ISSN: 2454-9940

INTERNATIONAL JOURNAL OF APPLIED SCIENCE ENGINEERING AND MANAGEMENT

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INTERNATIONAL JOURNAL OF APPLIED SCIENCE ENGINEERING AND MANAGEMENT

ISSN 2454-9940

www.ijasem.org

Vol 19, Issue 1, 2025

MODELING AND SIMULATION OF DYNAMIC VOLTAGE RESTORER WITH IMPROVED POWER QUALITY FEATURES

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ABSTRACT

The series connected DVR will inject three-phase compensating voltages through the three-phase injection transformer or three single-phase injection transformers with the main supply. The filtered VSI output voltage is boosted to the desired level with the injection transformer. The transformer also isolates the DVR circuit from the distribution system. The capacity of the voltage source inverter (VSI) and the values for the link filter connected between the injection transformer and the inverter play a crucial in the design of the DVR. In this research project, new Dynamic Voltage Restorer (DVR) topology has been proposed. The capacity of the voltage source inverter (VSI) and values of the link filter is small that will improve the compensation capabilities for voltage harmonic, swell and voltage sag mitigation under various fault conditions. The new RLC filter is able to eliminate the switching harmonics. The capacity of the dc supply voltage is reduced when the value of inductance is small. The new DVR topology has high efficiency and the ability to improve the quality of voltage. An outline architecture of the RLC filter parameters for the specific model has been presented. The new DVR with proposed controlled Dynamic Voltage Restorer topology is modeled and simulated using the MATLAB. The control scheme has good control dynamics with minimum transient current overshoot. The simulation results under transient performance are good.

I. INTRODUCTION

Day to day there is an increase in the intensity of sensitive loads in power systems, so the power quality issues play a vital role in the present days. There are extreme power quality problems mentioned as voltage swell, voltage sag, harmonics, flicker etc. Voltage sag generally origin from the faults on load or supply side, maloperation, electrical motor startup, electrical heaters turning on, etc. So the DVR is mitigating the voltage sag through injecting the voltage. Power quality problems are affected due to the appearance of various non-linear loads such as diode bridge rectifiers, adjustable speed drives (ASD), switched mode power supplies (SMPS), laser printers etc.As stated on voltage sag is the reduction in RMS voltage from 0.1pu to 0.9pu for a short time period of 0.5 cycles to few cycles. Generally, faults occurred in distribution systems having a reduction from 40% to 50% of the rated voltage until less than 2secs. Due to the above mentioned power quality problems on sensitive loads, minimization their effects are necessary. Furthermore, new power electronic devices are introduced and named as custom power devices. These devices are distribution static compensator (D-STATCOM), unified power quality conditioner (UPQC),

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dynamic voltage restorer (DVR). DVR is the perfect solution for restoring the load voltage at output terminals. When, the quality of source voltage is disturbed. DVR compensate the voltage sag with an appropriate injection of voltage in series with grid voltage, in order to maintain the rated load voltage with balance mode condition. Generally, DVR consists of inverter, injection transformer and energy storage device. The design of new inverter topology is to inject the voltage with proper control of the magnitude and phase angle, to maintain the constant load voltage and avoid disturbances at load voltage. The basic system model of DVR

DVR is a power electronic switching device which is connected in series to the load voltage bus to inject a dynamically controlled voltage. This voltage can eliminate effects of fault of voltage bus on a sensitive load. DVR is equipment used to recover a voltage or improve the voltage quality on the load side and its position is mounted in series between the source and the load. DVRs are coupled in series with distribution systems to protect sensitive equipment against the occurrence of voltage drop. The basic function of the DVR is to detect the occurrence of voltage drops that occur on the power system channel, and then inject the voltage to compensate for the voltage drop that occurs. Therefore the DVR is placed close to the sensitive load that is protected. The DVR works depending on the type of interference or an event occurring in the system, generating the injected voltage obtained from the DC energy storage unit and then converted to AC voltage by the voltage source inverter (VSI. To set the controller on the DVR is used dq0 transformation or Park transformation. The dq0 method will provide information on the depth of the voltage drop and the phase shift with the starting point and end point of the voltage drop.

II. LITERATURE SURVEY

Johan H. R. Enslin and Peter J. M. Heskes,[1]

"Harmonic interaction between a large number of distributed power inverters and the distribution network,"

In this paper discussed the harmonic interaction between a large number of distributed power inverters and the distribution network. This paper is to analyze the observed phenomena of harmonic interference of large populations of these inverters and to compare the network interaction of different inverter topologies and control options.

Uffe Borup, Frede Blaabjerg and Prasad N. Enjeti ,[2]

"Sharing of nonlinear load in parallel-connected three-phase converters,"

Presented about the sharing of linear and nonlinear loads in three-phase power converters connected in parallel, without communication between the converters. The paper focuses on solving the problem that arises when two converters with harmonic compensation are connected in parallel.

Pichai Jintakosonwit Hideaki Fujita, Hirofumi Akagi and Satoshi Ogasawara, [3]

"Implementation and performance of cooperative control of series active filters

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for harmonic damping throughout a power distribution system,"

This paper proposes cooperative control of multipleactive filters based on voltage detection for harmonic damping throughout a power distribution system. The arrangement of a real distribution system would be changed according to system operation, and/or fault conditions. In addition, series capacitors and loads are individually connected to, or disconnected from, the distribution system.

Pedro Rodríguez, JosepPou, Joan Bergas,J. Ignacio Candela , Rolando P. Burgos and DushanBoroyevich ,[4]

"Decoupled double synchronous reference frame PLL for power converters control,"

Presented the detection ofthe fundamental-frequency positive-sequence component of theutility voltage under unbalanced and distorted conditions. Specifically, it proposes a positive-sequence detector based on a new decoupled double synchronous reference frame phase-locked loop (PLL), which completely eliminates the detection errors of conventional synchronous reference frame PLL's. This is achieved by transforming both positive- and negative-sequence components of the utility voltage into the double SRF, from which a decoupling network is developed in order to cleanly extract and separate the positive- and negative-sequence components.

SoerenBaekhoejKjaer, John K. Pedersenand Frede Blaabjerg,[5]

"A review of single-phase grid-connected inverters for photovoltaic modules"

presents a Review of Single-Phase Grid-Connected Inverters for Photovoltaic Modules. This paper focuses on inverter technologies forconnecting photovoltaic (PV) modules to a single-phase grid. The inverters are categorized into four classifications: 1) the number of power processing stages in cascade; 2) the type of power decoupling between the PV module(s) and the single-phase grid; 3) whether they utilizes a transformer (either line or high frequency) or not; and 4) the type of grid-connected power stage.

POWER QUALITY AND ITS PROBLEMS

Electric systems and grids are complex dynamic systems. These systems suffer usually from unexpected or sudden changes of the currents and voltages. These changes are due mainly to the different types of linear and non-linear loads to which they are connected. In addition, to different types of accidents which can intervener into the grid. With the increasing use of power semiconductors in the most of industrial and domestic procedures, the electric grids are polluted with different harmonic currents and voltages. These harmonics affect the normal function of the most of the grid connected devices; in addition to considerable economic losses. Many classic and modern solutions have been proposed in the literary for the harmonic problems. In this chapter, the harmonic problem as one of the most common power quality problems will be presented. The different modern and traditional solutions will then be discussed.

2.1 Definition of Power Quality

Power quality is a term that means different things to different people. Institute of Electrical and Electronic Engineers (IEEE) Standard IEEE1100 defines power quality as "The concept of powering and

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grounding sensitive electronic equipment in a manner suitable for the equipment." As appropriate as this description might seem, the limitation of power quality to "sensitive electronic equipment" might be subject to disagreement. Electrical equipment susceptible to power quality or more appropriately to lack of power quality would fall within a seemingly boundless domain. All electrical devices are prone to failure or malfunction when exposed to one or more power quality problems. The electrical device might be an electric motor, a transformer, a generator, a computer, a printer, communication equipment or a household appliance. All of these devices and others react adversely to power quality issues, depending on the severity of problems.

A simpler and perhaps more concise definition might state: "Power quality is a set of electrical boundaries that allows a piece of equipment to function in its intended manner without significant loss of performance or life expectancy." This definition embraces two things that we demand from an electrical device: performance and life expectancy. Any power-related problem that compromises either attribute is a power quality concern.

III. PROPOSED DVR CONFIGURATION

3.1 Overview

Series active power filter compensates current harmonics by injecting equal-but-opposite harmonic compensating currents into the grid. In this case the series active power filter operates as a current source injecting the harmonic components generated by the load but phase shifted by 180°. This principle is applicable to any type of load considered as harmonic source. Moreover, with an appropriate control scheme, the active power filter can also compensate the load power factor. In this way, the power distribution system sees the non-linear load and the active power filter as an ideal resistor. The current compensation characteristics of the series active power filter is shown in Fig. 3.1

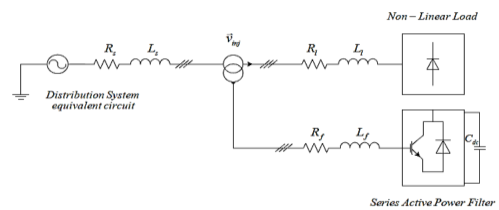

Fig. 3.1 Compensation Characteristic of DVR

3.2 Harmonic Current Extraction Methods

The aim of active power filtering is to compensate the harmonic currents produced by the non-linear loads, and to ensure the sinusoidal form of grid currents and voltages. The first step in active filtering is the harmonic currents extraction to be injected into the grid. The good extraction of harmonics is a keyword for a good active power filtering. Many extraction methods were proposed in literary. They can be divided into two families: the first family uses the Fast Fourier Transform (FFT) in the frequency domain to extract the current harmonics. The main disadvantages of this method are the bad results in transient, the heavy amount of calculations, and the use of considerable memory. In addition to a delay in the extraction of harmonics which can be at least one period.

The second family is based on the time domain calculations in the extraction of

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harmonics. Some of its methods are based on the instantaneous active and reactive power. Others are based on the calculation of direct and indirect current components. Recently, the neural networks and the adaptive linear neural networks have been used in the extraction of harmonic components of current and voltage.

3.2.1 Instantaneous Active and Reactive Power Theory

Most APFs have been designed on the basis of instantaneous active and reactive power theory (p-q), first proposed by Akagi et al in 1983. Initially, it was developed only for three-phase systems without neutral wire, being later worked by *Watanabe* and *Aredes* for three-phase four wires power systems. The method uses the transformation of distorted currents from three phase frame *abc* into bi-phase stationary frame $\alpha\beta$. The basic idea is that the harmonic currents caused by nonlinear loads in the power system can be compensated with other nonlinear controlled loads. The p-q theory is based on a set of 31 instantaneous powers defined in the time domain. The three-phase supply voltages (u_a, u_b, u_c) and currents (i_a, i_b, i_c) are transformed using the Clarke (or α-β) transformation into a different coordinate system yielding instantaneous active and reactive power components. This transformation may be viewed as a projection of the three-phase quantities onto a stationary two-axis reference frame. The Clarke transformation for the voltage variables is given by

$$\begin{bmatrix} u_\alpha \\ u_\beta \\ u_0 \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \\ \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \end{bmatrix} \begin{bmatrix} u_a \\ u_b \\ u_c \end{bmatrix} \quad (3.1)$$

Fig. 3.3 presents the principle of the active and reactive instantaneous power. This method offers the advantage of the possibility of harmonic compensation and/or reactive power compensation. In the case of reactive power compensation it is enough to send the reactive power q(t) directly to the reference current calculation bloc without the use of any extraction filter.

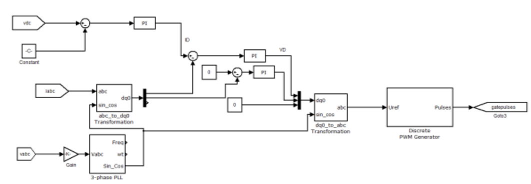

Fig. 3.3 proposed controller.

3.3 Voltage Source Inverter

Voltage source inverters (VSI) are one of the most important applications of power electronics. The main purpose of these devices is to provide a three-phase voltage source, where the amplitude, phase, and frequency of the voltages should always be controllable. The important development of VSI is a result, from the one hand to the development of fast, controllable, powerful, and robust semi-conductors, from the other hand to the use of the so-called pulse width modulation (PWM) techniques. In the high power applications, the three level VSIs are the most adopted in comparison with two levels ones. Because the THD of the output voltage and current of the three levels VSI is clearly lower.

The standard three-phase VSI topology is shown in Fig. 3.4. It is composed of three

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legs with current reversible switches, controlled for the open and close. These switches are realized by controlled switches (GTO or IGBT) with anti-parallel diodes to allow the flow of the free-wheeling currents.

The switches of any leg of the inverter (T1 and T4, T2 and T5, T3 and T6) cannot be switched on simultaneously because this would result in a short circuit across the dc link voltage supply. Similarly, in order to avoid undefined states in the VSI, and thus undefined ac output line voltages, the switches of any leg of the inverter cannot be switched off simultaneously as this will result in voltages that will depend upon the respective line current polarity.

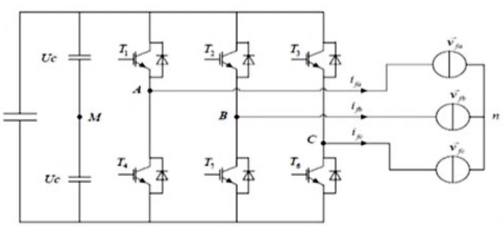

Fig. 3.4 Three-phase Two Levels VSI Topology

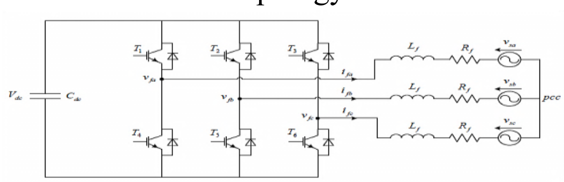

Fig. 3.5 SAPF Connection to the PCC

3.3.3 Control Methods of VSI

The aim of the control of the VSC is to force the output currents of the inverter to follow their predefined reference currents. The main principle is based on the comparison between the actual current of the filter with the reference currents generated by the different extraction methods. In the next section, we are going to discuss some different methods in VSC control.

The current control strategy plays an important role in fast response current controlled inverters such as the active power filters. The hysteresis current control method is the most commonly proposed control method in time domain. This method provides instantaneous current corrective response, good accuracy and unconditioned stability to the system. Besides that, this technique is said to be the most suitable solution for current controlled inverters. Hysteresis current control is a method of controlling a voltage source inverter so that an output current is generated which follows a reference current waveform.

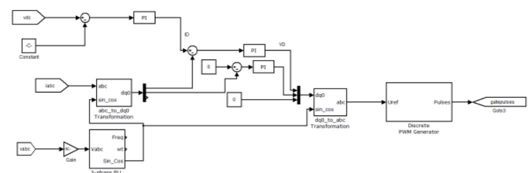

Fig. 3.6 proposed controller.

The basic structure of PWM voltage source inverter with hysteresis controller is shown in Fig. 3.6. The hysteresis control strategy aims to keep the controlled current inside a defined rejoin around the desired reference current. The status of the switches is determined according to the error. When the current is increasing and the error exceeds a certain positive value, the status of the switches changes and the current begins to decrease until the error reaches a certain negative value, then the switches status changes again.

In the fix hysteresis band control of the VSI, the switching frequency is a function of the derivative of the output current. This one depends on the value of the inductance of the decoupling filter and the voltage drop around it. It is important to

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notice that the coupling filter affects the switching frequency and the dynamic behavior of the active filter. The simple implementation procedure is the main advantage of this control method. However, the variable switching frequency is the major draw-back of this method. This variable frequency affects mainly the function of power electronic elements which can't support high switching frequency in high power applications. In order to solve the problem of variable switching frequency, a new hysteresis control strategies like "modulated hysteresis control" and "variable hysteresis band" were proposed. In the modulated hysteresis control it is difficult to define the hysteresis band width. Over more, the fix switching frequency achieved using this method affects the rapidity obtained by hysteresis control.

The control techniques based on the PWM solve the problem of switching frequency of the VSI. They use a fix switching frequency which makes it easier to cancel the switching harmonics. The PWM can be realized using different techniques such as carrier based PWM, PWM with harmonics minimization, and space vector PWM. The carrier PWM can be natural PWM, symmetric PWM, and asymmetric PWM.

The most simple and well known PWM technique is the sinusoidal PWM. This technique uses a controller which determines the voltage reference of the inverter from the error between the measured current and its reference. This reference voltage is then compared with a triangular carrier signal (with high frequency defining the switching frequency). The output of this comparison gives the switching function of the VSI. The choice of the ratio between the frequency of the reference signal and the frequency of the carrier signal is very important in the case of symmetric and periodic reference. As a consequence, in the case of sinusoidal reference, the ratio between the two frequencies must be integer to synchronize the carrier with the reference. Over more, it is preferable that the carrier frequency be odd to conserve the reference symmetry. In all cases this ratio must be sufficiently high to ensure the fast switching and to take the switching harmonics away from the fundamental produced by the inverter.

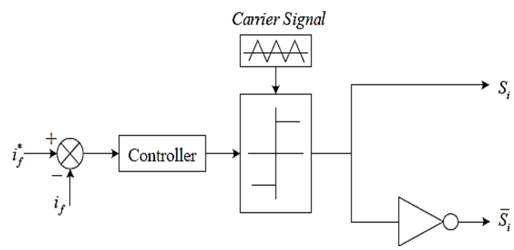

Fig. 3.7 The Principle of Sinusoidal PWM Control Method

Recently, new control techniques called space vector PWM were implemented. The difference between this technique and the sinusoidal technique is that it doesn't use carrier signal to define switching orders.

3.3.3.3 Space Vector PWM Control (SVPWM)

Space vector modulation technique was first introduced by German researchers in the mid of 1980s. This technique showed several advantages over the traditional PWM technique and has been proven to inherently generate superior PWM waveforms. By implementing the SVM technique, the number of switching is

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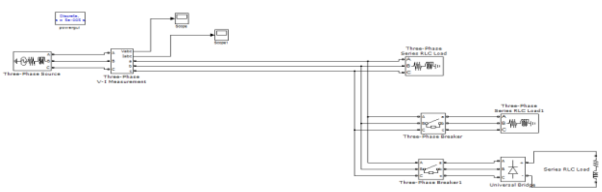
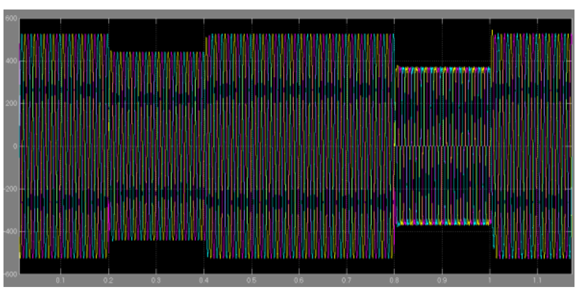
reduced to about 30% at the same carrier frequency of the sinusoidal pulse width modulation (SPWM) method. It offers better DC bus utilizations with lower THD in the AC current and reduces of switching losses too. The maximum modulation index for the SPWM method is 0.785 with the sinusoidal waveform between the phase and the neutral current of the system. However, the modulation index can be increased to 0.907 for the SVPWM.

IV. ROPOSED DVR SIMULATION RESULT

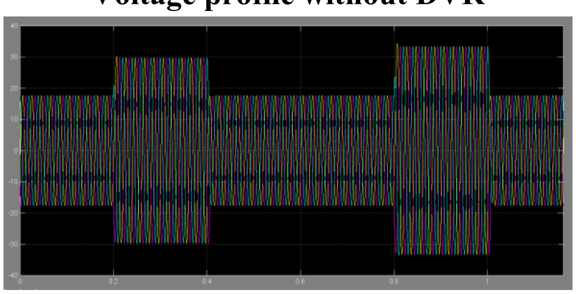
4.11 SIMULATION CIRCUIT WITHOUT NOVEL DVR



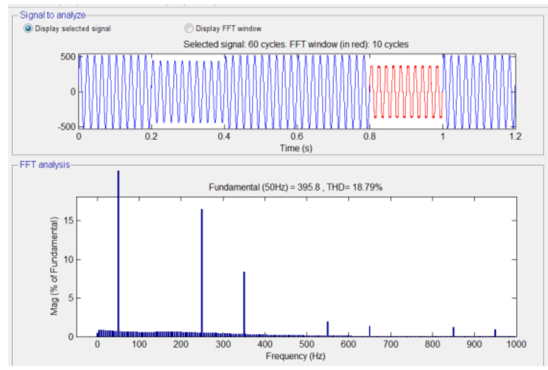
Circuit without DVR



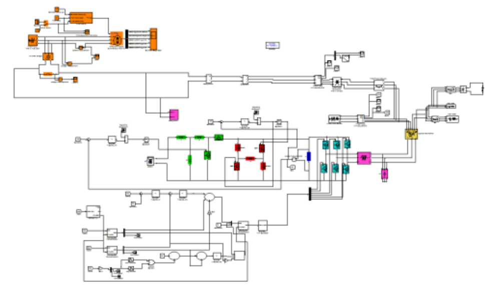
Voltage profile without DVR



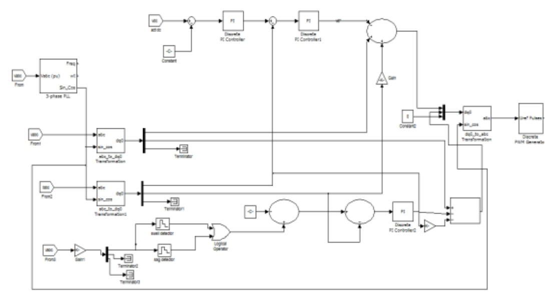
Current profile without DVR



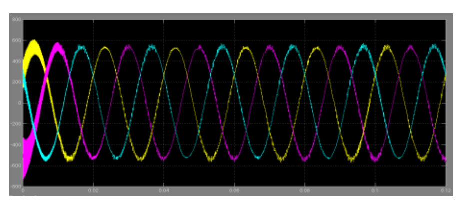
Total harmonic distortion



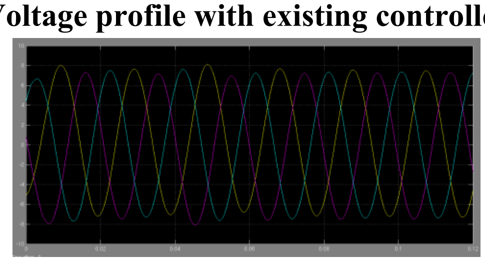
Total circuit configuration with existing controller



Simulink diagram for existing controller



Voltage profile with existing controller



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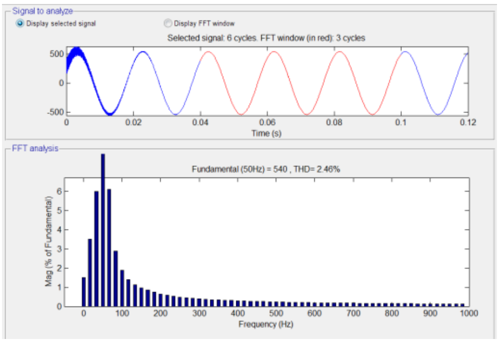
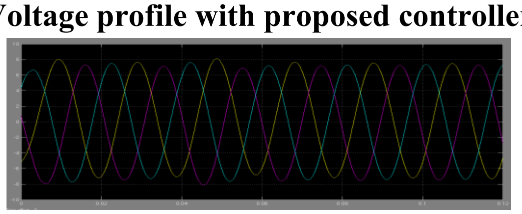
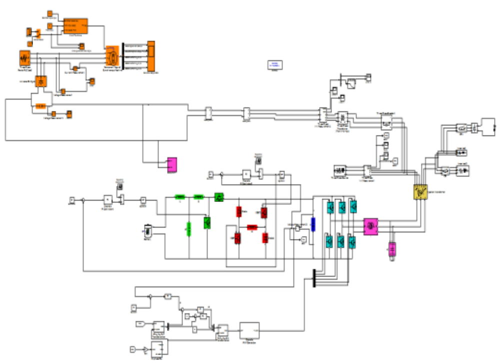
Current profile with existing controller



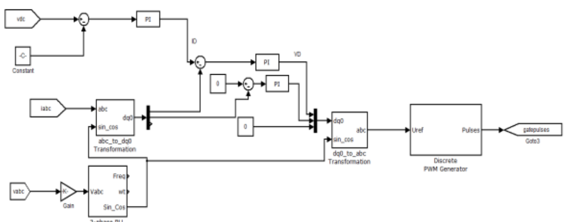
Total harmonic distortion existing controller



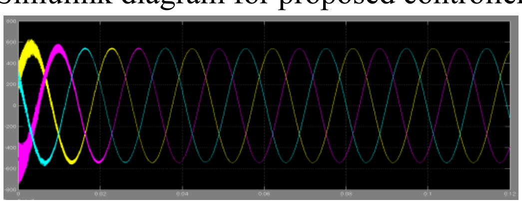
Total circuit with proposed controller



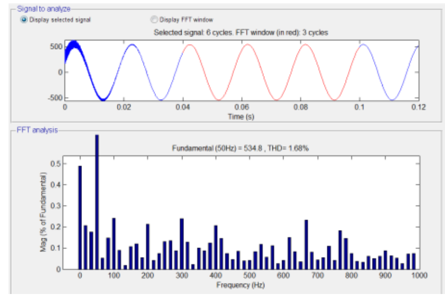
Simulink diagram for proposed controller



Voltage profile with proposed controller



Current profile with proposed controller



Total harmonic distortion proposed controller

V. CONCLUSION

The simulation results show that the proposed DVR is capable of repairing power quality interference. The DVR control block will detect the disturbance of voltage that occurs and the DVR functions as a compensator. phase injection transformer or three single-phase injection transformers with the main supply. The filtered VSI output voltage is boosted to the desired level with the injection transformer. The transformer also isolates the DVR circuit from the distribution system. The capacity of the voltage source inverter (VSI) and the values for the link filter connected between the injection transformer and the inverter play a crucial in the design of the DVR. In this research project, new Dynamic Voltage Restorer (DVR) topology has been proposed. The capacity of the voltage source inverter (VSI) and values of the link filter is small that will improve the compensation capabilities for voltage harmonic, swell and voltage sag mitigation under various fault conditions. The new RLC filter is able to eliminate the switching harmonics. The capacity of the dc supply voltage is reduced when the value of inductance is small. The new DVR topology has high efficiency and

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