disturbance can be defined as the deviation of the voltage and the current from its ideal waveform. When a fault happens at the system it may cause voltage sag or swell in the entire system [1]. For mitigating that issues, Flexible AC Transmission System (FACTS) devices are introduced as an effective solution where shunt devices, commonly called Distributed Static Synchronous Compensator (D-STATCOM) and series devices, commonly called Dynamic Voltage Restorer (DVR) are most suitable for voltage quality improvement [2]. Normally, D-STATCOM is intended to be used to compensate reactive power or control voltage operation at it connected bus [3]. On the other hand, DVR is preferred to enhance the voltage profile of the system under different voltage sag and swell conditions [4, 5]. Besides, DVR rating can be reduced by adding a battery energy storage system [6]. The effectiveness and robustness in voltage stability and power quality control for custom power devices by using DVR and D-STATCOM are introduced and tested in PSCAD/ETDMC environment [7].

To have a better understanding of DVR's and D-STATCOM's application, in this paper, D-STATCOM and DVR are respectively used for the load bus voltage control and their performance will be analyzed and compared. This paper includes the following: Basic structures of DVR and D-STATCOM are introduced in Section 2 and 3, respectively. System configuration is shown in section 4. The simulation results are described and analyzed in Section 4. Finally, the conclusions are made in the Section 5.

2. BASIC STRUCTURE OF DVR

As one of the FACTS devices, Dynamic Voltage Restorer (DVR) is connected in series to power system for the purpose of protecting sensitive loads in case of the line fault such as voltage sags. However, the primary function of the DVR is not only to compensate the voltage sags but also perform as harmonics elimination, fault current limitation and voltage transient reduction [9].

Figure 1 shows the basic structure in single line of the DVR which is connected between the AC source and the load. In this figure, a Voltage Source Converter (VSC) with a DC supply is connected in series to the AC line via a transformer. When the voltage sags occurs at the load side, the VSC injects or draws an amount of compensating ac voltage to or from the scource voltage in order to mitigate voltage sags. Note that, the compensating ability of the DVR strongly depends on the amount of energy that stored at the DC side of the VSC.

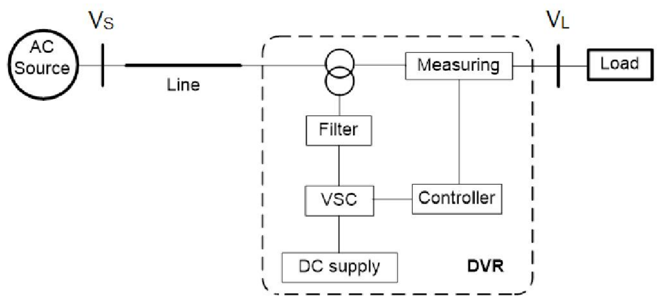


Figure 1. Basic DVR Model

3. BASIC STRUCTURE OF D-STATCOM

In general, Distribution Static Compensator (D-STATCOM) is a shunt FACTS device that can regulate network voltage at its connection point, mitigate the impact of disturbing loads such as voltage variations, unbalance and harmonics and compensate load reactive power [10, 11].

Figure 2 presents the single line model of a D-STATCOM. It consists of a VSC with DC supply connected to the AC source via a transformer. The operating principle of the D-STATCOM is based on the comparison between the AC voltage at the AC side of the VSC and the AC voltage of the grid at the point of common coupling. When the grid voltage is greater than the D-STATCOM voltage, D-STATCOM will absorbed reactive power, on the contrary, when the grid voltage is less than the D-STATCOM voltage, D-STATCOM will inject reactive power to the distributed [11].

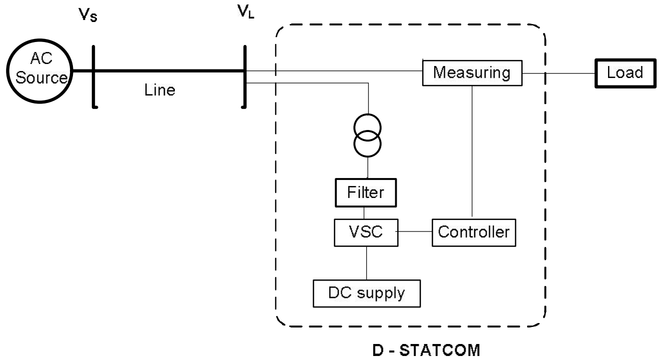


Figure 2. Basic D-STATCOM Model

4. PROBLEM DEFINITION

4.1. Test system

The studied distribution system in this paper is referred (in Figure 3) to the IEEE 13-bus distribution test feeder configuration with a source bus (bus 650) and 12 load buses [8] is used. This is a typically industrial distribution feeder where various power quality events can be assumed for analysis. The paper modified the line configuration to three-phase for the whole test systen for taking account of the distribution system in Vietnam in practice.

Problem definition:

For comparatively analysing the effectiveness of DVR and D-STATCOM on power quality mitigation, the following main issues are assumed:

Event modeling: The paper considers the case where DVR or D-STATCOM can mitigate the voltage sag caused by short-circuit inside the system under the test. Therefore, for fault modeing, the paper introduces the three-phase short-circuit at the bus 633 with the fault impedance at the fault location Z = 0.257 + j0.000175.

Alternatives of DVR and D-STATCOM location: Two cases of study are considered where a proposed DVR is supposed to be coupled on the branch 632-645 or a D-STATCOM is assumed to be connected in parallel with at bus 632 as shown in Figure 3. As the distribution feeder topology, these locations are possibly the best for analysing the DVR and D-STATCOM effectiveness on voltage quality mitigation.

Test system parameters are assumed in Table 1.

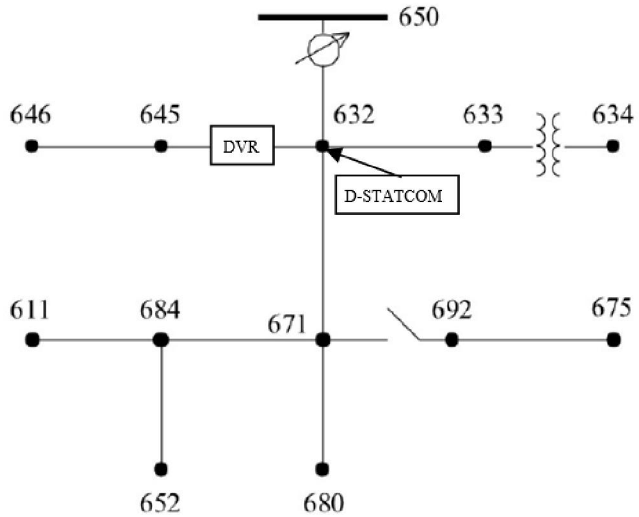


Figure 3. Configuration of the studied system with DVR /D-STATCOM

Table 1. Test system parameters

AC source	Constant voltage, 12kV, 50Hz
DVR's main parameters	
Filter circuits	$L=0.76\times10^{-4}$(H), $R=0.26\Omega$, $C=30\times10^{-3}$(F)
Coupling Transformer	10MVA, ratio 1:1 at 6.9kV
D-STATCOM's main parameters	
Filter circuits	$L=0.001\times10^{-6}$(H), $R=0.00001\Omega$, $C=10^{-12}$(F)
Coupling Transformer	100MVA, ratio 1:1 at 12kV

4.2. Simulations on Simulink

Figure 4 is the test system with DVR in Simulink. Detailed DVR and D-STATCOM coupling and controls are simulated in Figure 5 and 6.

Figure 5 shows the configuration of the proposed DVR design using MATLAB/SIMULINK, where the outputs of a three-phase half-bridge inverter are connected to the utility supply via wye-open connected series transformer. Once a voltage disturbance occurs, with the aid of d-q-o transformation based control scheme, the inverter output can be steered in phase with the incoming ac source while the load is maintained constant.

The basic functions of a controller in a DVR and D-Statcom in Figure 5, 6 are the detection of voltage sag events in the system; computation of the correcting voltage, generation of trigger pulses to the sinusoidal PWM based DC-AC inverter, correction of any abnomalities in the series voltage injection and termination of the trigger pulses when the event has passed. The controller may also be used to shift the DC-AC inverter into rectifier mode to charge the capacitors in the DC energy link in the absence of voltage sags. The d-q-o method gives the sag depth and phase shift information with start and end times. The quantities are expressed as the instantaneous space vectors. Firstly convert the voltage from a-b-c reference frame to d-q-o reference. For simplicity zero phase sequence components is ignored. The detection is carried out in each of the three phases.

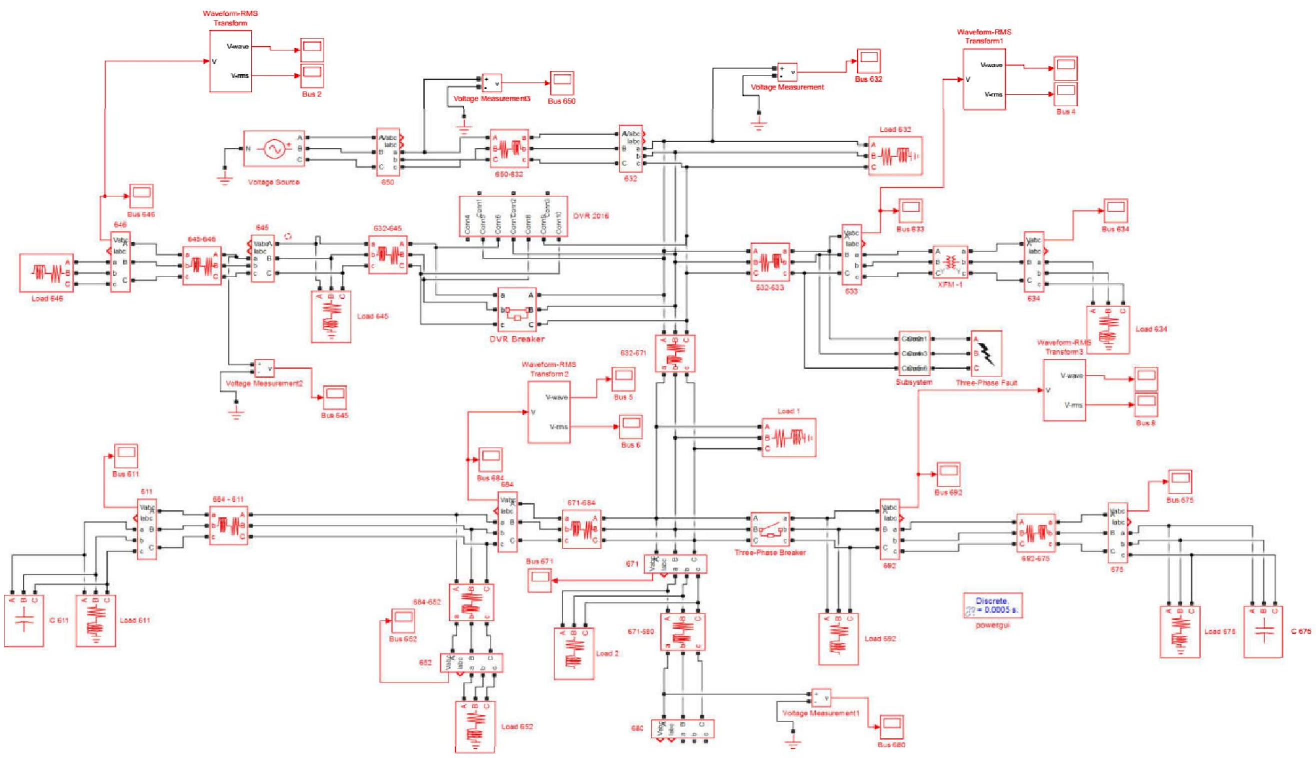


Figure 4. IEEE 13 bus test feeder with DVR in Simulink

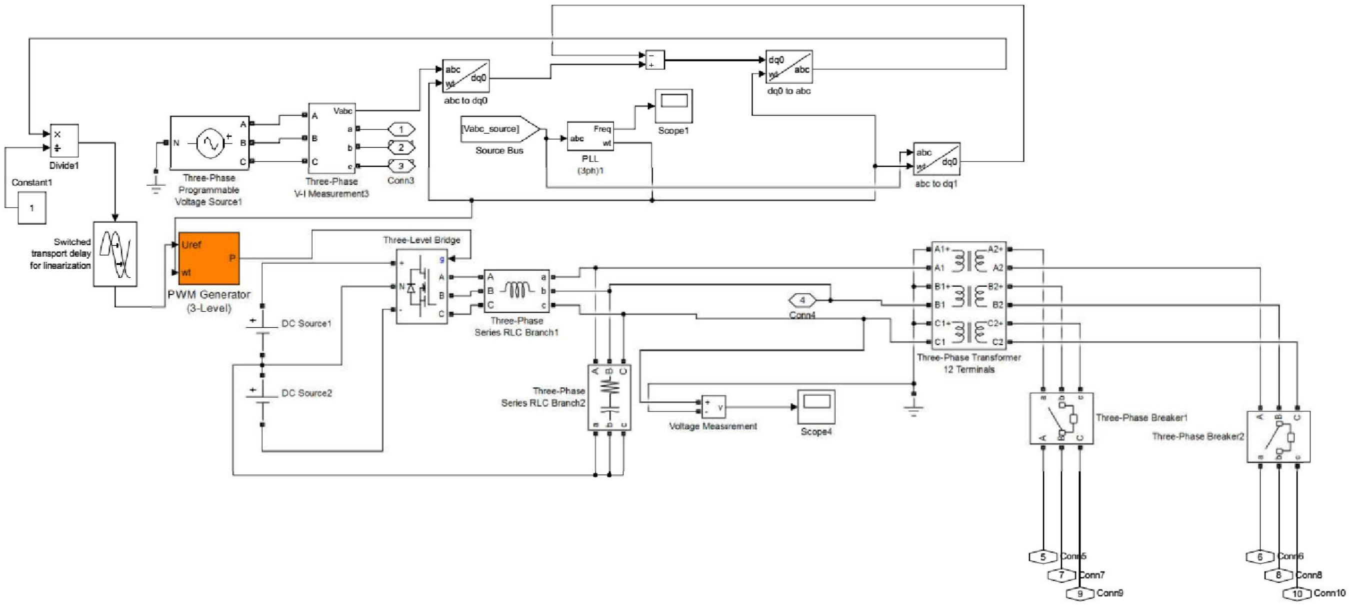


Figure 5. DVR control and coupling

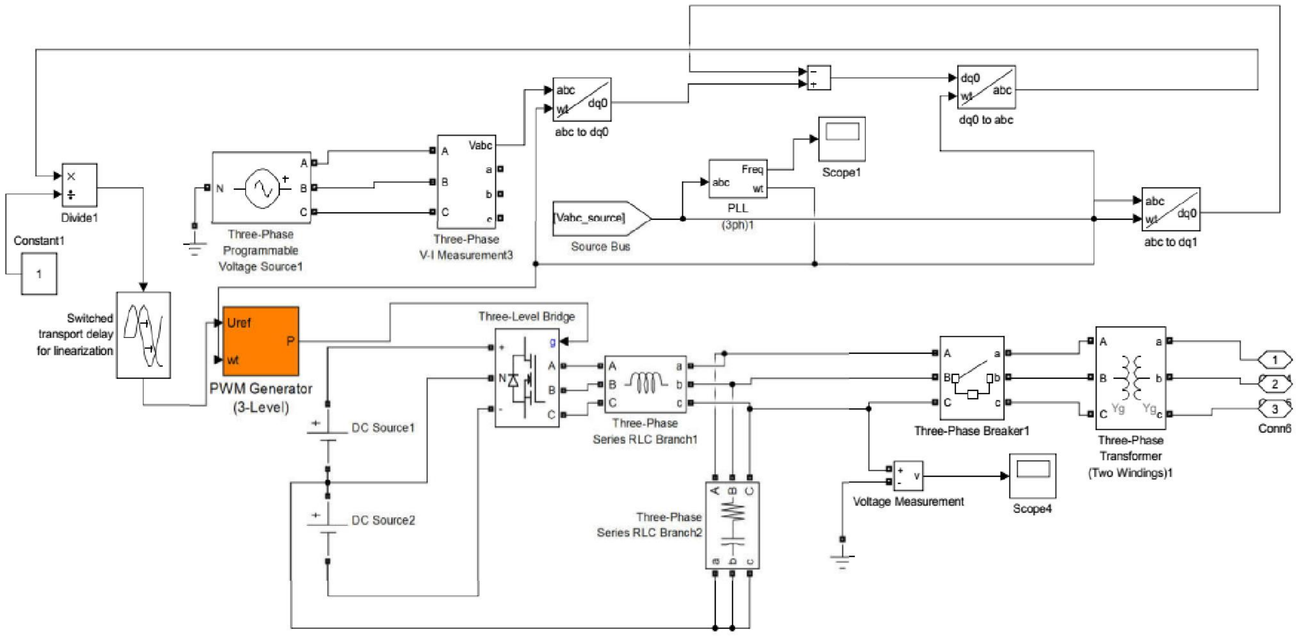


Figure 6. D-STATCOM control and coupling

The control scheme for the proposed system is based on the comparison of a voltage reference and the measured terminal voltage (V_a, V_b, V_c). The voltage sags is detected when the supply drops below 90% of the reference value whereas voltage swells is detected when supply voltage increases up to 25% of the reference value. The error signal is used as a modulation signal that allows to generate a commutation pattern for the power switches (IGBT's) constituting the voltage source converter. The commutation pattern is generated by means of the sinusoidal pulse width modulation technique (SPWM); voltages are controlled through the modulation. The block diagram of the phase locked loop (PLL) is illustrated in Figure 5, 6. The PLL circuit is used to generate a unit sinusoidal wave in phase with mains voltage

5. SIMULATION RESULTS

The simulation results of the test system are performed in MATLAB/Simulink. Figures 7 to 9 show the comparative transient responses at a couples of buses in the test system with or without the the proposed DVR and D-STATCOM when a three-phase short-circuit through an admittance fault Z_f = 0.257 + j0.000175 happens at bus 633 and is cleared after 0.2 s.

In these figures, the red lines, blue lines and black lines are used to present the performance of the rms voltage of phase A, phase B, and phase C in p.u. respectively.

The Figure 7 shows the deepest voltage sag at bus 633 in case of without DVR or D-STATCOM. Because it is a through an admittance fault, the voltage at bus 633 does not decrease to zero.

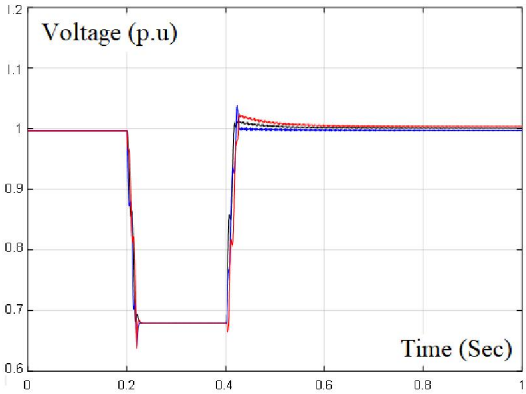
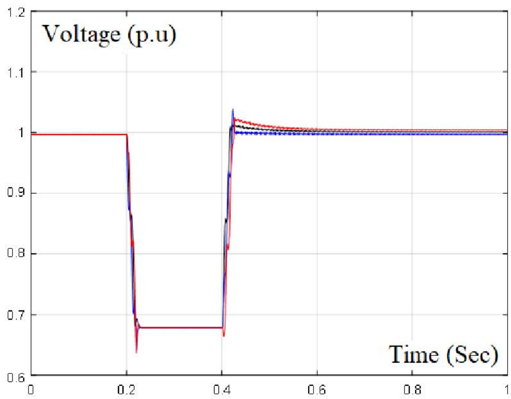
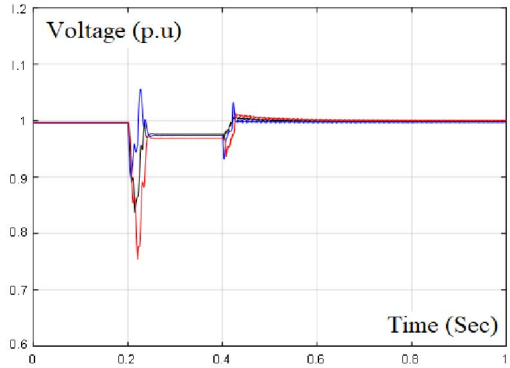


Figure 7. Voltage at bus 633 (short-circuit position) without DVR/D-STATCOM

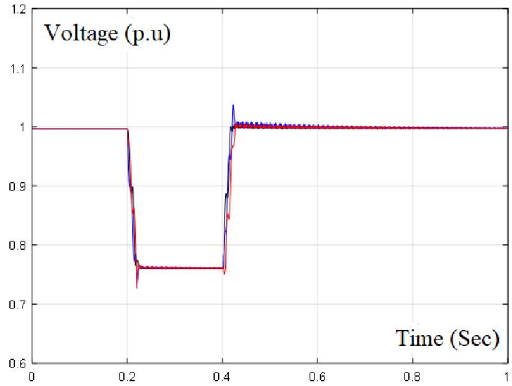
When DVR or D-STATCOM is respectively inserted in the test system, their effects of voltage sag mitigation are tested. Through the Figure 8 to 9, the voltage quality at three buses are again monitored and the results show that the voltage sags are more or less mitigated. Firstly, we consider the case the test system with DVR. The voltage sag at bus 633 (fault location) is almost unimproved (Fig. 8a). However, at the bus 646, the voltage sag is nearly 100% mitigated (Fig. 8b). That means the load behind the DVR is well protected. Now, we look at the voltage of another bus in the test system before the DVR from the fault location, such as bus 684. When fault occurs at bus 633, fault current flows through the path 650-632-633. So the voltage sag at 648 is the same as that of the bus 632 (as the point of common coupling). It experiences a rather deep sag (Fig. 8c). So we can say that the bus 648 is not protected. The similar voltage sag can also be experienced by buses downstream the feeder from the bus 632.



a. Voltage at bus 633 with DVR

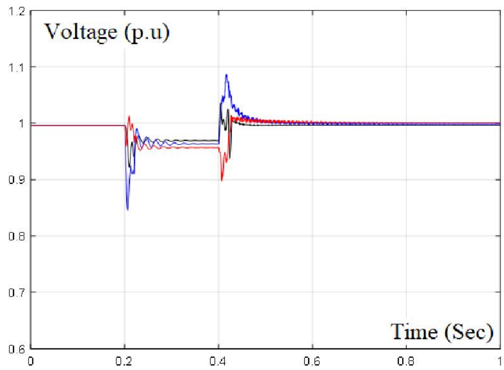


b. Voltage at bus 646 with DVR

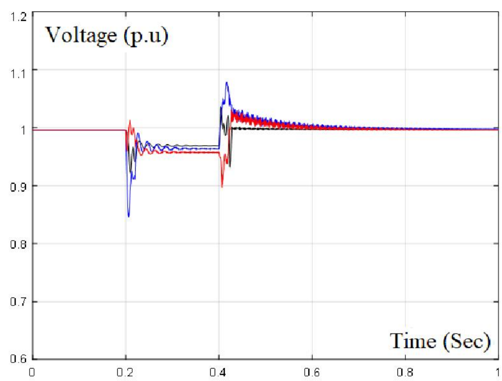


c. Voltage at bus 684 with DVR

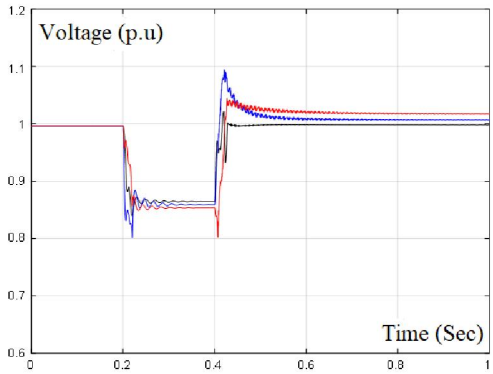
Figure 8. Simulation results of the test system with DVR when a three-phase short-circuit fault happened at bus 633



a. Voltage at bus 646 with D-STATCOM



b. Voltage at bus 684 with D-STATCOM



c. Voltage at bus 633 with D-STATCOM

Figure 9. Simulation results of the test system with D-STATCOM when a three-phase short-circuit fault happened at bus 633

If we consider the test system with D-STATCOM connected at the bus 632, the voltage sag in the system look more mitigated even at the fault location (bus 633 as Fig. 9c). The voltage sag at bus 646 is almost mitigated (Fig. 9a). For the bus 648, the voltage is also improved (Fig. 9b). That means when D-STATCOM is in service, not only the voltage at D-STATCOM connected bus is protected but also the voltage of other buses near D-STATCOM location are improved. Therefore, from the viewpoint of system indices of voltage sag (SARFI), we can conclude that using D-STATCOM have a better performance than DVR.

6. CONCLUSIONS

This paper presents a casestudy of mitigating voltage sag due to fault in the IEEE 13-bus distribution power system. A DVR and a D-STATCOM have been introduced and integrated to the test system as the solution for voltage sag mitigation. The results of the simulation indicate that regarding the system indice (SARFI), the D-STATCOM is generally better than DVR for mitigating voltage sags due to short-circuits in distribution system. While DVR is preferred as the solution for a single (load) circuit protection, D-STATCOM is seen as a systematic solution. This research can be developed with other power quality events including voltage flutuation or harmonics.

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