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# Mitigation of Voltage Sag for Different Types of Fault by Using Dynamic Voltage Restorer (DVR)

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**Abstract**: The power Quality (PQ) problem is a crucial study in electrical power, and it can be defined as changes in amplitude, frequency, and waveform in a voltage and current. Voltage sag is one of the PQ problems that commonly occurs in power systems, and it is usually caused by Three Phase Fault (TPF) and switching on heavy loads. The aim of this project is to modify the IEEE 5 busbar network system and simulate it in MATLAB Simulink, to create the voltage sag in the modified system, and to mitigate the voltage sag created by using a Discrete Fourier Transform (DFT) controlled Dynamic Voltage Restorer (DVR). The voltage sag was created by applying TPF using the Three Phase Fault block in Simulink and switching on heavy load was created by connecting the heavy load to the modified system using the Three Phase Breaker block in Simulink. The result shows that the voltage sag created by using TPF was 50.1%, and 20.5% for switching on heavy load in the modified system and it was successfully mitigated by using the DFT-controlled DVR.

**Keywords**: Power Quality, Voltage Sag, Three Phase Fault, Switching On Heavy Load, Dynamic Voltage Restorer

## 1. Introduction

Power Quality (PQ) has always been an interesting and crucial study for electrical power utility and any type of power system. Poor electric PQ was not only limited to interruptions in the energy supply but also due to the increment of sensitive loads in the power system [1]. Changes in amplitude, frequency, and waveform in a grid voltage and current can be defined as PQ problems [2]. PQ issues can be triggered by various external and internal events. The external events that could potentially cause PQ issues are diverse and may include lightning strikes, contact of animals with power lines, and tree branches coming into contact with the power line. Meanwhile, the common internal events that have been identified to give rise to PQ issues include the starting and stopping of heavy loads, switching operations, and faults in the distribution network. These events have been shown to have a significant

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impact on the PQ of the system, leading to deviations from the desired voltage, frequency, and waveform characteristics. These events lead to PQ problems such as voltage sag, voltage swell, transient, and interruptions. Voltage sag can have a significant impact on the operation of voltage-sensitive loads, such as computers and other electronic equipment, and can cause disruptions in power quality.

Voltage sag is described as the sudden reduction of voltage amplitude between 0.1 and 0.9 pu in a time from 10 milliseconds to a minute [1]. In power systems, voltage sag is normally caused by short-circuit faults [3], also usually by the starting of a large rating induction motor [4]. Other types of faults that may occur in power distribution systems are single line to ground fault (SLGF), double line to ground fault (DLGF), and three phase fault (TPF). The problem of voltage sag caused by SLGF, DLGF, and TPF can have a significant impact on the reliability and efficiency of power systems. These types of faults may create a problem for voltage-sensitive load operations that are mostly based on electronic components that may experience system shutdown. Not only to prevent damage to sensitive equipment, the power factor also can be improved by mitigating voltage sag phenomena in the power system. Therefore, there are many types of methods that were introduced to deal with the issues of voltage sag in electrical power systems. One of the methods is the use of DVR technology that can effectively mitigate the voltage sag, ensuring a stable and reliable power supply.

## 2. Methodology

The test case was modified and simulated using the MATLAB Simulink simulation software. The test case circuit was modified to create the steady state condition, fault condition, and mitigation condition.

### 2.1 Steady state condition

Figure 1 shows the modified test case in MATLAB Simulink. The test case consists of 25kV three-phase sources, 25kV/11kV step-down transformer, 11kV/0.4kV step-down transformer, a three-phase breaker connected to three phase large load, and a sensitive load. The sensitive load was created as the load that needed to be protected from the voltage sag. Meanwhile, three phase large load was added as a purpose to create a situation of switching on heavy load to create voltage sag. The steady-state case was also simulated according to Figure 1 without the TPF and switching on a heavy load. Therefore, no voltage sag was created in the modified test case, and it was simulated under steady-state conditions.

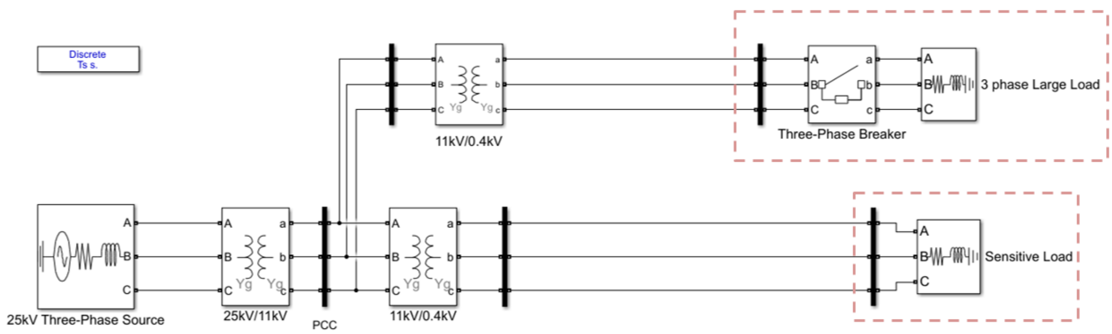


**Figure 1: Modified Test Case**

### 2.2 Fault Condition

Figure 2 shows the modified test case for the fault condition of TPF. In this project, a three-phase fault block in the Simulink library was used to create the TPF in the modified test case system. The three-phase block was connected to the upper power line of a modified test case to create the voltage sag that affects the power line that consists of voltage-sensitive load.

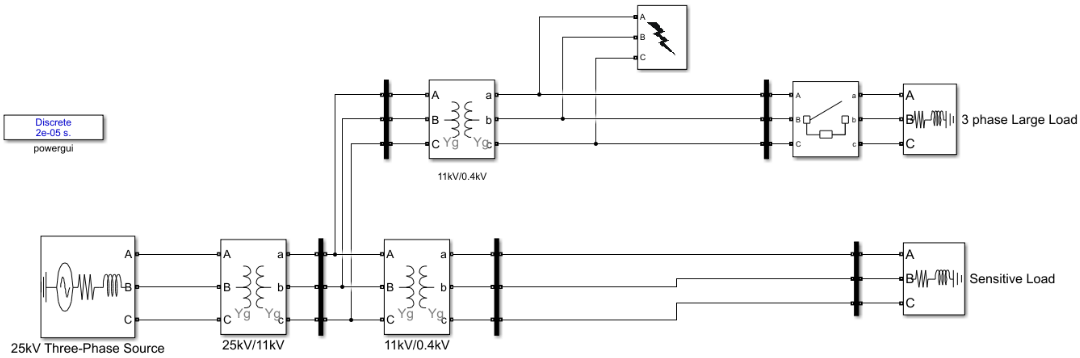


**Figure 2: Modified test case with TPF**

Figure 3 shows the modified test case for the fault condition of switching on heavy loads. In this project, a three-phase breaker block in the Simulink library was used to create the situation of switching on a heavy load. The three-phase breaker block was connected to three phase large load at the upper power line of a modified test case to create the voltage sag that affects the power line that consists of voltage-sensitive load. The switching time of three phase large load was set to 2 seconds to 2.5 seconds. In this condition, the three-phase heavy load was connected to the modified test case system.

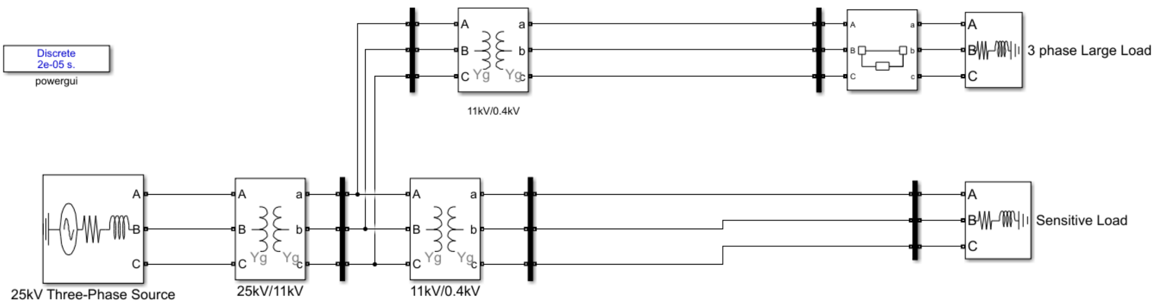


**Figure 3: Modified test case with switching on heavy load**

## 2.3 Mitigation Condition

Figure 4 shows the DFT-controlled DVR was connected to the modified test case for the fault condition of TPF. The DVR was connected to the power line of voltage-sensitive load in the test case system to mitigate the voltage sag created by the TPF. The DVR was connected in series to the power line to inject the voltage to compensate for the voltage sag. Meanwhile, for the switching on heavy load fault condition, the connection of DVR was similar to the condition during TPF. The DVR was connected in series to the power line that consisted of voltage-sensitive load. The aim of the DVR for both types of faults was to mitigate the voltage sag created.

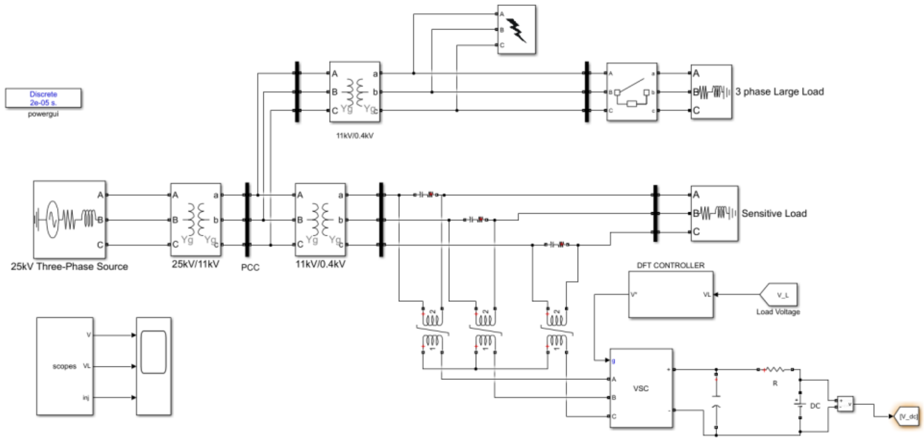


**Figure 4: Modified test case with DVR connected**

2.3 DVR modelling

Mathematical modelling of DVR can be composed as (Eq. 1). The injection voltage from DVR should satisfy the (Eq. 1) as to provide the additional voltage for mitigation of voltage sag.

$$V_{DVR} = V_L + Z_{TH} I_L - V_{TH} \quad (Eq.1)$$

Where,
$V_{DVR}$ is injection voltage from DVR.
$V_L$ is nominal load side voltage magnitude.
$Z_{TH}$ is sensitive load side impedance.
$I_L$ is sensitive load side current.
$V_{TH}$ is fault voltage.

The load current $I_L$ is given by (Eq. 2)

$$I_L = \frac{P_L + jQ_L}{V} \quad (Eq.2)$$

When $V_L$ is considered as a reference, equation can be written as (Eq. 3)

$$V_{DVR}\angle\alpha = V_L\angle 0 + Z_{TH}\angle(\beta - \theta) - V_{TH}\angle\delta \quad (Eq.3)$$

Figure 5 shows the model of DVR modelled in Simulink. The DVR model used a principle of PWM-based control scheme to control the VSI used in DVR. Figure 5 shows the DVR with the DFT controller. In this simulation, the DFT controlled DVR was used in this simulation to mitigate the voltage sag that were created in the system. The DVR in Figure 5 consists of a 3-phase RC filter, 3-phase injection transformer, control circuit, voltage source converter, with DC link. Figure 6 shows the algorithm of the DFT controller of the DVR [5].

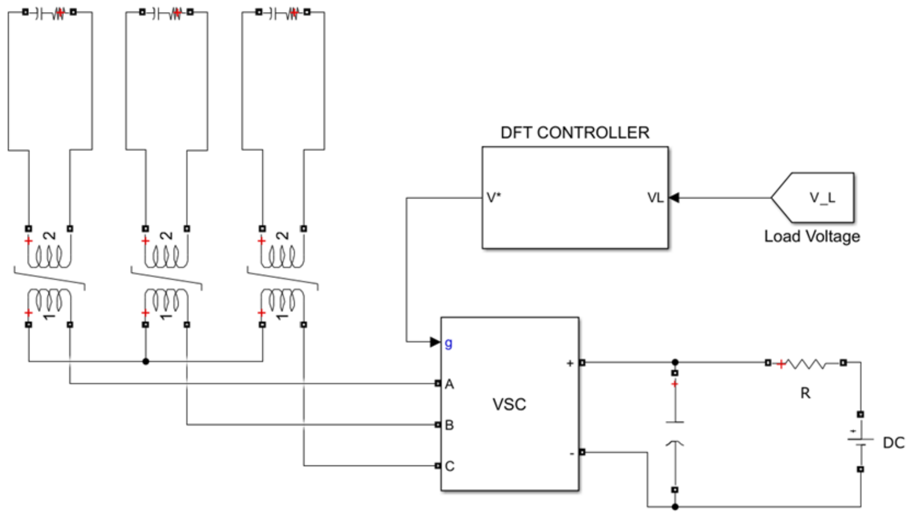


**Figure 5: DVR model**

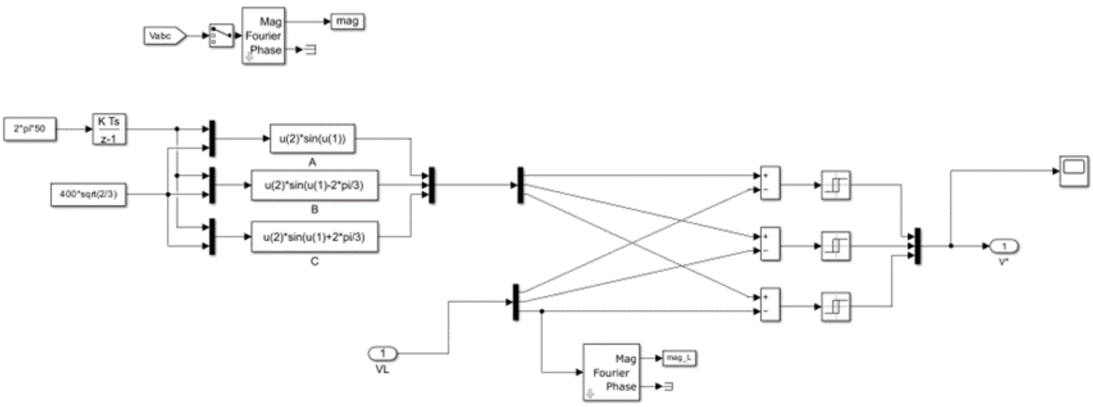


**Figure 6: Model of DFT algorithm control circuit**

## 3. Results and Discussion

### 3.1 Steady state condition

The system model was simulated without TPF and sudden switching on of a large load. The three-phase breaker block and three phase fault block were not manipulated. No voltage sag was created in the test case system. Figure 7 shows the voltage waveform for the system under normal conditions. The voltage measured for the source and load side was 324V for each phase. No changes were observed in voltage amplitude for load voltage. Voltage reduction was not in the system. Therefore, the distribution system was in normal condition without any fault.

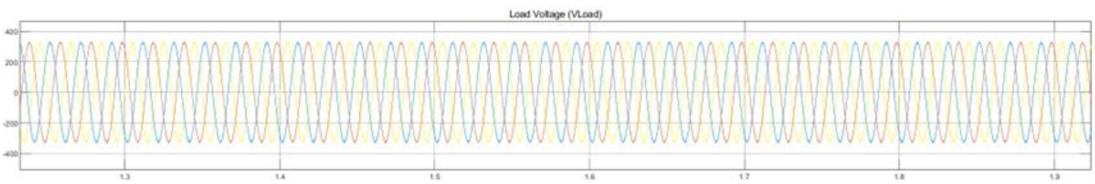


**Figure 7: Sensitive load voltage waveform under normal condition**

3.2 Fault condition

The system model was simulated for fault conditions without connecting the DVR to the test case system. A voltage sag was observed from 0.2 seconds to 0.5 seconds, with a magnitude of 160.5V and a 50.6% reduction in voltage level. The reduction in voltage amplitude of the load side was depicted in Figure 8. Therefore, the TPF-caused voltage sag was successfully simulated with the three-phase fault block.

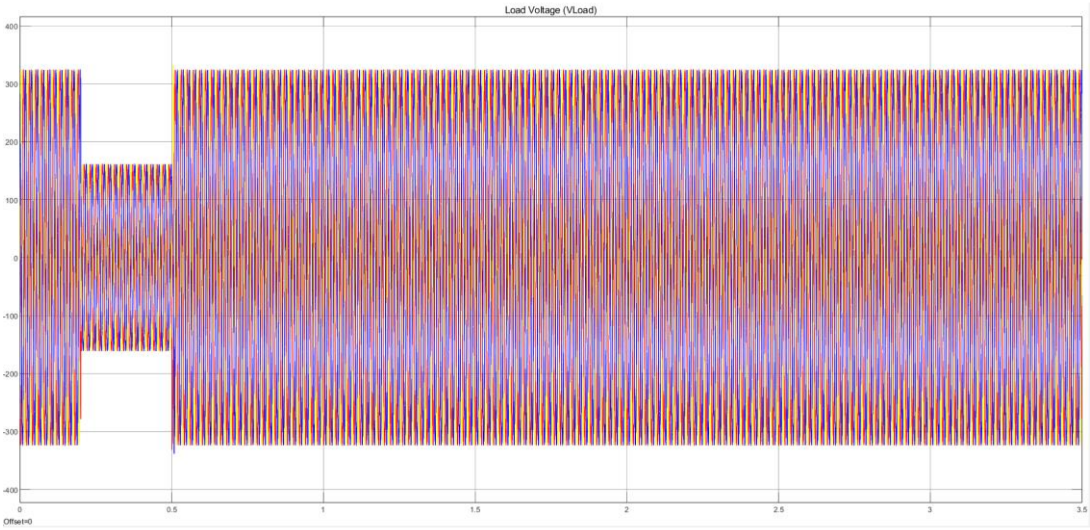


**Figure 8: Sensitive load voltage during the TPF**

Next, Figure 9 shows the load voltage waveform for switching on of large load type of fault. This type of fault was created by connecting the large load to the test case system by using three phase breaker. The switching time selected for this simulation was 2 seconds to 2.5 seconds. The large load was connected to the system at a time of 2 seconds and disconnected at 2.5 seconds. The voltage amplitude during the fault was 257.4V, which is there was 20.5% reduction in the voltage level for source voltage and load voltage as shown in Figure 9.

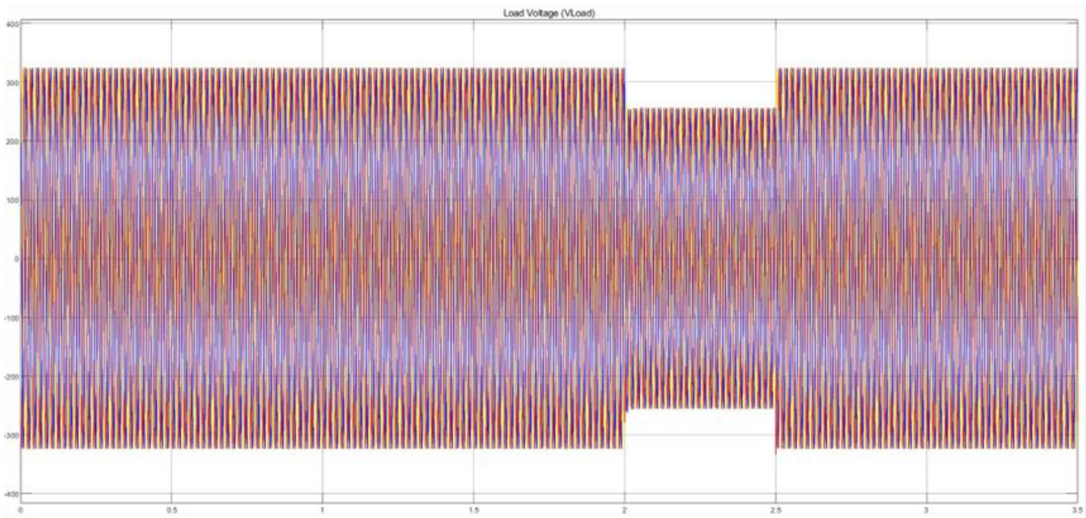


**Figure 9: Sensitive load voltage during the switching on heavy load**

3.3 Mitigation condition

The test case power system model with the fault that causes the voltage sag to occur in the system was connected with the DFT-controlled DVR to mitigate the different types of faults for voltage sag.

Figure 10, and Figure 11 show the voltage waveform of the load voltage, and injection voltage respectively during the mitigation process. Figure 10 shows that the voltage sag caused by the TPF was successfully mitigated by the DFT-controlled DVR. The waveform shows the same level of magnitude for the load voltage from 0 to 3.5 seconds of Simulation time. It can be said that the voltage sag was compensated by the injection voltage from DVR. It shows that there was no reduction in voltage amplitude for the load side. In addition, it is shown in Figure 11 that the DVR injected the voltage amplitude during the fault duration to mitigate the voltage sag. In this case, the DVR system was able to detect the voltage sag created and inject the required voltage to maintain the amplitude for the voltage sensitive load.

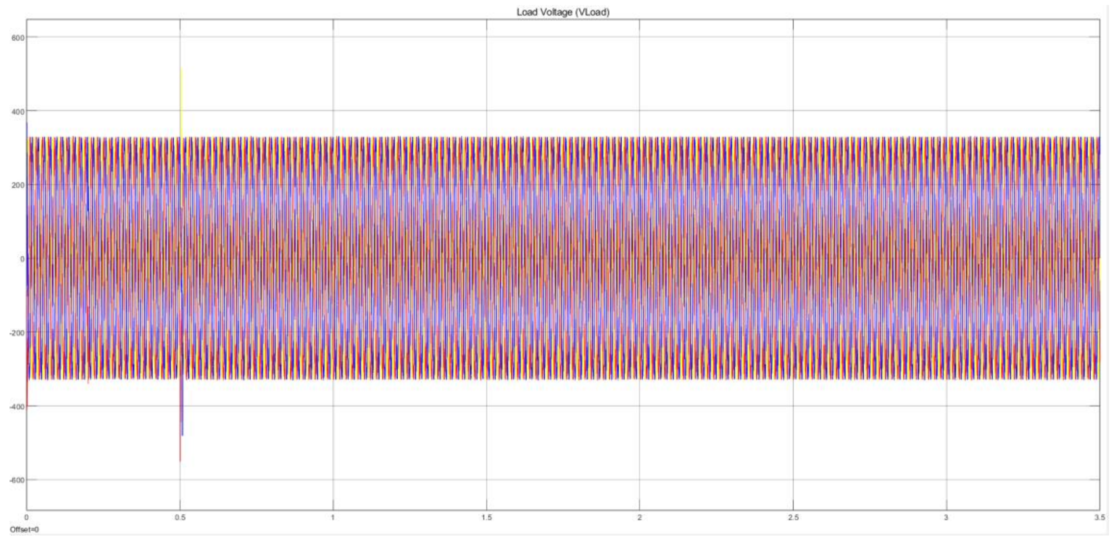


**Figure 10: Sensitive load voltage during mitigation process of TPF**

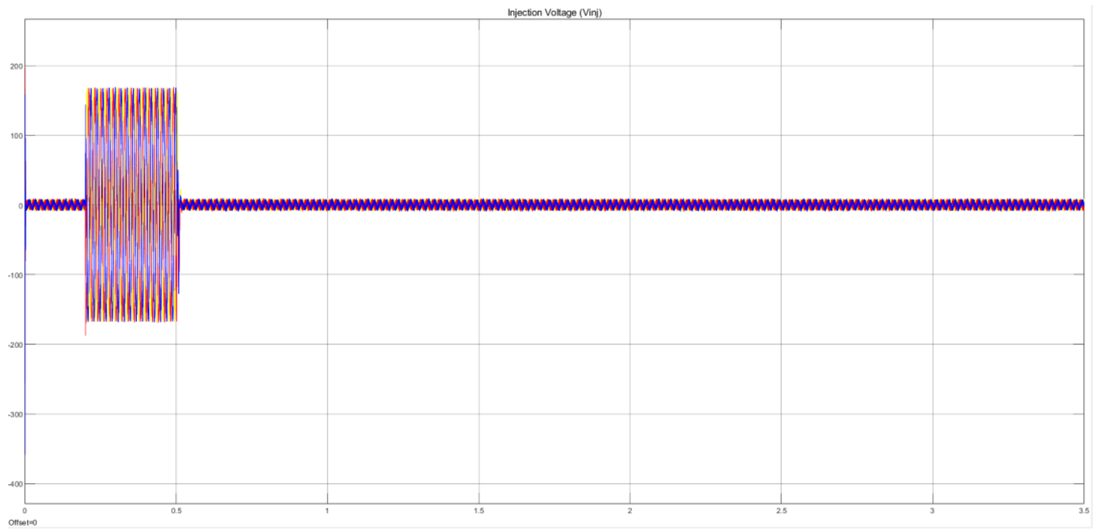


**Figure 11: Injection voltage from DVR during the mitigation process of TPF**

Next, for the fault of switching on a large load, the result shows that the DFT-controlled DVR successfully mitigated the voltage sag. Figure 12, and Figure 13 show the result of voltage waveform for the load voltage, and injection voltage of the DVR during the mitigation process of switching on large load respectively. Figure 12 shows that there was no reduction in load voltage amplitude during the voltage sag duration which was 2 seconds to 2.5 seconds. It shows that the voltage sag caused by switching on a large load was mitigated by the DFT-controlled DVR. To support the result, Figure 13 shows the injection voltage from the DVR at a duration of 2 seconds to 2.5 seconds which was to mitigate the voltage sag and inject voltage to the voltage sensitive load line. It shows that the DVR successfully mitigated the voltage sag caused by the sudden switching on of a large load.

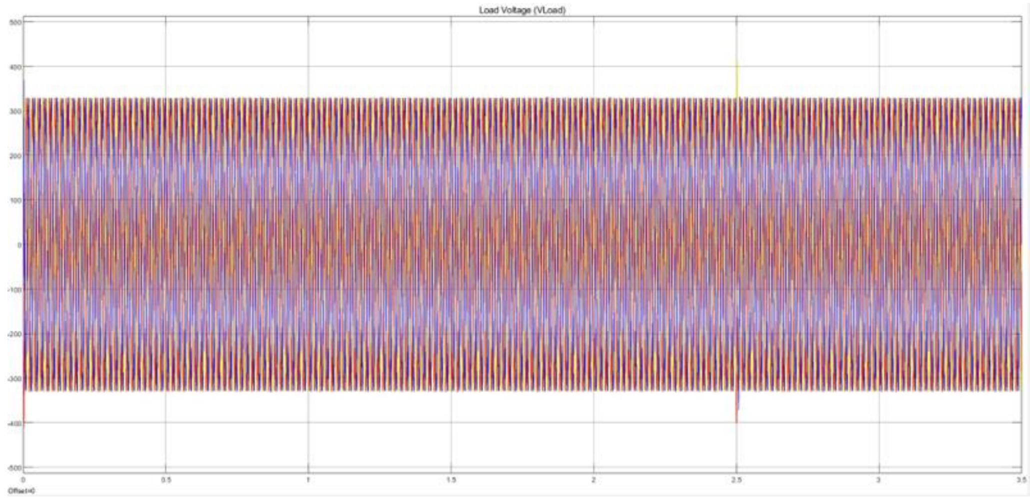


**Figure 12: Sensitive load voltage waveform during the mitigation process of switching on heavy load**

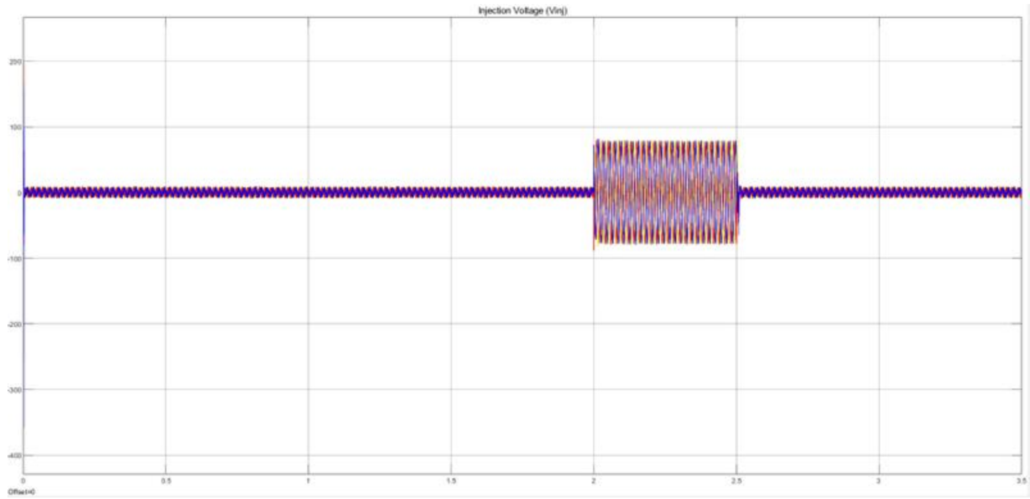


**Figure 13: Injection voltage from DVR during the mitigation process of switching on heavy load**

## 4. Conclusion

Three objectives of this project were successfully achieved by modifying the IEEE 5-busbar network system to a test case system that was used in this project. The modified IEEE 5-busbar was used to create the voltage sag events by using TPF and switching on of large load. The result shows that the voltage sag was successfully created by using the TPF and switching on of large load in the modified IEEE 5-busbar test case system. The voltage sag created was mitigated by applying the DFT-controlled DVR. The DFT-controlled DVR was able to mitigate the voltage sag for the TPF and switching on of large load in the test case system. The present study necessitates certain recommendations for its further development. One such recommendation is to design and simulate the test case system model utilizing diverse software, for instance, Power System Computer Aided Design (PSCAD). Additionally, to observe the behavior of voltage sag in a standard system, the IEEE standard of system model can be implemented in the project. The DVR may be equipped with a variety of techniques such as Pulse Width Modulation (PWM), Direct-Quadrate-Zero (DQ0) transformation, and Proportional Integral Derivative (PID) controllers. Certain controllers may offer prompter detection and solutions to abate the voltage sag. In addition to this, diverse techniques of mitigation, such as Uninterruptible Power Supply (UPS) and Distribution Static Synchronous Compensator (D-STATCOM), can be employed to mitigate the voltage sag.

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