Project Report on

"Mitigation of Voltage Sag and Swell using Dynamic Voltage Restorer (DVR)"

UDP Project

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ACKNOWLEDGMENT

Success of any work depends upon the dedication, sincerity and hard work. It also requires some ingredients such as motivation, guidance, encouragement and time.

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ABSTRACT

Power quality problem is an occurrence manifested as a nonstandard voltage, current or frequency that can cause failure or a miss-operation of equipment. With power quality problem utility distribution networks, industrial loads, sensitive loads etc. are suffered. Power quality problem dealt here is Voltage Sag/Swell. To overcome the problem related to power quality, custom power devices are introduced. A number of power quality solutions are provided by custom power devices. At present a wide range of very flexible controllers, which capitalize on newly available power electronics components, are introduce for custom power applications.

Power system capability can be increased by the use of Flexible AC Transmission System devices (FACTS) in transmission systems experiencing high power flows. The Dynamic Voltage Restorer (DVR) is the key series compensation devices that open up new opportunities to control the power on transmission systems in order to enhance their utilization, increase power transfer capability and to improve voltage profile. The fast response of this device makes it the efficient solution for improving power quality in distribution systems.

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CERTIFICATE

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Annexure 2

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LIST OF ABBREVIATIONS

DVR	Dynamic Voltage Restorer
IEEE	Institute of Electrical and Electronics Engineers
P.u.	Per unit
RMS	Root Mean Square
SLG	Single Line to Ground
VAR	Voltage Ampere Reactive
VSC	Voltage Source Converter
DSTATCOM	Distribution Static Synchronous Compensators
UPS	Uninterruptible Power Supplies
Hz	Hertz
ms	mili second
PCC	Point of Common Coupling
GTO	Gate Turn-Off Thyristor
MOSFET	Metal Oxide Semiconductor Field Effect Transistors
IGBT	Insulated Gate Bipolar Transistor
IGCT	Integrated Gate Commutated Thyristor
KV	Kilo Volt
SMES	Super Conducting Magnetic Energy Source

Chapter – 1

INTRODUCTION

1.1 Introduction to power Quality

Power Quality determines the fitness of electrical power to consumer devices. Synchronization of the voltage frequency and phase allows electrical systems to function in their intended manner without significant loss of performance or life expectancy. IEEE Standard (IEEE1100) defines Power Quality as "the concept of powering and grounding sensitive electronic equipment in a manner suitable for the equipment". The Power Quality of a system expresses to which degree a practical supply system resembles the ideal supply system. If the Power Quality of the network is good, then any loads connected to it will run satisfactory and efficiently. If the Power Quality of the network is bad, then loads connected to it will fail or will have a reduced lifetime, and the efficiency of the electrical installation will reduce. [1]

1.1.1 Power Quality Problems

A Power Quality problem is defined as any change in the rating of Voltage, Current and Frequency from its standard rating that result in failure or mal-operation of customer equipment. Power quality problems include a wide range of disturbance such as Voltage Sag, Voltage Swell, Frequency Disturbances, Harmonic Distortion, Impulse Transients, Electro Magnetic Interference and Electro Static Discharge. Power quality problems are mention in Figure 1.1.

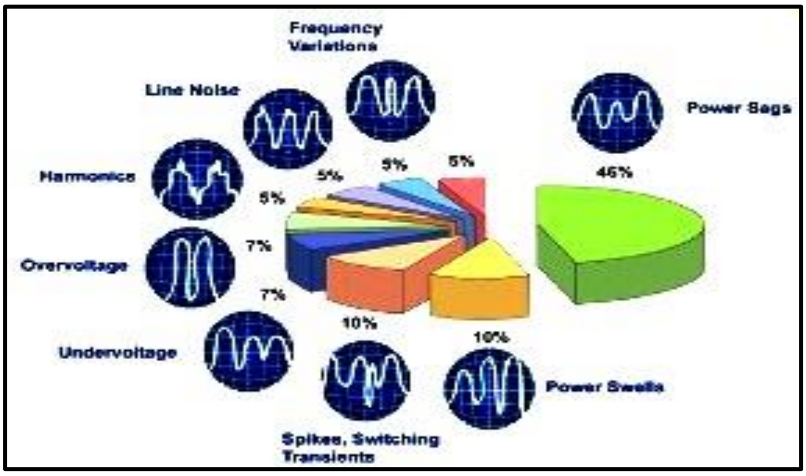

Figure 1.1: Power Quality problems

Sources of Major Power Quality Problems

- Short circuits (faults) on the electric power system, motor starting, Customer load additions, and large load additions in the utility service area which leads to Voltage Sag.
- Capacitive load additions, Open circuits, large load changes in utility service area and power line switching in transmission line which leads to Voltage Swell.

1.1.2 Voltage Sag

One of the most common power frequency disturbances is Voltage Sag. Voltage Sag is defined as a short reduction in voltage magnitude for duration of time, and it is the most important and commonly occurring Power Quality issue. The definition to characterize Voltage Sag in terms of duration and magnitude vary according to the authority. IEEE standard (IEEE1159, 1995) defines Voltage Sag as a decrease of RMS voltage from 0.1 to 0.9 per unit (p.u.), for duration of 0.5 cycles to 1 minute. Voltage Sags are mostly caused by system fault and last for duration ranging from 3 cycles to 30 cycles depending on the fault clearing time. Voltage Sag is caused by Short Circuit fault on the system, Transformer energizing, heavy load switching, motor starting, customer load addition, large load addition in utility service area etc. [1]

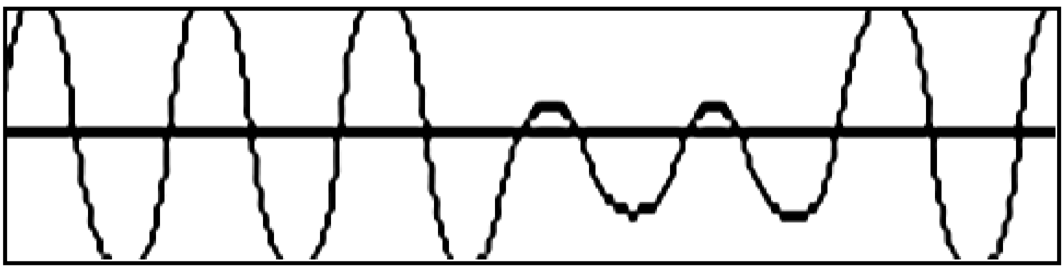

Figure 1.2: Voltage Sag

1.1.3 Voltage Swell

IEEE standard (IEEE1159) defines Voltage Swell as an increase in the RMS voltage level to 110% - 180% of nominal, at the power frequency for durations of 0.5 cycles to 1 minute. It is classified as a short duration voltage variation phenomena. Voltage swell is basically the opposite of Voltage Sag or Dip. A Single L-G (Line to Ground) fault can result in a Voltage Swell in the healthy phases. Due to large load changes and power line switching Voltage Swell occur.

In an underground system, the line to ground voltage on the ungrounded phase is 1.73p.u., during Single L-G (Line to Ground) fault. Voltage Swell can also result from energizing a large capacitor bank. [1]

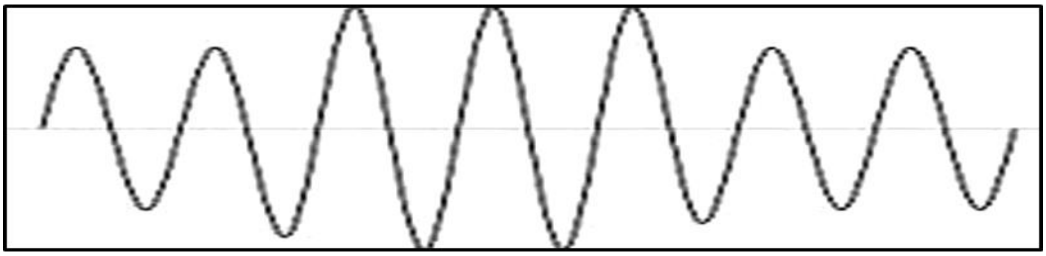

Figure 1.3: Voltage Swell

1.2 Aim and objectives of DVR

For different load conditions and distribution systems on devices with different loading test the effectiveness of compensation is observed that there is a scope. Distribution system locates the end of the power system and is directly connected to the customer, so the reliability of the power system depends mainly on the distribution system. Customer demand for the reliability of the power system is increasing day by day, as the reliability of the distribution system will be increased. System distribution network failures account for about 90% of the average customer interruption. So it is highly necessary to enhance the reliability of the distribution system.

The objective of the proposed scheme with the use of custom power device is reliability or to improve the quality of electricity in the distribution system. Various fault conditions to improve power quality in the distribution system to analyze the operation of the DVR is considered with different loads. The main goal of this project is to design DVR which can capable to mitigate Voltage Sag and Voltage Swell disturbances.

1.3 Solution to Power Quality Problems

DVR (Dynamic Voltage Restorer) is a static VAR device. It has wide applications in a variety of transmission and distribution systems. It is a series Compensation device, which protects sensitive electric load from Power Quality problems such as Voltage Sags, Voltage Swells, Voltage and Frequency unbalances and Harmonics distortion with the help of power electronic devices which are used in Voltage Source Converters (VSC).

The first DVR was installed on 12.47 KV system located in Anderson, South Carolina, North America in 1996.

DVR is small in size and it is a better power effective device as compared to other FACTs devices like DSTATCOM, SSSC and UPFC. DVR is the most effective and efficient custom power device because it has certain advantages like lower cost, smaller size and its fast response towards the disturbances. [6]

The capability of injection voltage by DVR system is 50% of nominal voltage. This allows DVRs to successfully provide protection against sags to 50% for durations of up to 0.1 seconds. Furthermore, most Voltage Sags rarely reach less than 50%.The Dynamic Voltage Restorer is also used to mitigate the damaging effects of Voltage Swells, voltage unbalance and other waveform distortions.

DVR Works to mitigate any supply voltage disturbance, especially Voltage Sag, by inserting a voltage with the required magnitude and phase shift in order to restore the load voltage to its rated value.

DVR maintains the load voltage at a rated value and phase by compensating the Voltage Sag, Voltage Swell, voltage unbalance, Frequency unbalance and Harmonics which are presented at the point of common coupling.

1.4 Literature Review

C. SANKARAN [1], "Power Quality" handbook, CRC Press, 2002. In this handbook Power Quality is defined very well. Different Power Quality problems are also presented in brief with its Measuring method and different solutions are also given to eliminate them from the healthy power systems.

Dr. Vic Smith [2], "Voltage Sag Mitigation," Endeavour Energy Power Quality & Reliability Center, University of Wollongong, Australia, August, 2012. This paper presents basic Power Quality Problem Voltage Sag with its terminology. Measurement of Voltage Sag with its characteristic is explained very well. Different Voltage Sag mitigation technologies with the help of compensating devices are also given.

F. Ghezal, S. Hadjeri, M. Benghanem and S. Zidi [3], "Dynamic Voltage Restorer behaviour" from Intelligent Control and Electrical Power Systems Laboratory ICEPS Electrical Engineering Department Djillali Liabes university, Sidi Bel Abbes, Algeria, March, 2014. In this paper principle operation of DVR is elaborated with its control system. Different compensation techniques of DVR are also given.

H.P. Tiwari and Sunil Kumar Gupta [4], "Dynamic Voltage Restorer against Voltage Sag," International Journal of Innovation, Management and Technology, Vol. 1, No. 3, ISSN: 2010-0248, August 2010. In this paper introduction to DVR is given. Control strategy of DVR is also given with the help of IGBT inverter and PI controller to maintain voltage at load terminals.

John Godsk Nielsen [5], "Design and Control of a Dynamic voltage Restorer", Aalborg University, Denmark Institute of Energy Technology, March, 2002. This book introduces the Power Quality problems and different controllers which are used for voltage dip mitigation, DVR, design of DVR, control strategy for DVR, Location of DVR, and Control and testing of DVR is explained very well.

K. R. Padiyar [6], "FACTS Controllers in Power Transmission and Distribution," New AGE International Publishers hand book, 2007. In this book the complete guideline about FACTs devices are given, with the using of these FACTs devices how can we improve the Power Quality and stability of the power system that all things are explained.

Rosli Omar, N.A. Rahim and Marizan Sulaiman [7], "Dynamic Voltage Restorer for Application of Power Quality Improvement in Electrical Distribution System: An Overview," Australian Journal of Basic and Applied Sciences, 5(12): 379-396, ISSN 1991-8178, 2011. In this paper introduction to custom power devices is presented. Basic components which are used in configuration of DVR are explained. Operating principle of DVR and its topology in distribution system with control philosophy is also given. DVR has basic three operating modes i.e., protection mode, standby mode and injection mode which is elaborated in this paper.

Ravilla Madhusudan and G.Ramamohan Rao [8], “Modeling and Simulation of a DVR for Power Quality Problems Voltage Sags and Swells,” IEEE student member, International Conference on Advances in Engineering, Science and Management (ICAESM -2012) March 30, 31, 2012. In this paper a sources of Power Quality Problems is manifested with its appropriate solution. Different operating modes of DVR and different voltage injection techniques are also elaborated.

Sanjay Haribhai Chaudhary and Mr. Gaurav gangil [9], “Mitigation of voltage Sag/Swell using DVR,” IOSR Journal of Electrical and Electronics Engineering (IOSR-JEEE) e-ISSN: 2278-1676, p-ISSN: 2320-3331, Volume 8, Issue 4, PP 21-38 (Nov. - Dec. 2013). In this paper Location of DVR with its basic configuration is given. Different equations related to DVR are also elaborated. Basic control strategy which is used to mitigate Voltage Sag and Swell is presented. Functional block diagram of DVR is explained very well.

Chapter – 2

CANVAS REPORT

2.1 Types of Canvas

1. Ideation Canvas
2. Observation Matrix canvas
3. Product Development Canvas
4. Business Model Canvas

2.1.1 Ideation Canvas

In this type of Canvas there are mainly four blocks are available on which sheet is stick with appropriate answer.

1. People
2. Activities
3. Situation/Context/Location
4. Props/Possible solutions

First block is all about different peoples who are already being used DVR or in future it would be used. In this block different application of DVR is specified for which purposes people are already being used of it or in future it will use by people. Example of different application is reduction of harmonics, different loading condition to avoid Voltage Sag etc. In second block different activities are available which is generally performed by DVR. Examples of such types of activities are Absorption, Injection, Switching, Controlling etc. In third block Location of DVR is available i.e., at distribution network and at medium voltage level. Last block of this Canvas different props and possible solution should be mentioned. Here in different components of DVR includes voltage source converter, injecting transformer, dc charging circuit, harmonic filter and by-pass switch. While in different possible solution includes Mitigation of Voltage Sag and Swell, reduction in under voltage and over voltage, reduced transient condition, reduction in harmonic, decrease Voltage dip etc.

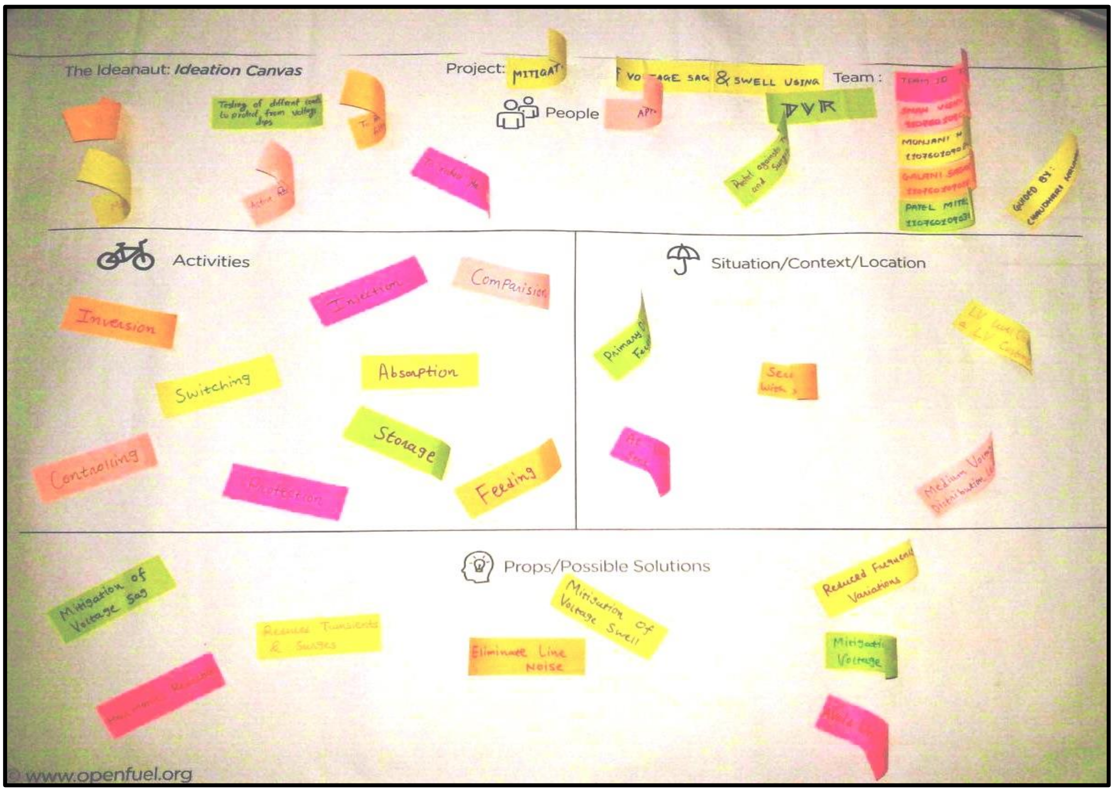

Figure 2.1: Ideation Canvas

2.1.2 Observation Matrix Canvas

In this type of Canvas there are mainly four blocks are available on which different sheets is stick with appropriate answer. Here one more block is available i.e., photo grid at the center of Canvas in which photos of DVR is added.

1. Observations
2. Scouted Challenges
3. Top five problems
4. Select one from Top five.
5. Photo Grid

Here in Observation block different problems which are generally arises in power system are added. Then after in second block which is entitled as Scouted Challenges in which added different challenges which are going to be faced by customer in future i.e., Switching and controlling operation of DVR.

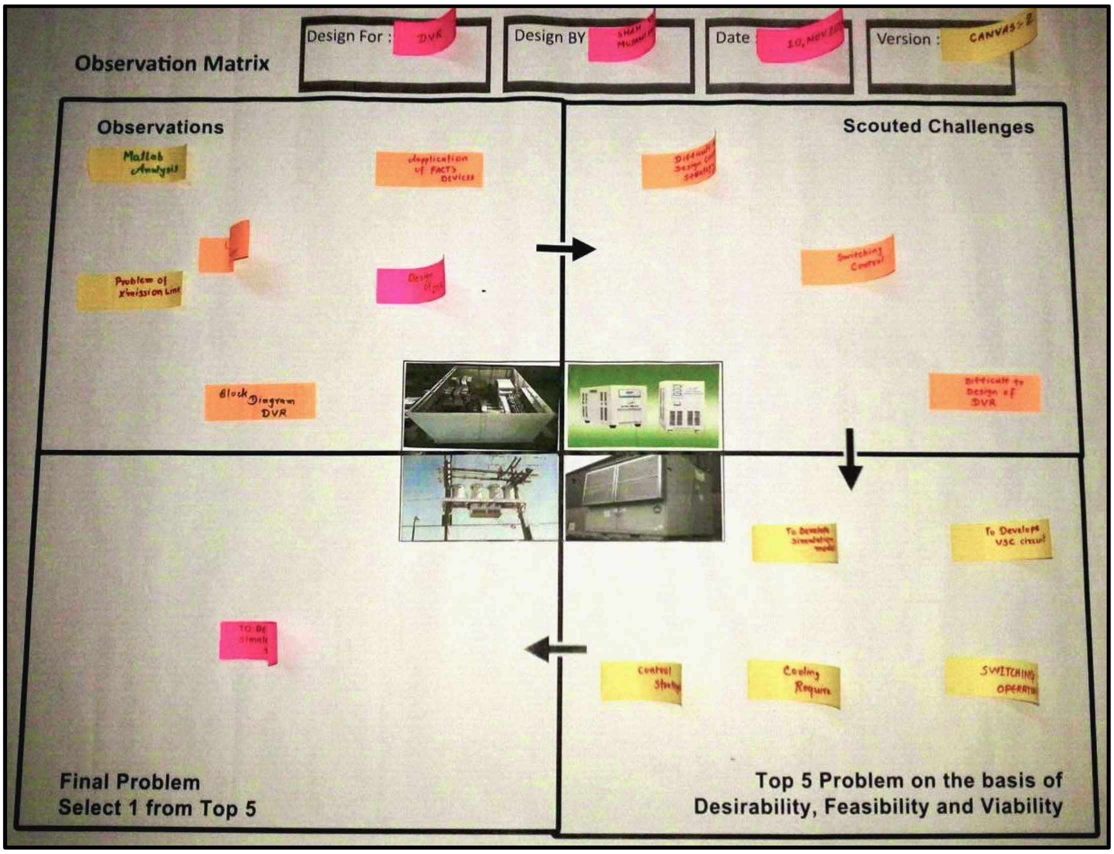

Figure 2.2: Observation Matrix Canvas

After that in third block basic five problems which are generally arises at the time of operation of DVR. Switching and Control problem are two basic problems which are included in five basic problems. From those five basic problems simulation development of DVR is mentioned as final problem. In middle of the block of observation matrix Canvas consist of different types of DVR images, this block of observation matrix Canvas is known as photo grid.

2.1.3 Product Development Canvas

In this type of Canvas there are mainly eight blocks are available on which different sheet is stick with the appropriate answer.

1. Purpose
2. Product Experience
3. Product Functions
4. Product Features

5. Components
6. Customer Revalidation
7. Reject, Redesign, Retain
8. People

Also DVR is used for different industrial application. DVR also includes different features like fast response, high speed operation with the different components like DC charging circuit, injection transformer, voltage source converter all those things are available in Canvas. Here in customer revalidation are included some features like reduce harmonic and reduction of negative sequence component. Due to different control strategy and different industrial application of DVR, it is rejected by customer so the redesigning of DVR is needed.

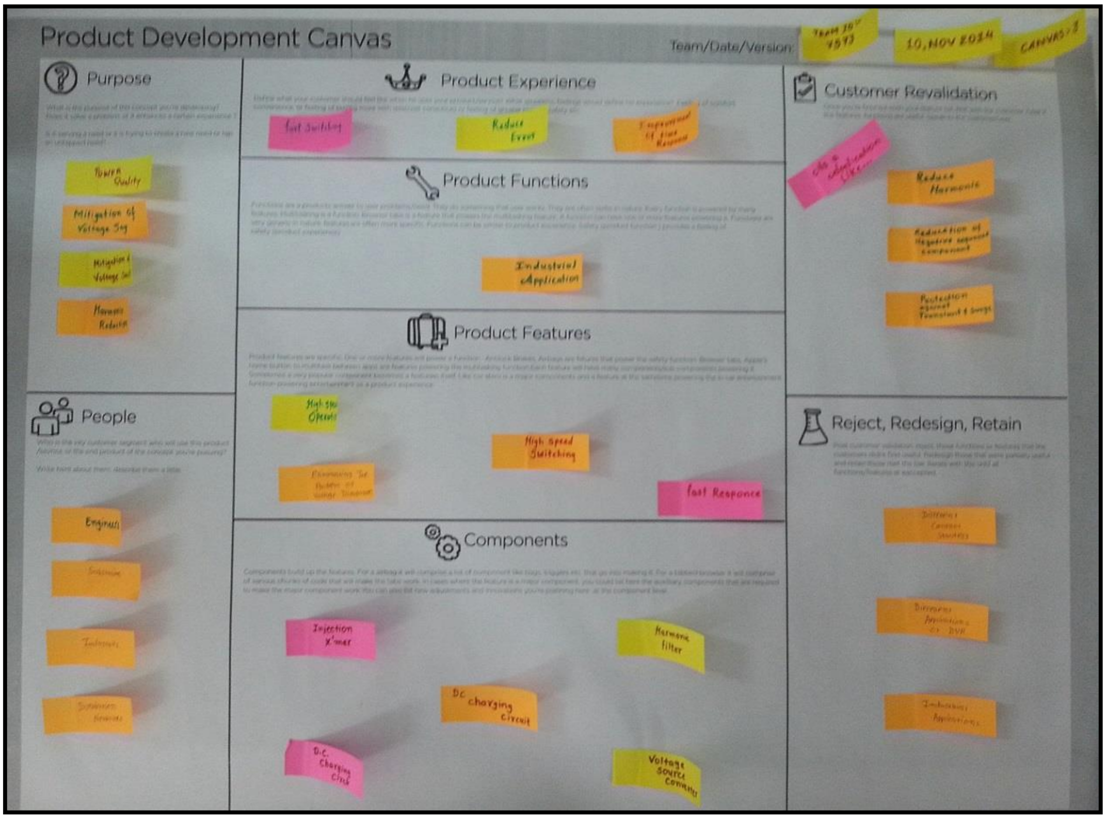

Figure 2.3: Product Development Canvas

After completing product development Canvas the main eight parameters like purpose, product experience, product functions, product features, components, customer revalidation, reject, people can easily identify in accordance with DVR.

2.1.4 Business Model Canvas

In this type of canvas there are mainly nine blocks are available on which different sheet is stick with the appropriate answer.

1. Key Parameters
2. Key Activities
3. Key Resources
4. Value Propositions
5. Customer Relationships
6. Channels
7. Customers Segments
8. Cost Structure
9. Revenue Streams

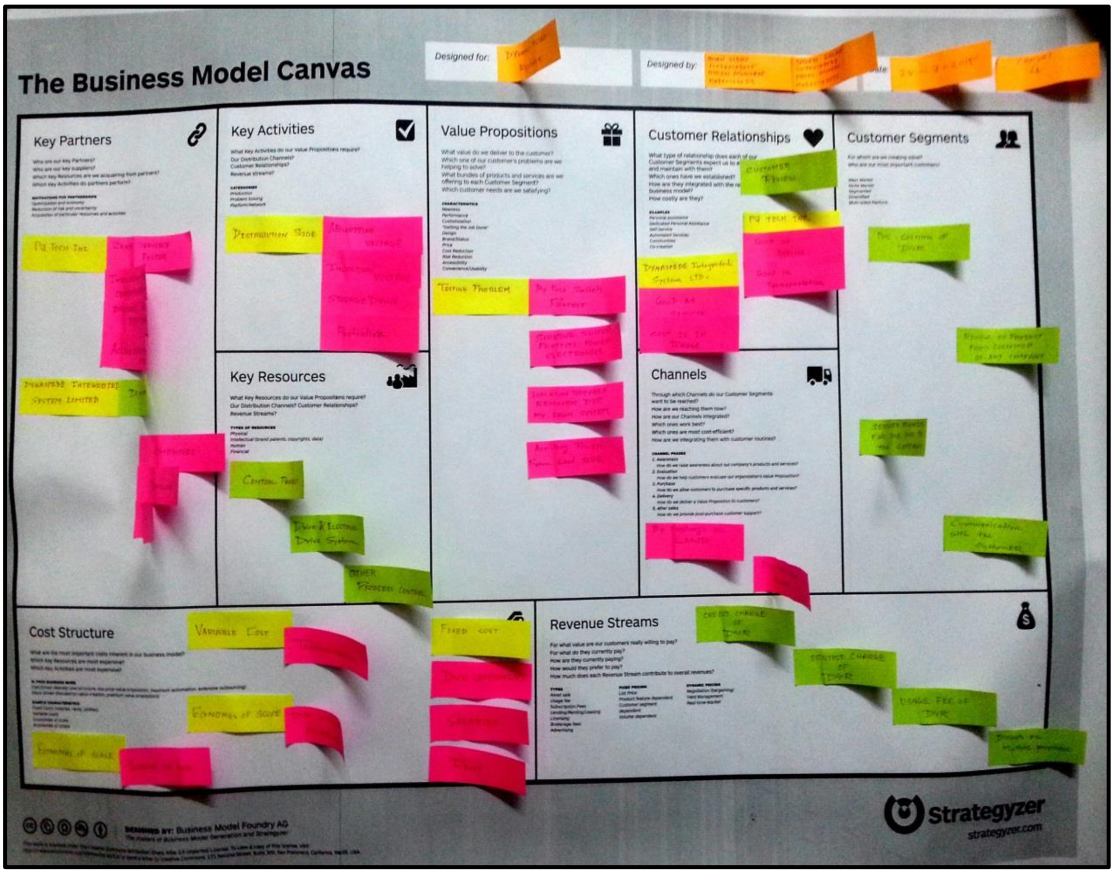

Figure 2.4: Business Model Canvas

DVR is used according to different purposes which are included in business model canvas. Here in Key parameter block two major industries i.e., PQ TECH INC and Dynaspede Integrated System Limited, which are selling the DVR is included. Here also describes the other products which are sold by these companies like Zero Sequence Filter, Intelligent VAR Compensator (IVC), and Active Harmonic Filter. Distribution City of Dynaspede Integrated System Limited that is Chennai, Bangalore, and New Delhi is also mentioned.

After that in the second block key activity of DVR at distribution side that is absorption voltage, injecting voltage, storage device, protection is mentioned. In the third block the key resources of the DVR that is Drive & Drive System, Control Panels and other Process Control is included. In the fourth block Value propositions problem at the time of testing of DVR which is Bypass Switch Protection, Shorting Switch Protect the power electronics, Isolation breaker remove DVR MV from System, Auxiliary Power from load side are mentioned. In the fifth block the channels by which DVR is taken away to install at location is described very well i.e., two channel by roadways and by streamer.

In the Sixth block cost structure about the different cost like fixed cost, variable cost, Economics of Scale and Economics of Scope is mentioned. In the eighth block the different types of revenue streams like Credit charge of DVR, Service charge of DVR, Usage fee of DVR, Discounts on multiple purchase is mentioned. In the last block customer segment in pre costing of DVR, Review of product from customer of any company, service provided for the DVR by the company, and communication with the customer is mentioned.

Chapter – 3

DYNAMIC VOLTAGE RESTORER

3.1 Introduction

Among the power quality problems like Voltage Sag, Voltage Swell, Harmonics, and Transient condition of three phase power system the Voltage Sag is the most severe disturbance. In order to overcome these problems the concept of custom power devices is introduced recently. One of those devices is the Dynamic Voltage Restorer (DVR), which is the most efficient and effective modern custom power device used in power distribution networks. DVR is a recently proposed series connected solid state device that injects voltage into the system in order to regulate the voltage at terminal loads. It is normally installed in a distribution system between the supply and the critical load feeder at the point of common coupling (PCC). Other than Voltage Sag and Swell compensation, DVR can also added other features like line voltage harmonics compensation, reduction of transients in voltage and fault current limitations. [5]

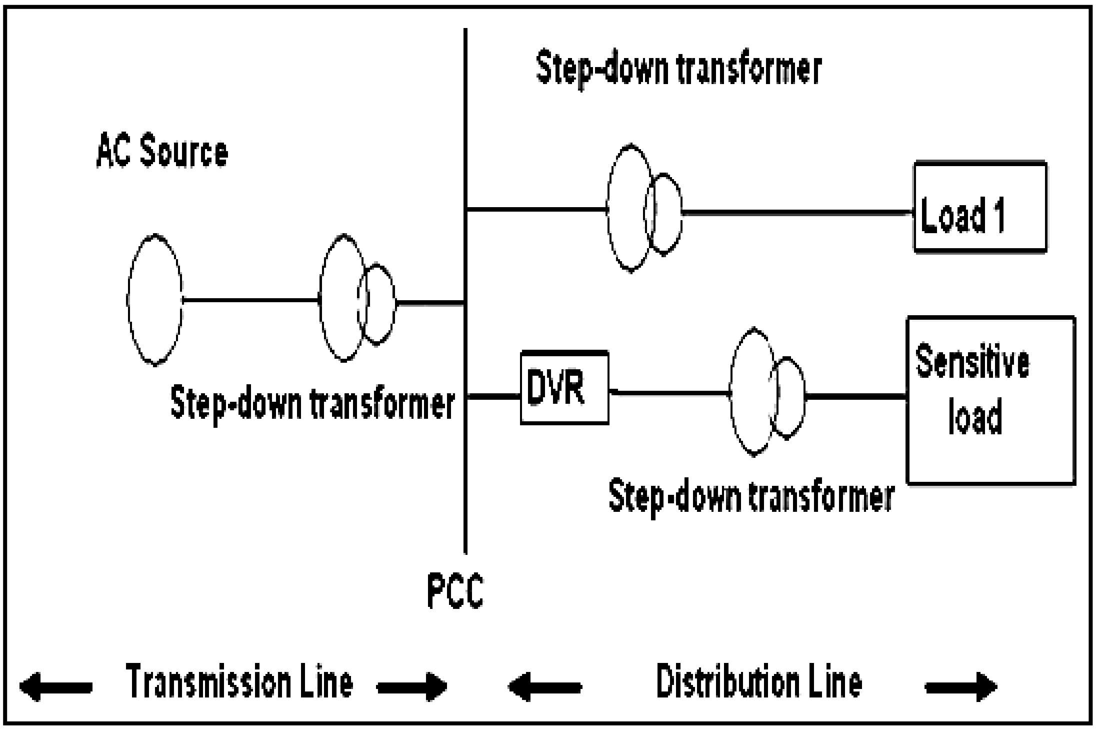

Figure 3.1: Location of DVR

3.2 Principle Operation of DVR

A DVR is a solid state power electronics switching device which comprises of either GTO or IGBT, a capacitor bank as energy storage device and injection transformers. From figure it can be seen that DVR is connected in between the distribution system and the load. The basic idea of DVR is that by means of an injecting transformer a control voltage is generated by a forced commuted convertor which is in series to the bus voltage. A regulated DC voltage source is provided by a DC capacitor bank which acts an energy storage device.

Under normal operating condition when there is no Voltage Sag, DVR provides very less magnitude of voltage to compensate for the voltage drop of transformer and device losses. But when there is a voltage sag in distribution system, DVR will generate require amount of controlled voltage with high magnitude and desired phase angle which ensures that load voltage is uninterrupted and maintained. In this case the capacitor will be discharged to keep the load supply constant. [3], [4]

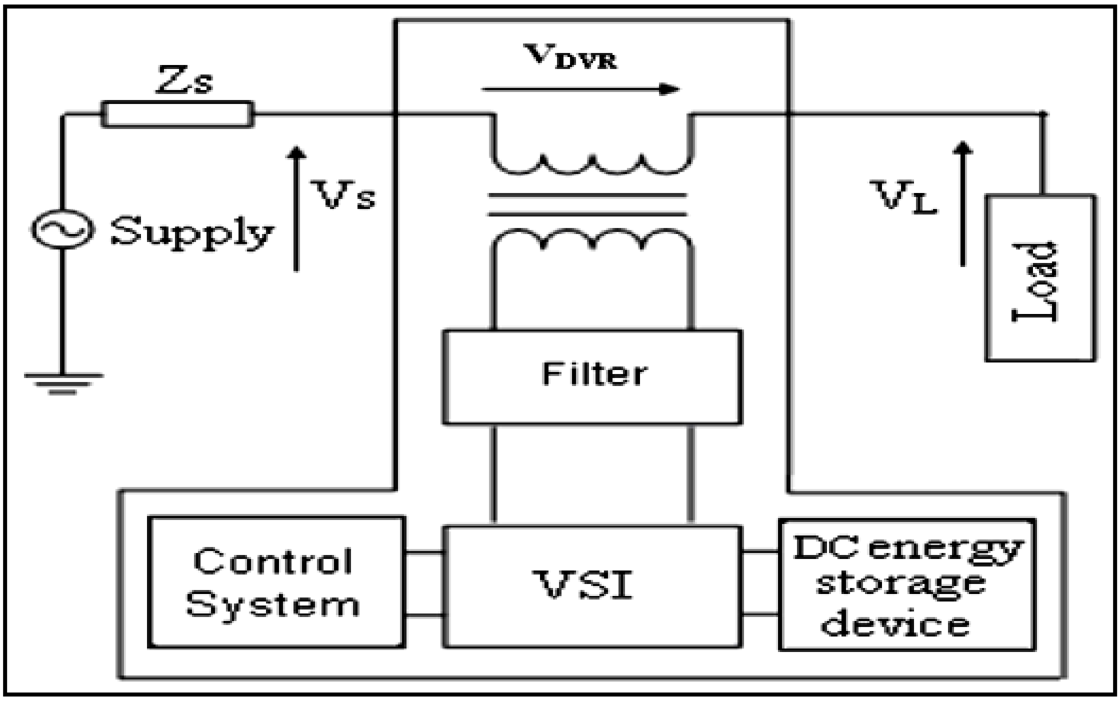

Figure 3.2: Principle of DVR

Note that the DVR capable of generating or absorbing reactive power but the reactive power injection device must be provided by an external energy storage system.

The response time of DVR is very short and is limited by the power electronics devices and the voltage sag detection time. The expected response time is about of 10ms, and which is much less than the traditional methods of voltage correction such as tap-changing transformers.

3.3 Basic Configuration of DVR

DVR consist of following components

1. A Voltage Source converter(VSC)
2. An Injection/Booster transformer
3. Harmonic filter
4. Storage Devices
5. DC charging circuit
6. By Pass switch
7. A Control and Protection system

Configuration of DVR is shown below Figure 3.3 [7]

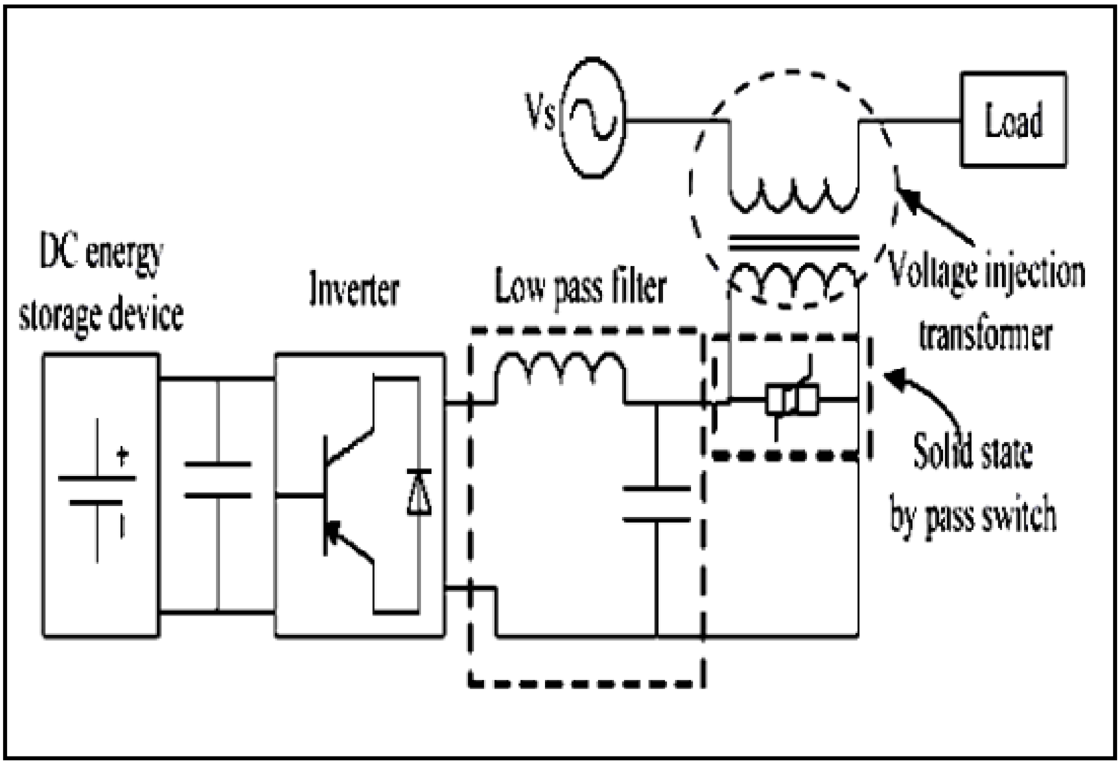

Figure 3.3: Basic component of DVR

3.3.1 A Voltage Source converter (VSC)

It is a power electronic system, which consists of switching devices and storage unit to generate sinusoidal voltage at any required frequency, magnitude, and phase angle. This could be a 3 phase–3 wire VSC or 3 phase–4 wire VSC. The latter permits the injection of zero–sequence voltages. Either a conventional two level converter or a three level converter is used. In VSC Metal Oxide Semiconductor Field Effect Transistors (MOSFET), Gate Turn-Off Thyristors (GTO), Insulated Gate Bipolar Transistors (IGBT), Integrated Gate Commutated Thyristors (IGCT) and many other devices from Thyristor family can be used as switching devices. The converter is most likely a Voltage Source Converter (VSC), which will modulate the pulse width of DC from the DC-link/storage to AC-voltages injected into the system. [7]

3.3.2 An Injection/Booster transformer

In most DVR applications the DVR is equipped with injection transformers to ensure galvanic isolation and to simplify the converter topology and protection equipment. Three single phase transformers are connected in series with the distribution feeder to couple the VSC to the higher distribution voltage level. Three single phase transformers can be connected with star/open star winding or delta/open star winding. The latter does not permit the injection of the zero sequence voltage. The choice of the injection transformer winding depends on the connections of the step down transformer that feeds the load. If a $\Delta-Y$ connected transformer (as shown in Figure 3.3) is used, then no need to compensate the zero sequence voltages. However if $Y-Y$ connection with neutral grounding is used, then the zero sequence voltage may have to be compensated. It is essential to avoid the saturation in the injection transformers. [7]

3.3.3 Harmonic filter

The filter is inserted to reduce the switching harmonics generated by the PWM VSC. The filters can be placed either on the high voltage side or the converter side of the boosting transformer. The advantages of the converter side filters are (a) the components are rated at lower voltage and (b) higher order harmonic currents do not flow through the transformer windings. The demerits are that the filter inductor causes voltage drop and phase angle shift in the voltage injected. This can affect the control scheme of DVR.

The location of the filter on the high voltage side overcomes the drawbacks, but result in higher rating of the transformer as high frequency currents can flow through the windings. [7]

3.3.4 Storage Devices

This is required to provide active power to the load during deep voltage sags. Lead–acid batteries, flywheel or Super Conducting Magnetic Energy Source (SMES) can be used as energy storage.

It is also possible to provide the required power on the DC side of the VSC by an auxiliary bridge converter that is fed from an auxiliary AC supply. A DC-link voltage is used by the VSC to synthesize AC voltage into the grid and during a majority of voltage dips active power injection is necessary to restore the supply voltages. [7]

3.3.5 DC charging circuit

DC charging circuit is used to charge the energy source after sag compensation event. It is also use to maintain DC link voltage at nominal DC link voltage. [7]

3.3.6 By–Pass Switch

Fault current causes fault in the downstream, which will flow through the inverter circuit of the DVR. Therefore to avoid high currents flowing to the inverter, a protection device namely by–pass switch is used, which is incorporated to by–pass the inverter circuit. Normally the by–pass switch will be in active mode and sense the current flowing in the distribution circuit and if the current flowing over than the inverter current. The by–pass switch will become inactive when the source current is at its rated value. [7]

3.3.7 A Control and Protection system

The control and protection of DVR is designed to compensate voltage sags must consider the following functional requirements.

1. When the supply voltage is normal, the DVR operates in a standby mode with zero voltage injection. However if the energy storage device is to be charged, then the DVR can operate in a self–charging control mode.
2. When a voltage sag/swell occurs, the DVR needs to inject three single phase voltages in synchronism with the supply in a very short time. Each phase of the injected voltage can be controlled independently in magnitude and phase.

However, zero sequence voltage can be eliminated in this situation when it has no effect. The DVR draws active power from the energy source and supplies this along with the reactive power to the load.

3. If there is a fault on the downstream of the DVR, the converter is by–passed temporarily using thyristor switches to protect the DVR against overcurrent. The threshold is determined by the current ratings of the DVR. [7]

3.4 Equation related to DVR

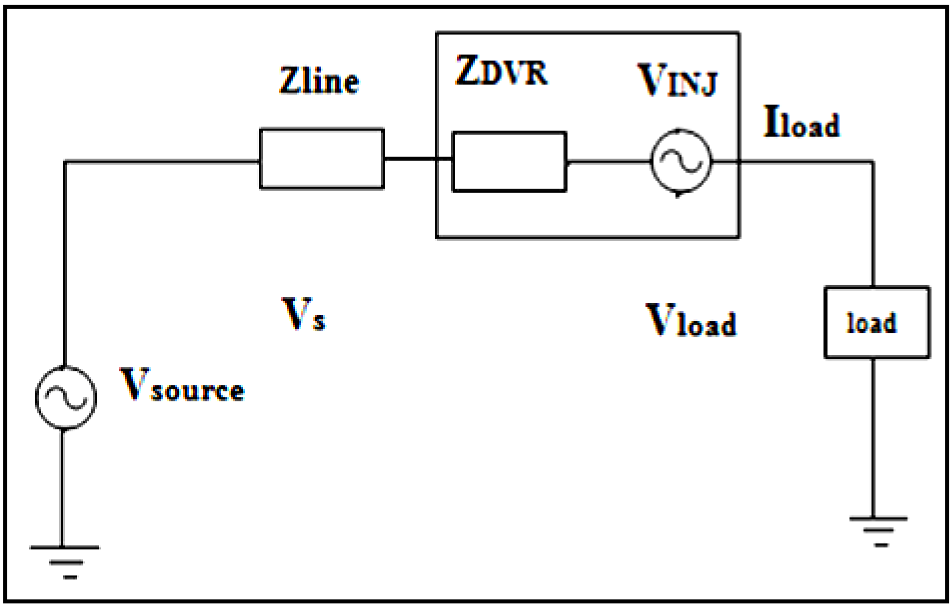

Figure 3.4: Equivalent Circuit diagram of DVR

The system impedance $\mathbf{Z_{th}}$ depends on the fault of the load bus. DVR injects a series voltage $\mathbf{V_{DVR}}$ through the injection transformer when the system voltage i.e., $\mathbf{V_{th}}$ drops, so that the desired load voltage magnitude $\mathbf{V_L}$ can be maintained. The series injected voltage of the DVR can be written as,

$$\mathbf{V_{DVR}} = \mathbf{V_L} + (\mathbf{Z_{th}} * \mathbf{I_L}) - \mathbf{V_{th}}$$

"Where", $\mathbf{V_{DVR}}$**:** Injected voltage of the DVR

$\mathbf{V_L}$**:** The desired load voltage magnitude

$\mathbf{Z_{th}}$**:** The load impedance

$\mathbf{I_L}$**:** The load current

$\mathbf{V_{th}}$**:** The system voltage during fault condition

The load current I_L is given by,

$$\mathbf{I_L} = \frac{[\mathbf{P_L} + \mathbf{jQ_L}]}{\mathbf{V}}$$

Let, $\mathbf{V_L}$ is considered as a reference load voltage so equation of $\mathbf{V_{DVR}}$ can be rewritten as,

$$\mathbf{V_{DVR}\angle\alpha = V_L\angle 0 + [Z_{th}\angle(\beta - \theta) \ * \ I_L] - V_{th}\angle\delta}$$

Here $\boldsymbol{\alpha}$, $\boldsymbol{\beta}$, $\boldsymbol{\delta}$ are angles of $\mathbf{V_{DVR}}$, $\mathbf{Z_{th}}$, $\mathbf{V_{th}}$, respectively and $\boldsymbol{\theta}$ is Load power angle

$$\boldsymbol{\theta} = \mathbf{tan^{-1}\frac{\theta_L}{P_L}}$$

The complex power injection of the DVR can be written as,

$$\mathbf{S_{DVR} = V_{DVR} \ * \ I_L{*}}$$

It demands the injection of only reactive power and the DVR itself is capable of generating the reactive power. [8]

3.5 Operating modes of DVR

The basic function of the DVR is to inject a dynamically controlled voltage V_{DVR} which is generated by a forced commutated converter. Series injection of the voltage is done by means of a booster transformer to the load bus. The momentary amplitudes of the three injected phase voltages are controlled such as to eliminate any detrimental effects of a bus fault to the load voltage V_L. It means that if any differential voltages are caused due to transient disturbance in the ac feeder, then that will be compensated by an equivalent voltage generated by the converter and injected on the medium voltage level through the booster transformer. [7]

The DVR has three modes of operation which are

1. Protection mode
2. Standby mode
3. Injection/boost mode

3.5.1 Protection Mode

If the over current on the load side exceeds a permissible limit due to short circuit on the load or due to large inrush current, the DVR will be isolated from the system by using the bypass switches (S2 and S3 will open) and source will continue to supply the current form another path (S1 will be closed). [7]

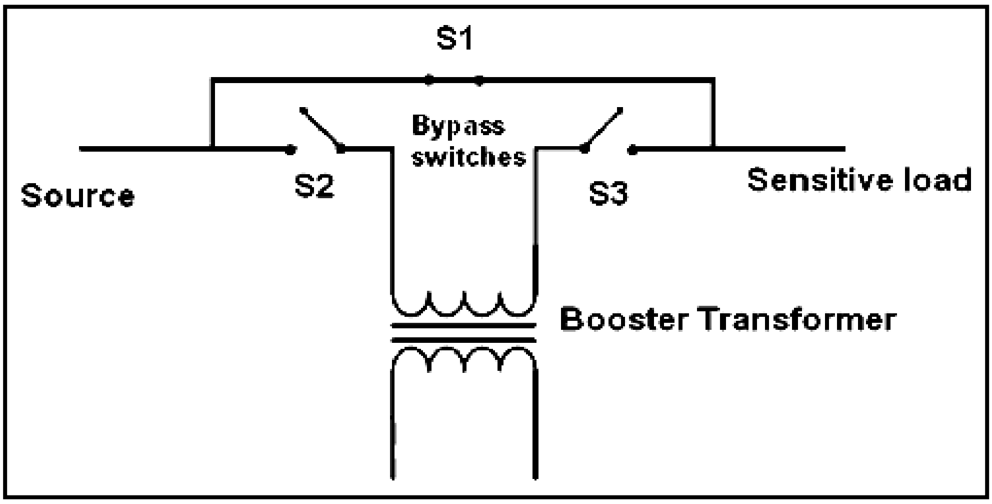

Figure 3.5: Protection Mode

3.5.2 Standby Mode (V_{DVR}=0)

In the standby mode low winding of booster transformer is shorted through the converter. No switching operation of Bypass switch is taken place in this mode of operation and the full load current will pass through the primary. [7]

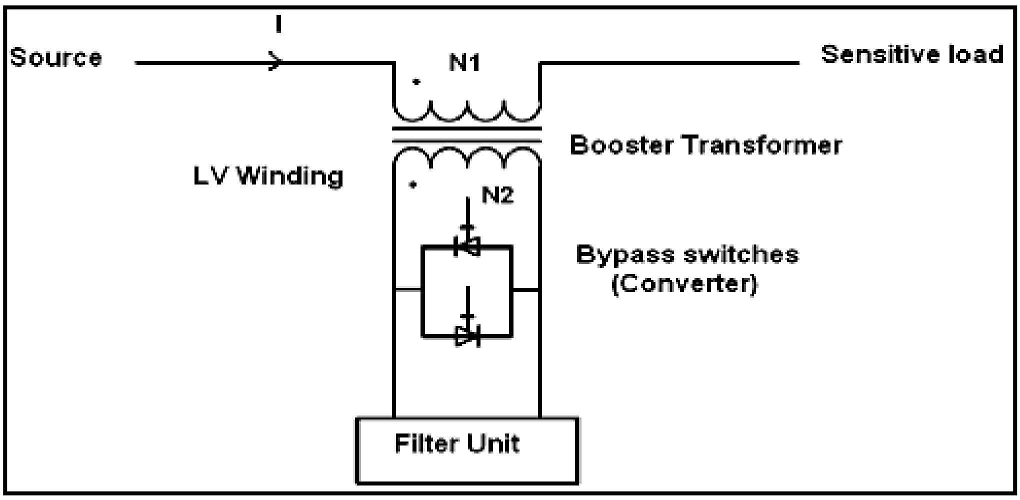

Figure 3.6: Standby Mode

3.5.3 Injection/Boost Mode (V_{DVR}>0)

In the Injection/Boost mode the DVR will inject the compensate voltage through the booster transformer when the supply voltage is detect below to its normal value i.e., Voltage Sag condition. Here three phase ac voltages are injected in series with the required magnitude and phase. The compensation of Voltage Sag is depends upon the types of Voltage Sag, load conditions and power rating of DVR. [7]

3.6 Voltage injection methods of DVR

Voltage injection or compensation method by means of a DVR depends upon the limiting factor such as; DVR power ratings, various conditions of load, and different types of voltage sags. Some loads are sensitive towards change in magnitude and others are tolerant to these. Therefore the control strategies depend upon the type of load characteristics. [9]

There are four different methods of DVR voltage injection which are as follows

1. Pre-Sag compensation method
2. In-Phase compensation method
3. Minimum energy compensation method

3.6.1 Pre-Sag compensation method

In Pre-Sag compensation both magnitude and phase angle of voltage is compensated. DVR detects the difference between Pre-Sag and Voltage Sag and injects the different voltage. [9]

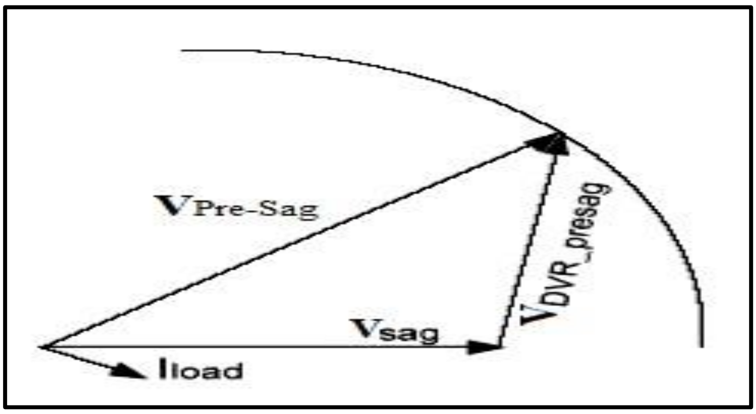

Figure 3.7: Pre-Sag compensation

3.6.2 In-Phase compensation method

In this compensation method the injection voltage is in phase with the source voltage. When Voltage Sag is occur on a transmission line then injection of voltage is done by voltage source converter based on magnitude of voltage drop. [9]

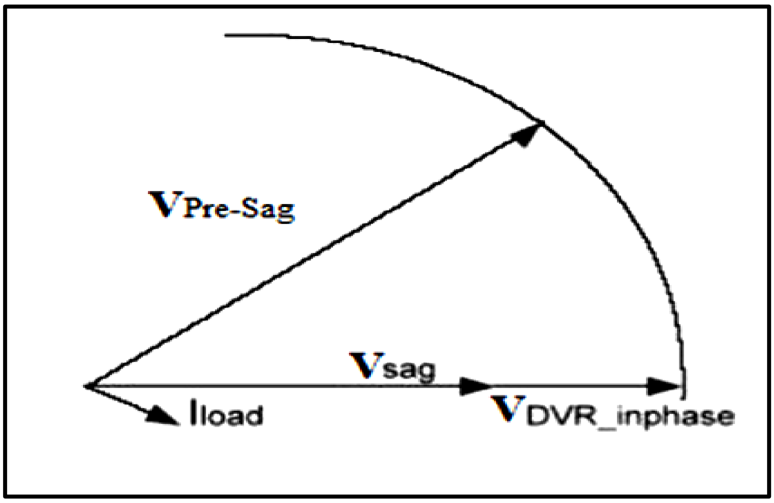

Figure 3.8: In-Phase compensation

3.6.3 Minimum energy compensation method

In this compensation method minimum energy is require i.e., only reactive power is require to be compensated. Here the injected voltage is in phase quadrature with the load current. Figure 3.9 illustrates the minimum energy compensation method. [9]

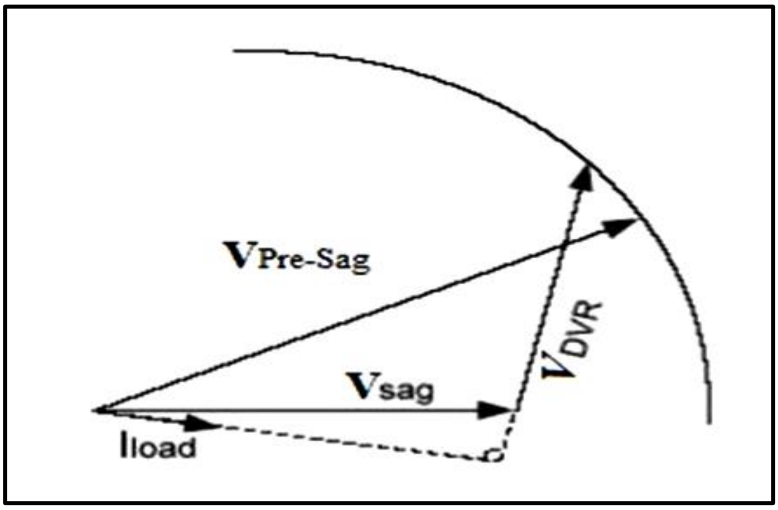

Figure 3.9: Minimum energy compensation

3.7 Control strategy of DVR

The basic function of a controller in a DVR is to detect the event of Voltage Sag and Voltage Swell, computation of the correcting voltage, generation of gate pulses to the PWM inverter, correction of any deviation in the series voltage injection and terminal of the gate pulses when the event has passed. When Voltage Sag and Voltage Swell are not present at that time the controller may also be used to shift the inverter into rectifier mode to charge the capacitor in the DC energy link.

The dq0 transformation or park's transformation is used for control purpose of DVR. The dq0 method gives information related to depth of the Sag and phase shift with starting and ending time. The quantities are expressed in terms of instantaneous space vectors. Firstly convert the voltage from abc frame to αβ0 frame i.e., Clarke's transformation. And then convert the voltage from αβ0 frame to dq0 frame i.e., Park's transformation. Indirectly three phase rotating frame is converted into stationary frame. Here for simplicity zero phase sequence component is ignored. Figure 3.10 illustrates a flow chart for control philosophy of DVR. [9]

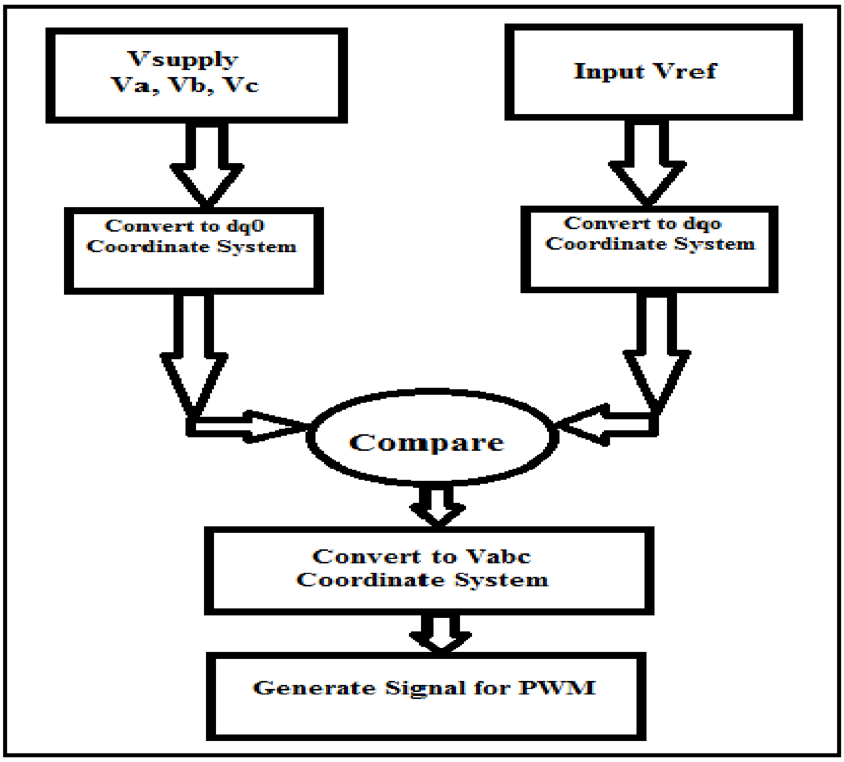

Figure 3.10: Flow chart for control strategy of DVR

The detection is carried out in each of three phases. The control of DVR is based on comparison of measured terminal voltage and the reference voltage. When supply voltage falls below 90% of the reference value at that time Voltage Sag is detected whereas Voltage Swell is detected when supply voltage increases up to 25% of the reference value.

The error signal is used as a modulation signal that allows generating commutation pattern for the power electronic 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.

3.7.1 Clarke park transformation

Clarke and Park transforms are used in high performance drive architectures related to permanent magnet synchronous and asynchronous machines. Through the use of the Clarke transform, the real and imaginary currents can be identified. The Park transform can be used to realize the transformation of the I_{ds} and I_{qa} current from the stationary to the moving reference frame. Clarke transformation is used to convert the three phase AC system (abc) to two phase AC system (αβ0), while park transformation is used to convert the two phase AC system (αβ0) to two DC quantities (dq0). Indirectly Clarke Park transformation is a mathematical transformation which converts the reference frame of three phase system to stationary frame.

Simplified calculation can then be carried out on these DC quantities before performing the inverse transform to recover the actual three phase AC results. It is often used in order to simplify the analysis of three phase synchronous machines or to simplify calculation for the control of three phase inverters, the power invariant, the right handed dq0 transform applied to any three-phase quantities like voltage, current, flux linkages for which matrix form is shown below. [9]

$$V_{dq0} = K * V_{abc} = \frac{\sqrt{3}}{\sqrt{2}} \begin{bmatrix} \cos(\theta) & \cos\left(\theta - \frac{2\pi}{3}\right) & \cos\left(\theta + \frac{2\pi}{3}\right) \\ -\sin(\theta) & -\sin\left(\theta - \frac{2\pi}{3}\right) & -\sin\left(\theta + \frac{2\pi}{3}\right) \\ \frac{\sqrt{2}}{2} & \frac{\sqrt{2}}{2} & \frac{\sqrt{2}}{2} \end{bmatrix} \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix}$$

Above matrix form is ultimately used to convert the three phase AC voltage (V_a,V_b,V_c) to two DC quantities (V_d,V_q,V_0).

The power invariant inverse form is,

$$V_{abc} = K^{-1} * V_{dq0} = \frac{\sqrt{3}}{\sqrt{2}} \begin{bmatrix} \cos(\theta) & -\sin(\theta) & \frac{\sqrt{2}}{2} \\ \cos\left(\theta - \frac{2\pi}{3}\right) & -\sin\left(\theta - \frac{2\pi}{3}\right) & \frac{\sqrt{2}}{2} \\ \cos\left(\theta + \frac{2\pi}{3}\right) & -\sin\left(\theta + \frac{2\pi}{3}\right) & \frac{\sqrt{2}}{2} \end{bmatrix} \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix}$$

The dq0 transformation can be thought of in geometric terms as the projection of the three separate sinusoidal phase quantities onto two axes rotating with the same angular velocity as the sinusoidal phase quantities. The two axes are called as the direct or d-axis and the quadrature or q-axis i.e., with the q-axis being at an angle of 90 degree from the d-axis.

Chapter – 4

SIMULATION AND RESULTS

4.1 Generation of Voltage Sag

A Voltage Sag is defined as a momentary decrease in the root mean square (RMS) of voltage ranging from 0.1 to 0.9p.u., and it is lasting for half a cycle to one minute.

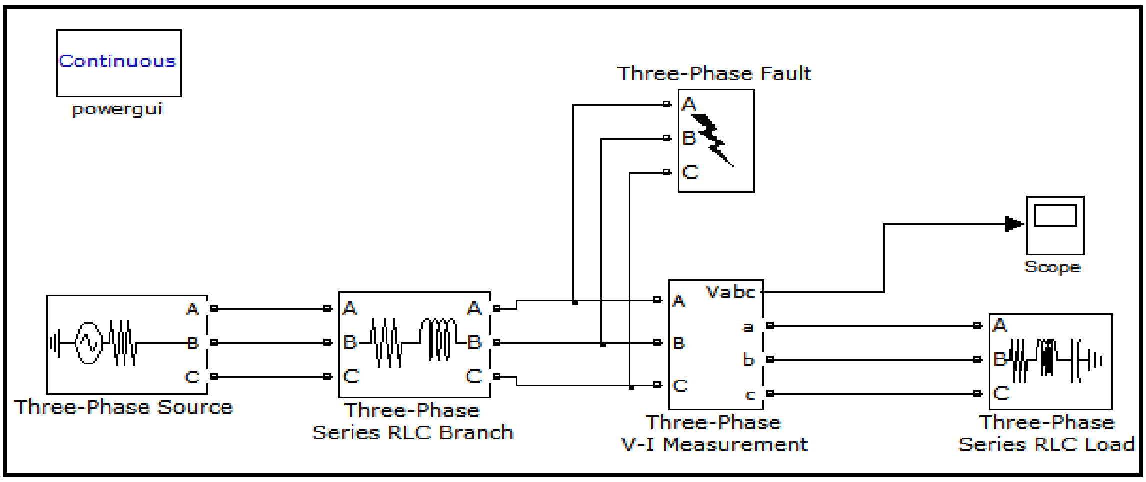

Figure 4.1: Simulation of Voltage Sag

Here as per shown in Figure 4.1 when three phase symmetrical short circuit fault (L-L-L-G) occur on the transmission line that can cause Voltage Sag disturbance in power system. Waveform of Voltage Sag for 11kv supply system is shown in below Figure 4.2

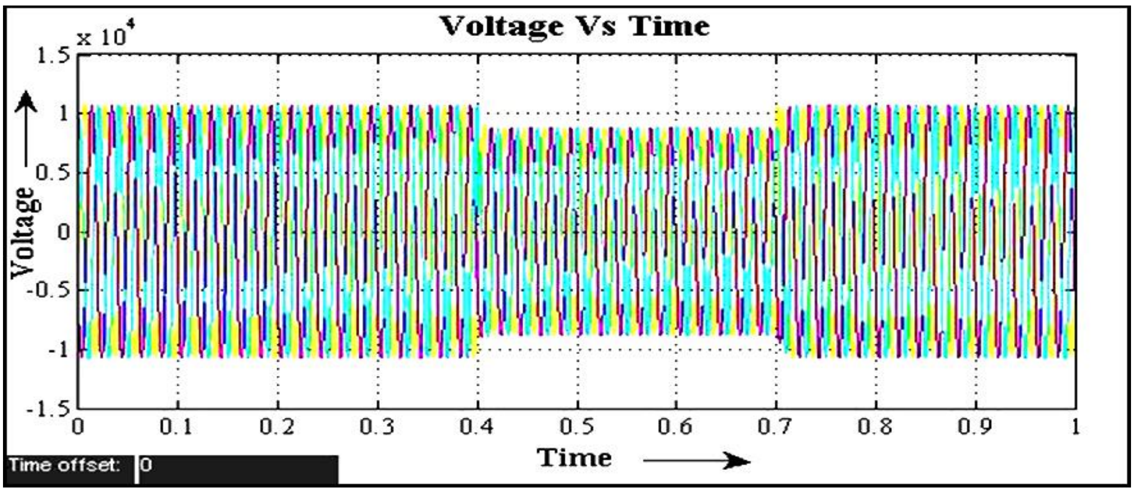

Figure 4.2: Waveform of Voltage Sag

Here Voltage Sag is occurring in between time from 0.4 to 0.7sec. To improve the visibility of Voltage Sag waveform the time period of waveform is divided into three parts. According to that different time period different waveforms are shown below.

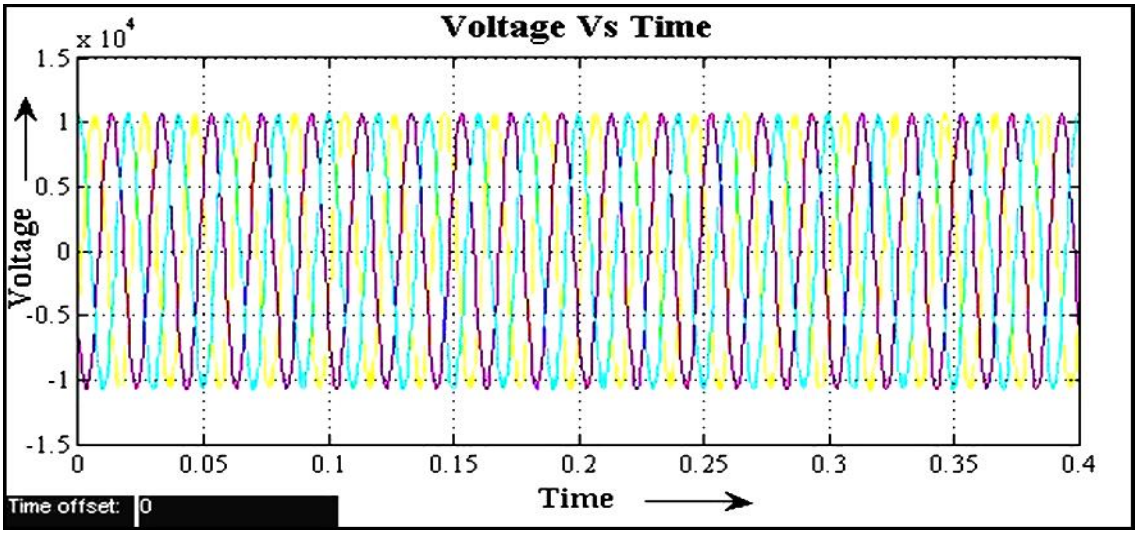

Figure 4.3: Pre-Sag condition

As per shown in above Figure 4.3 there is no any occurrence of Voltage Sag in between time from 0 to 0.4sce.

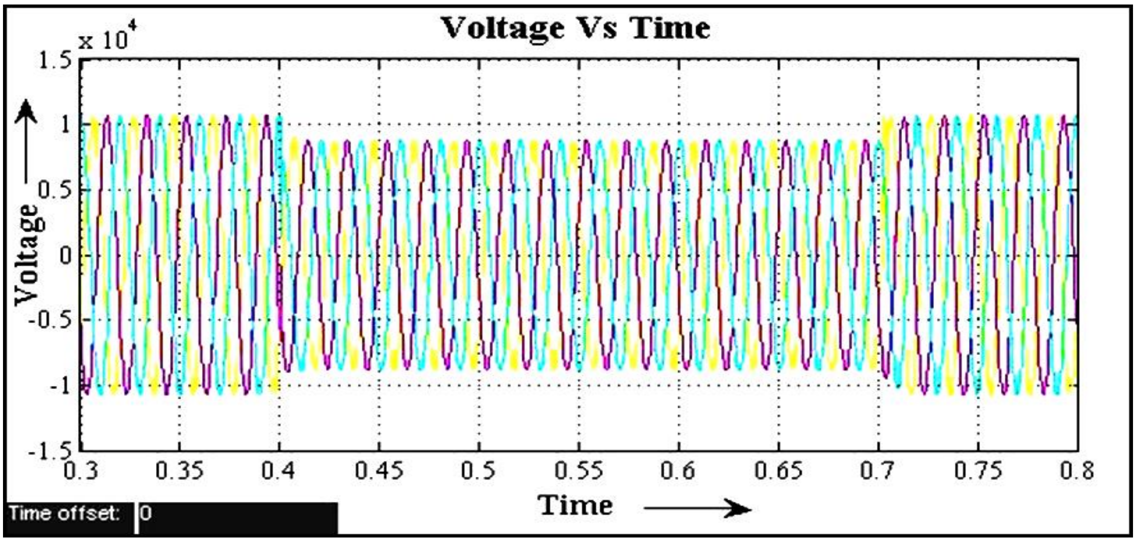

Figure 4.4: Voltage Sag condition

In between time from 0.3 to 0.8sec system has occurrence of Voltage Sag which is shown in above Figure 4.4

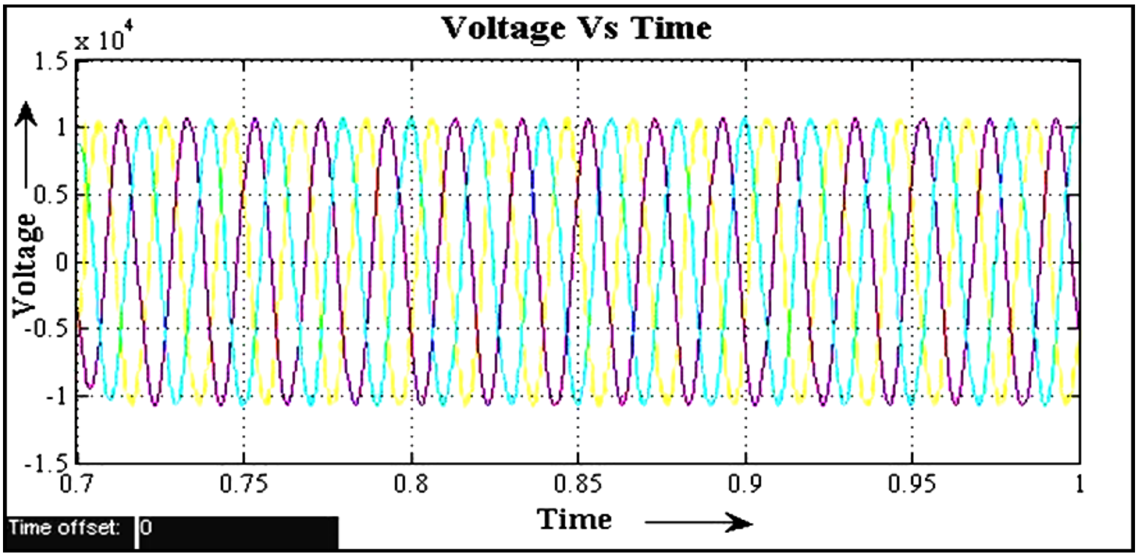

Figure 4.5: Post-Sag Condition

Here above Figure 4.5 shows that time from 0.7 to 1sec there is no any occurrence of Voltage Sag.

4.2 Generation of Voltage Swell

Voltage Swell is defined as an increase in the root mean square (RMS) of voltage ranging from 1.1 to 1.8p.u., and it is lasting for half a cycle to one minute.

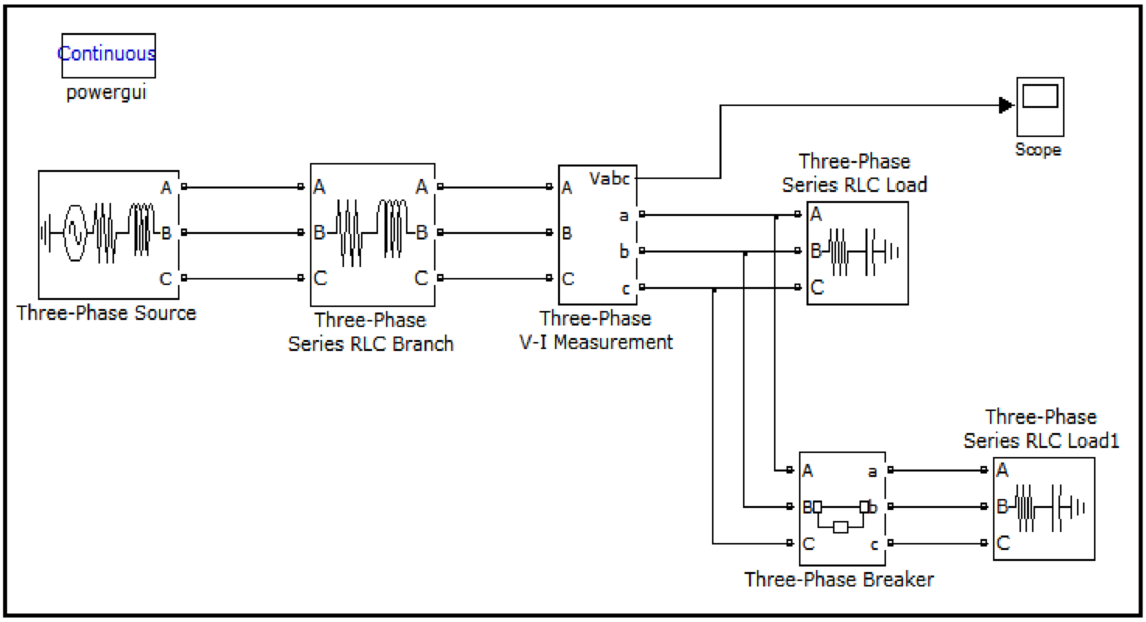

Figure 4.6: Simulation of Voltage Swell

Due to the faults like large load changes and power line switching suddenly voltage level increases that can cause Voltage Swell disturbance in power system. Waveform of Voltage Swell for 11kv supply system is shown in below Figure 4.7

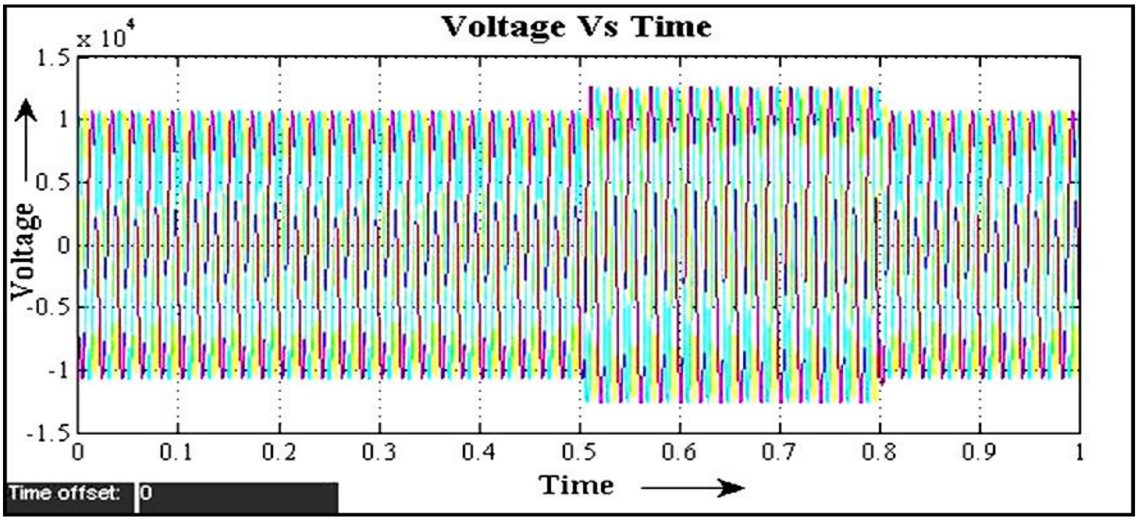

Figure 4.7: Waveform of Voltage Swell

Here Voltage Swell is occurring in between time from 0.5 to 0.8sec. The time period of Voltage Swell waveform is divided into three parts to enhance the visibility of waveform.

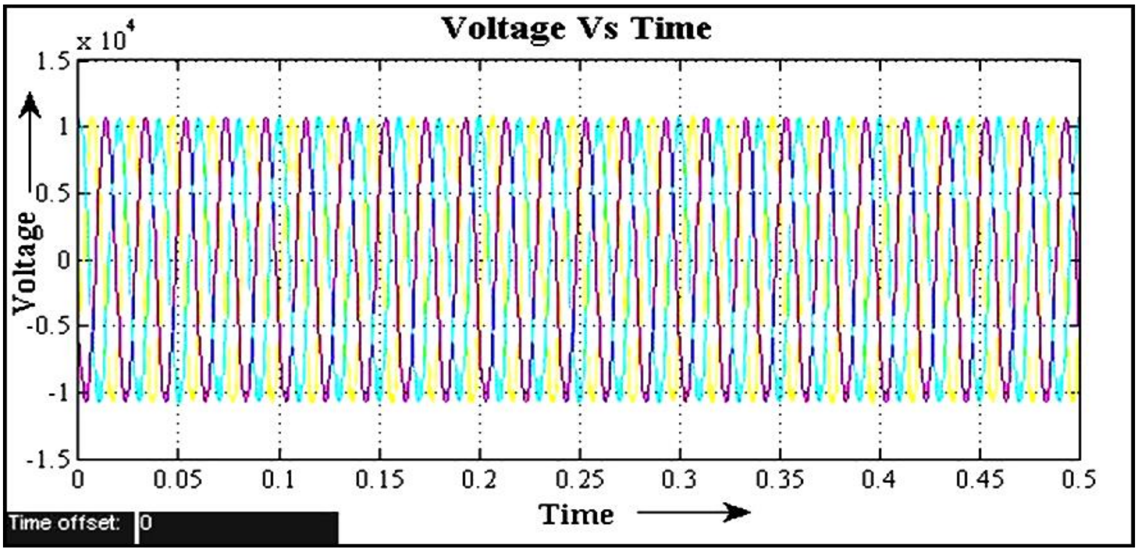

Figure 4.8: Pre-Swell condition

As per shown in above Figure 4.8 for the time from 0 to 0.5sec there is no any occurrence of Voltage Swell.

Figure 4.9 shows that system has occurrence of Voltage swell in between time from 0.5 to 0.8sec.

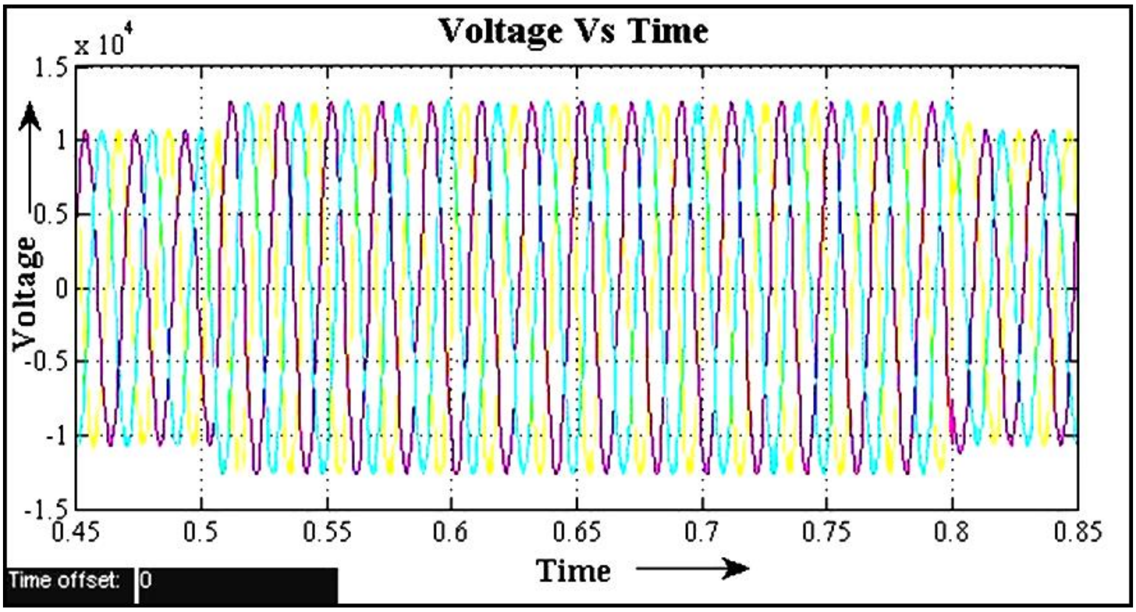

Figure 4.9: Voltage Swell condition

For the time from 0.8 to 1sec there is no any occurrence of Voltage Swell which is shown in below Figure 4.10.

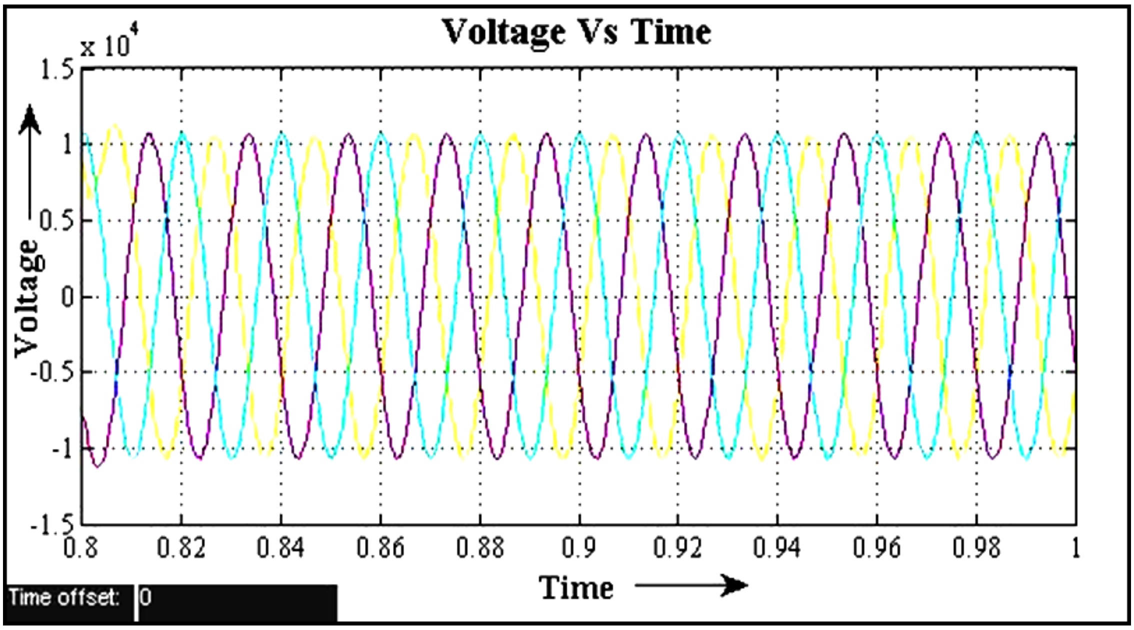

Figure 4.10: Post-Swell condition

4.3 Clarke Park transformation

Clarke transformation is used to convert the three phase AC system (abc) to two phase AC system (αβ0), while park transformation is used to convert the two phase reference AC quantities (αβ0) to two stationary DC quantities (dq0). Indirectly Clarke Park transformation is a mathematical transformation which converts the rotating frame of three phase system to stationary frame.

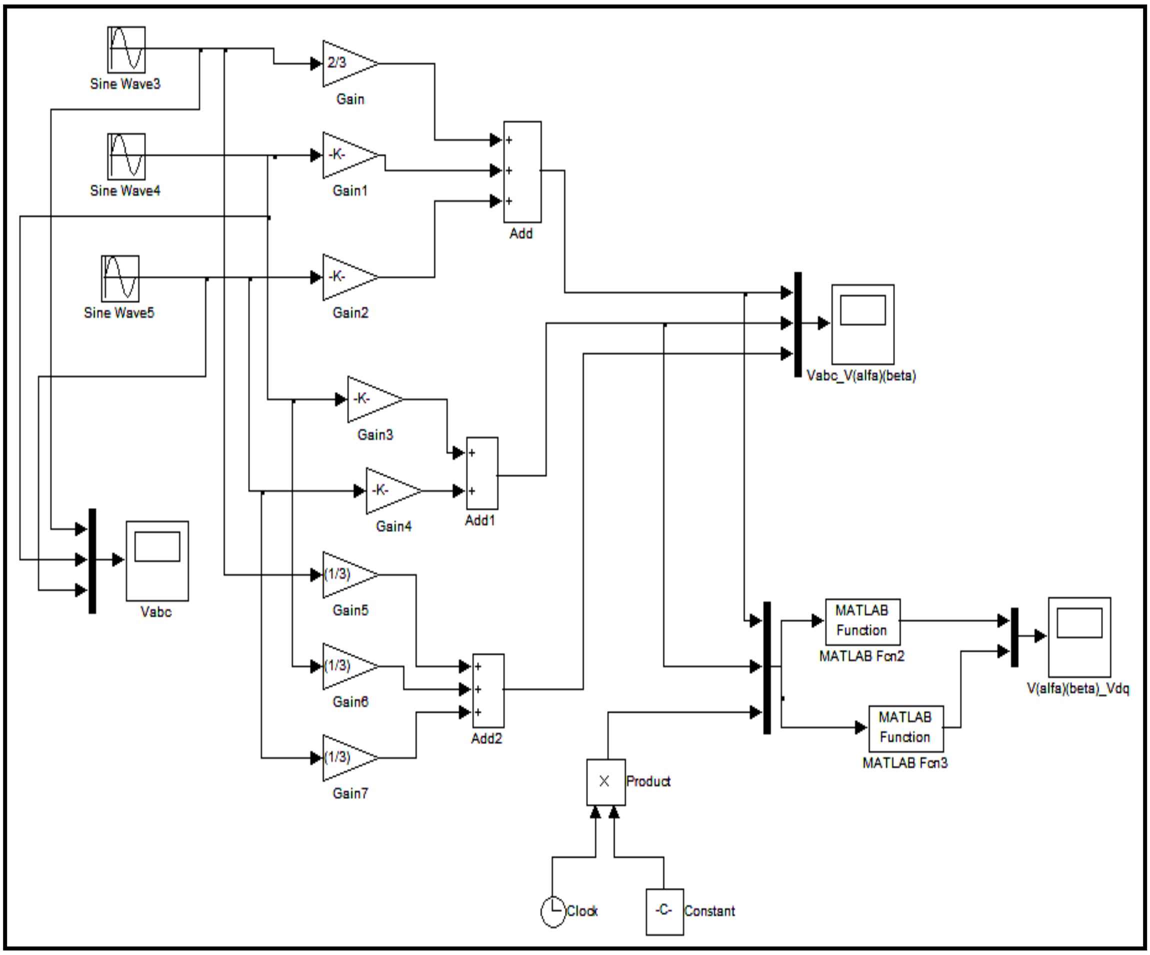

Figure 4.11: Simulation of Clarke Park transformation

Here Figure 4.11 shows the simulation of Clarke Park transformation with the help of mathematical equation which convert first V_{abc} to $V_{\alpha\beta 0}$ with a magnitude of sine wave is 100.

As per shown in below Figure 4.12 after the Clarke transformation i.e., for V_{abc} to $V_{\alpha\beta 0}$ transformation three phase system will be converted into two phase system, one phase will be shifted to zero position which is shown in waveform.

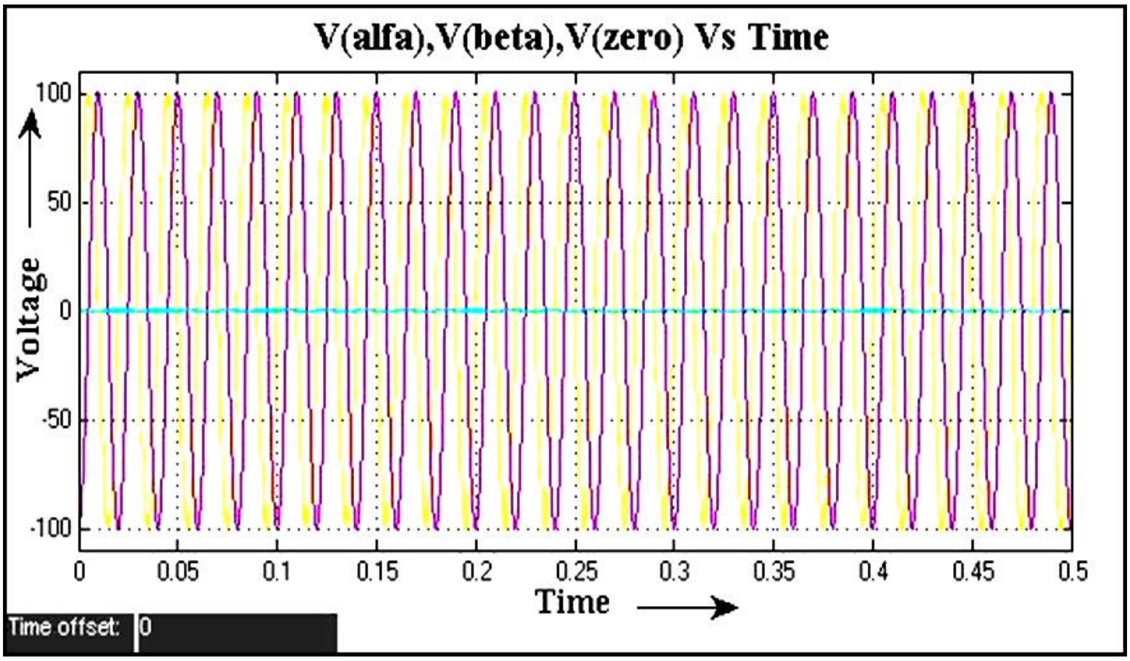

Figure 4.12: Waveform of $V_{\alpha\beta0}$

After Clarke transformation $V_{\alpha\beta0}$ is used to convert two phase AC quantities into two DC quantities i.e., Park transformation or $V_{\alpha\beta0}$ to V_{dq0} transformation.

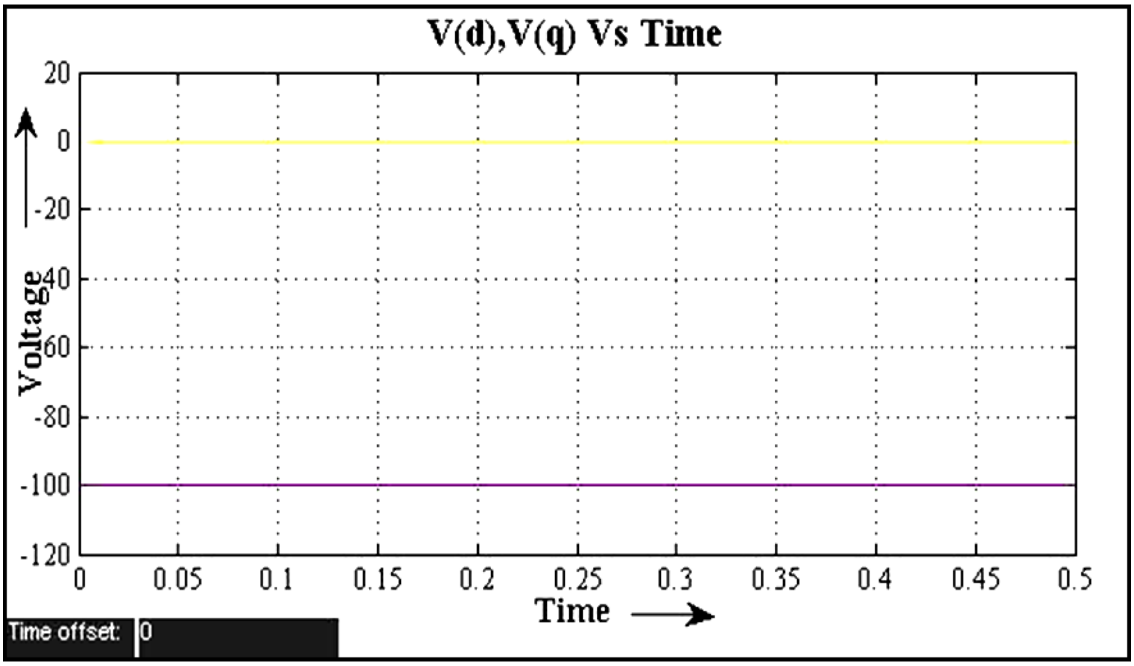

Figure 4.13: Waveform of V_{dq0}

4.4 Generation and Mitigation of Voltage Sag for R-L load

Here simulation of Voltage Sag Generation for R-L load is shown in below Figure 4.14

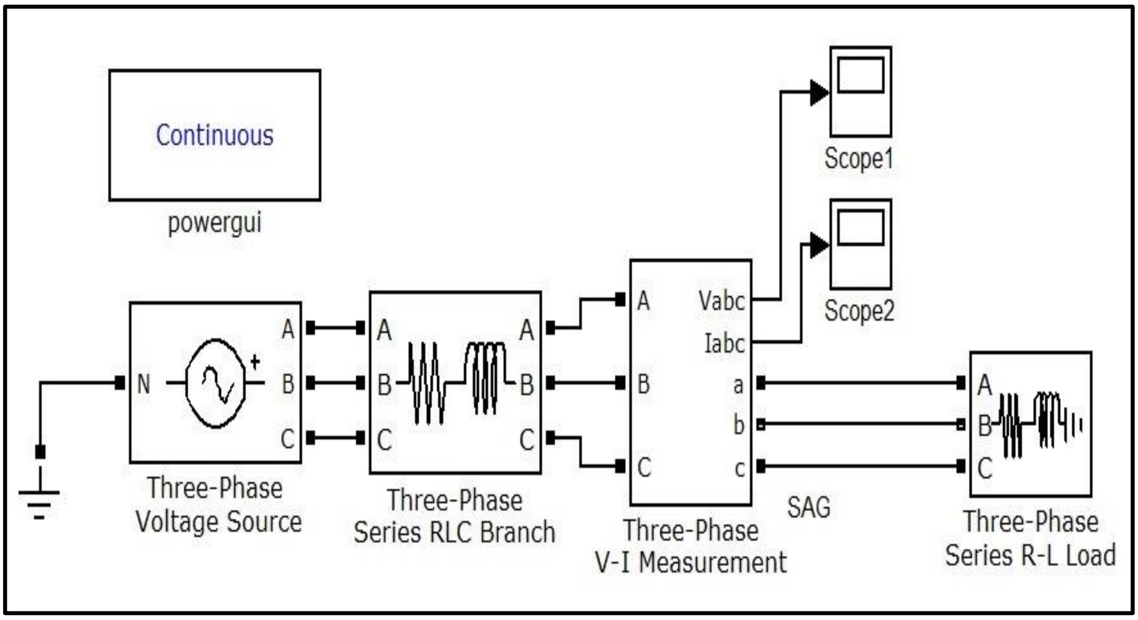

Figure 4.14: Simulation of Voltage Sag Generation for R-L load

Voltage Sag is generated with the help of programmable voltage source. Voltage Sag is occurring in between time from 0.1 to 0.2sec which is shown in below Figure 4.15.

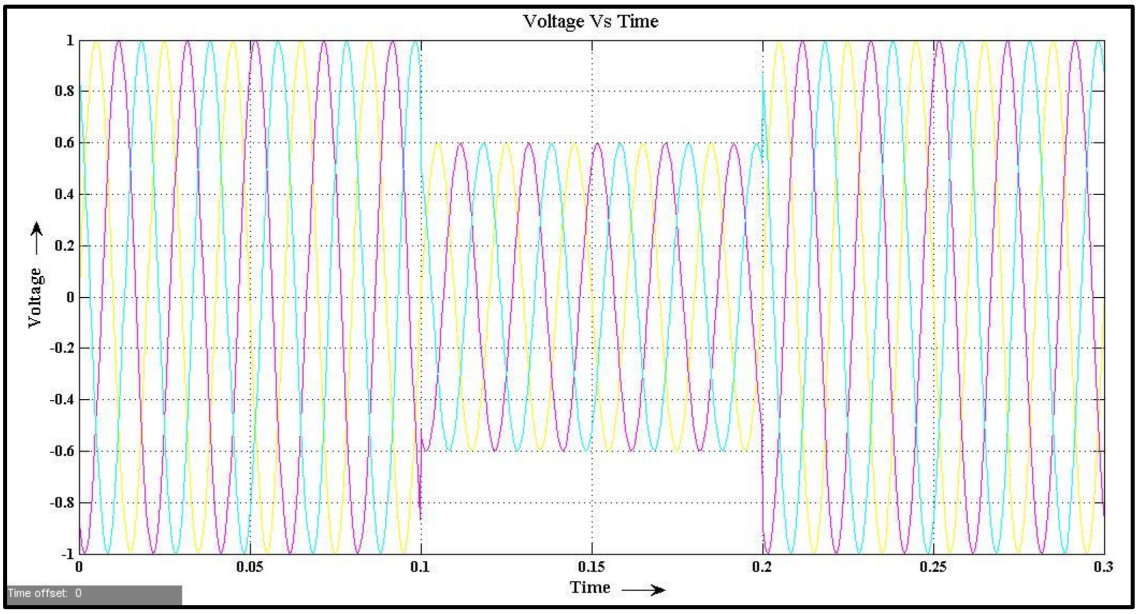

Figure 4.15: Waveform of Voltage Sag Generation for R-L Load

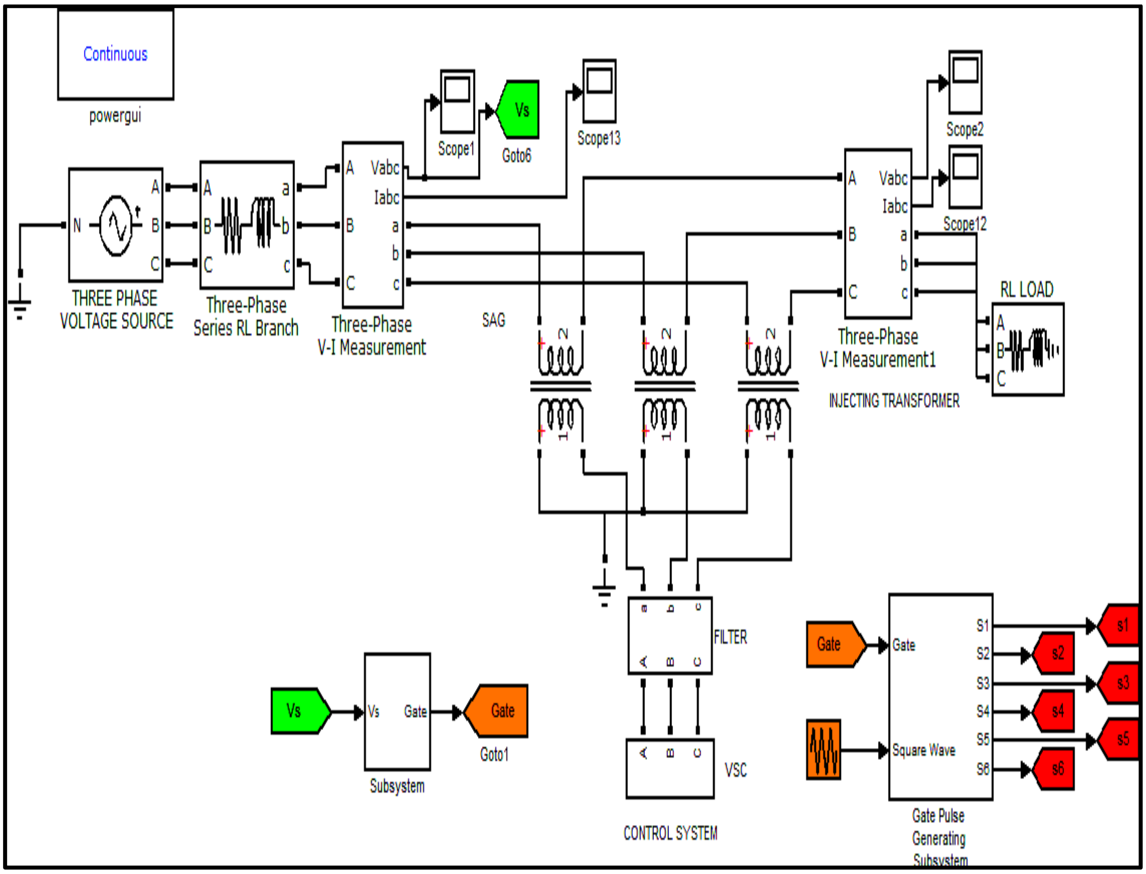

Figure 4.16: Simulation of Voltage Sag Mitigation for R-L load

To Mitigate Voltage Sag here basically three subsystems are used which are as follows

1. Control strategy of DVR
2. Voltage source converter
3. Generation of gate pulse for VSC

Here filter circuit is also used because when the DVR is suddenly inject the voltage to the transmission line connected to distribution system with the help of injecting transformer at the time of instance some disturbances are occur which leads to spike in a load voltage. To reduce that spikes L-C filter circuit is used.

Control strategy for Voltage Sag is based on abc to dq0 transformation i.e., Clarke Park transformation and dq0 to abc transformation i.e., inverse Clarke Park transformation, which is shown in below Figure 4.17

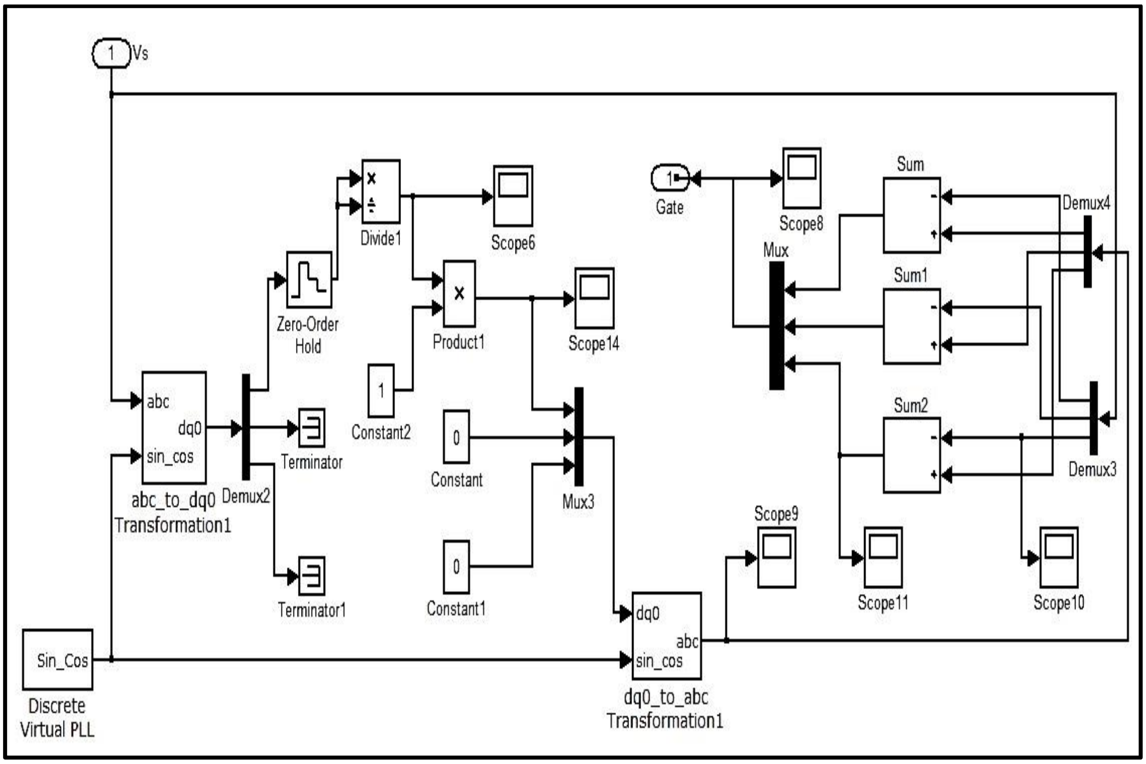

Figure 4.17: Control strategy for Voltage Sag

In a control strategy voltage is measured then after it is converted from abc to dq0 with the help abc to dq0 transformation block. Here reference sine wave, which is vectorized inputs in terms sine wave is provided for abc to dq0 transformation. After this transformation zero order hold is used to hold at Voltage Sag in the waveform of one axis either it is direct axis or quadrature axis. Here remaining two outputs of dq0 transformation is terminated to zero with the help of terminator, those two outputs are unconnected output.

After the zero order hold of Voltage Sag, signal will multiply and divided by itself due to that 1p.u. signal will be generated. That 1p.u. signal will compare with the constant 1 with the help of product block to generate 1p.u. signal. To generate 1p.u. in reference frame i.e., in rotating frame dq0 to abc transformation is performed. In this transformation two inputs are taken from terminator and remaining one input is taken from above generated 1p.u. in a stationary frame.

Here dq0 to abc transformation is done with the help of dq0 to abc transformation block in which stationary frame is converted into rotating frame and sine wave with the magnitude of 1p.u. is generated.

This 1p.u. reference sine wave is compared with the supply voltage (Voltage Sag) due to that error is generated in p.u., which is required to be injected in the system. Magnitude of error in p.u., will be injected to the system with the help of injecting transformer. Here injected voltage is provided by voltage source converter.

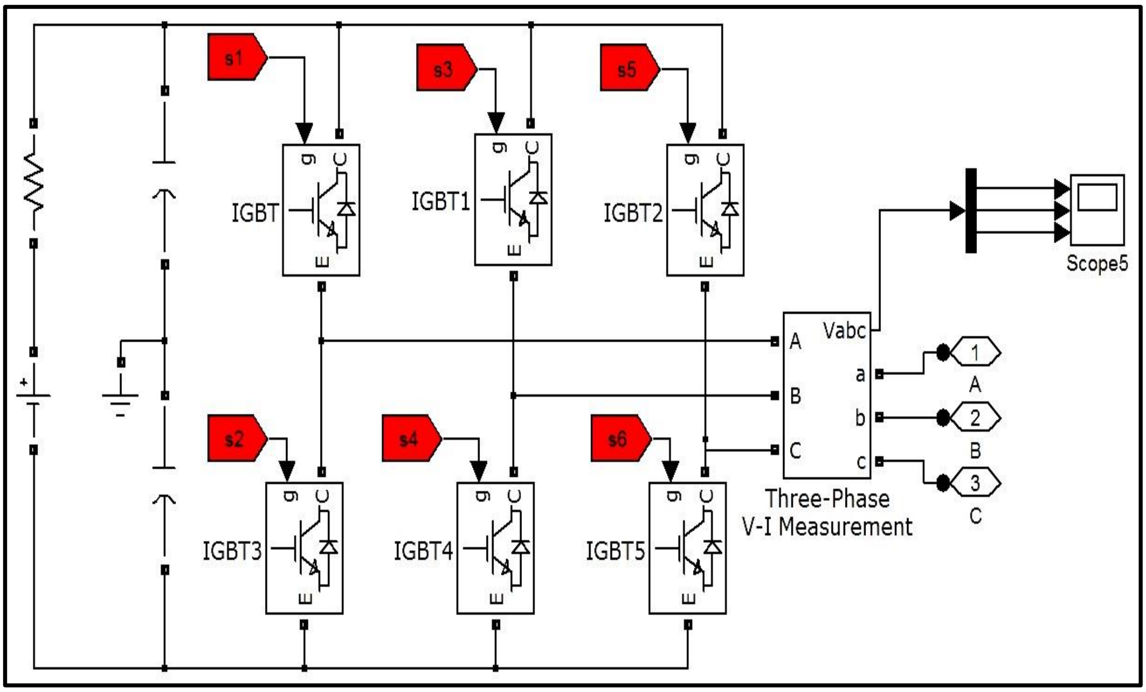

Figure 4.18: Voltage source converter

Voltage source converter is made up of combination of six IGBTs. Here separate gate signal is provided for each IGBT in voltage source converter. Each arm of voltage source converter consists of two IGBTs. Each IGBT is operated for 60° of conduction period. Two IGBTs in one arm cannot be operated simultaneously. Here gate pulse is generated with the comparison of two signals one is error signal which is generated in the control strategy of DVR and other one is triangular or carrier signal.

Here comparison of two signals is performed with the help of relational operator. According to this comparison gate pulse is generated in square wave which is given to the irrespective IGBTs. Comparison is made in between carrier signal which is in triangular form and modulating signal (error signal) which in sinusoidal form. Hence this voltage source converter is also known as sinusoidal pulse width inverter (SPWM). Gate pulse controlling mechanism is shown below in Figure 4.19. This gate pulse is fed to the irrespective IGBTs of voltage source converter

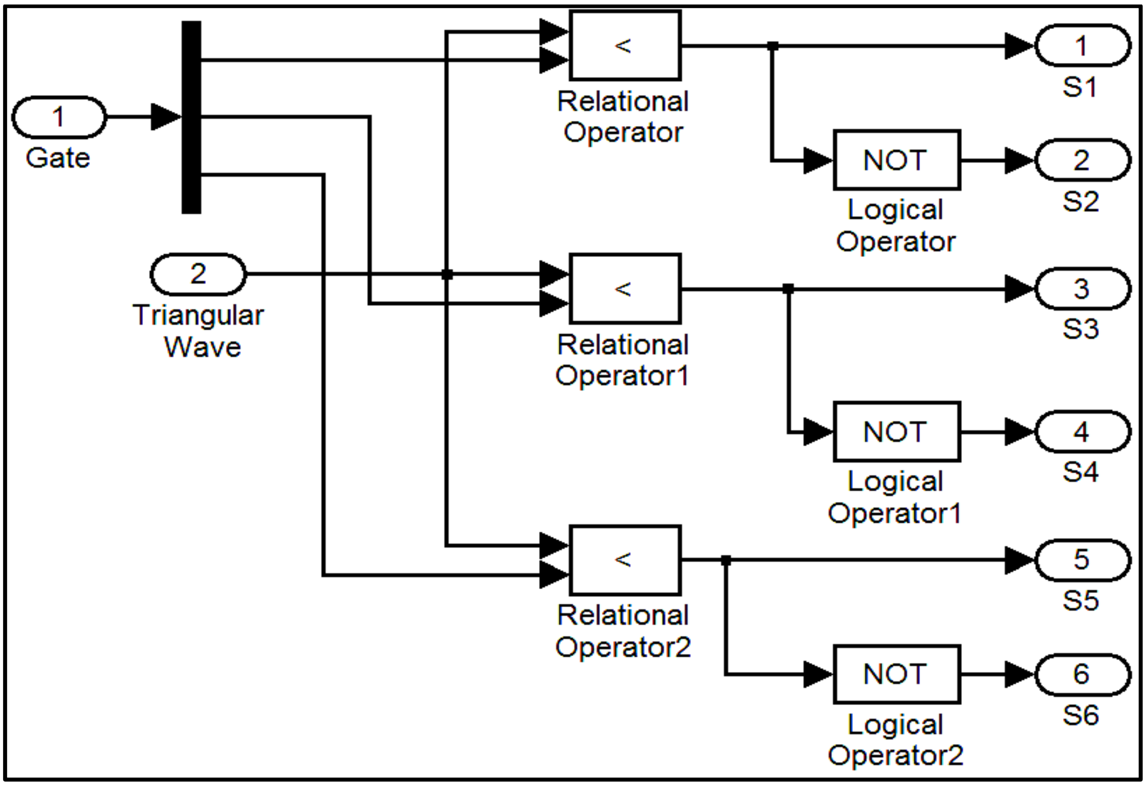

Figure 4.19: Gate pulse Controller

Due to that voltage source converter will generate error voltage in p.u., system, which is required to be injected in the system with the help of injecting transformer. After injection operation Voltage Sag will be mitigated.

Simulation Rating

1. Supply Voltage = 3-Ø 1p.u. 50Hz
2. Voltage at Sag = 3-Ø 0.6p.u. 50Hz
3. R-L load
   I. P_L = 1KW
   II. Q_L = 5000VAR
4. Injected Voltage = 3-Ø 0.4p.u. 50Hz

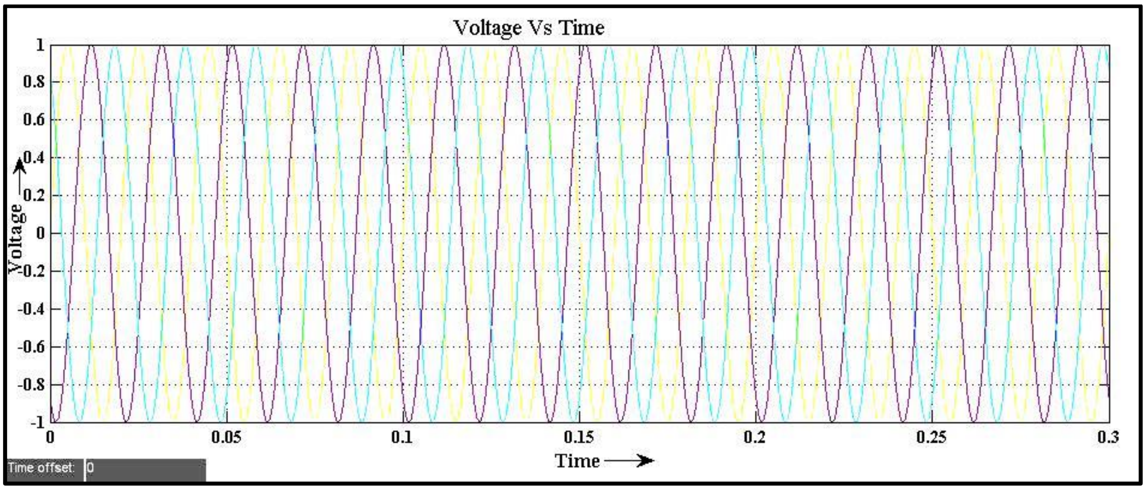

Figure 4.20: Waveform of supply voltage

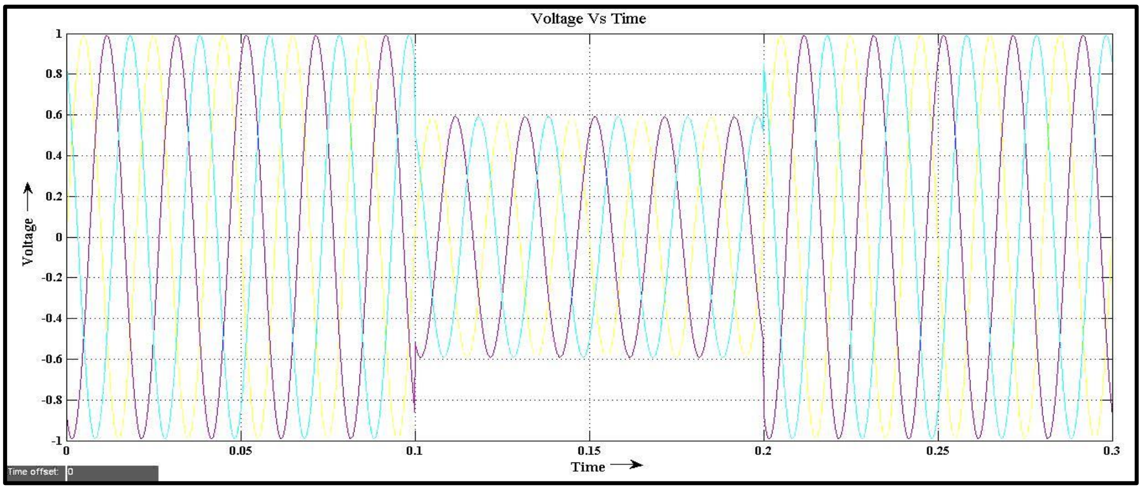

Figure 4.21: Waveform of Voltage Sag for R-L load

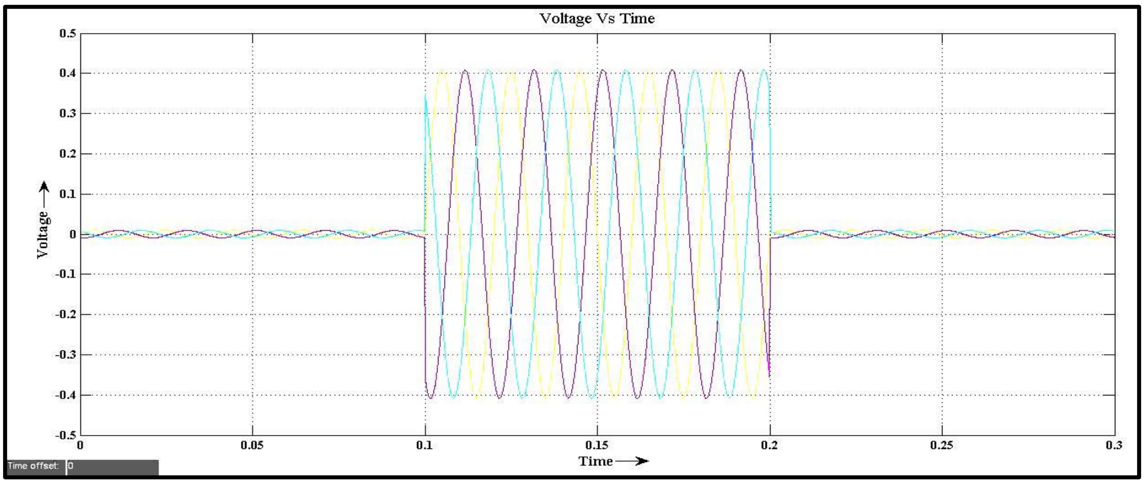

Figure 4.22: Waveform of injected voltage for R-L load

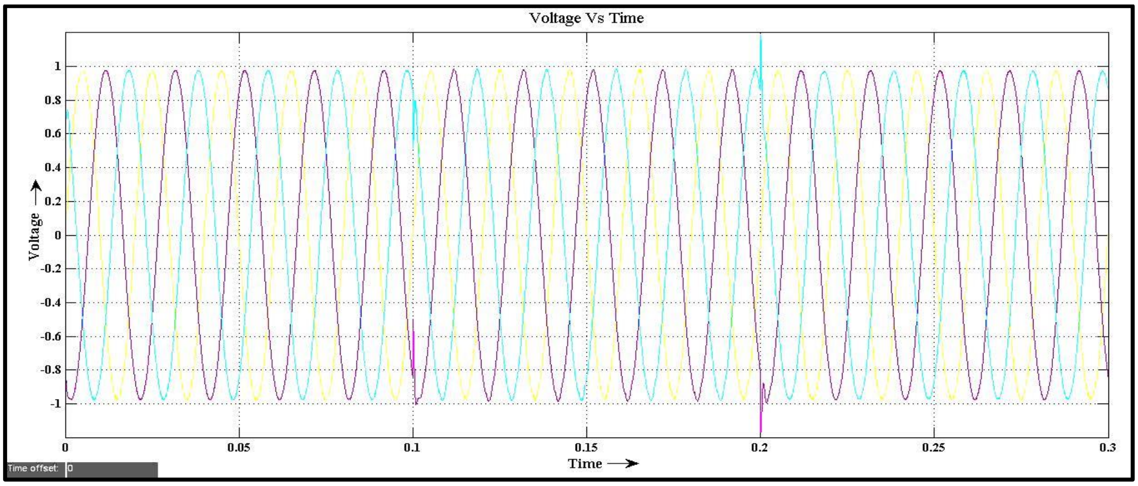

Figure 4.23: Waveform after Mitigation of Voltage Sag for R-L load

Here Figure 4.24 shows the FFT analysis of Voltage Sag waveform for R-L load. At Voltage Sag Total Harmonic Distortion in voltage is about 0.01% which is very less than acceptable limit of THD.

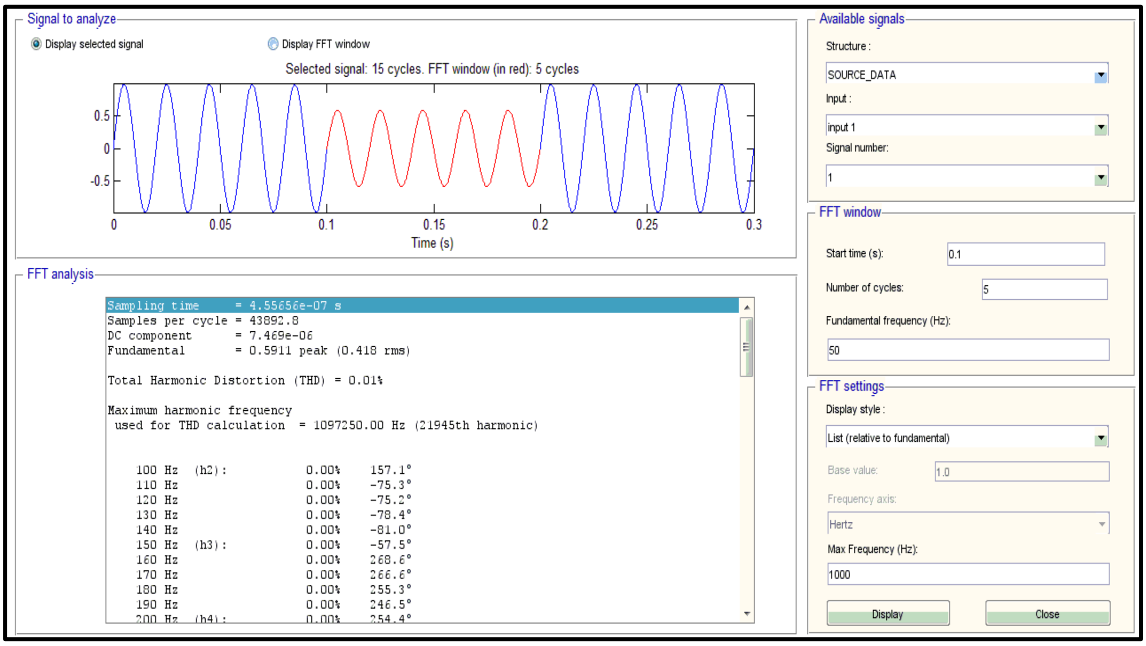

Figure 4.24: FFT analysis of Voltage Sag waveform for R-L load

FFT analysis after mitigation Voltage Sag waveform for R-L load i.e., Figure 4.25 shows that Total Harmonic Distortion in voltage rises to 0.19% because of voltage source converter and injecting transformer which are generally one type of harmonic generating sources, but here also THD is in acceptable limit of it.

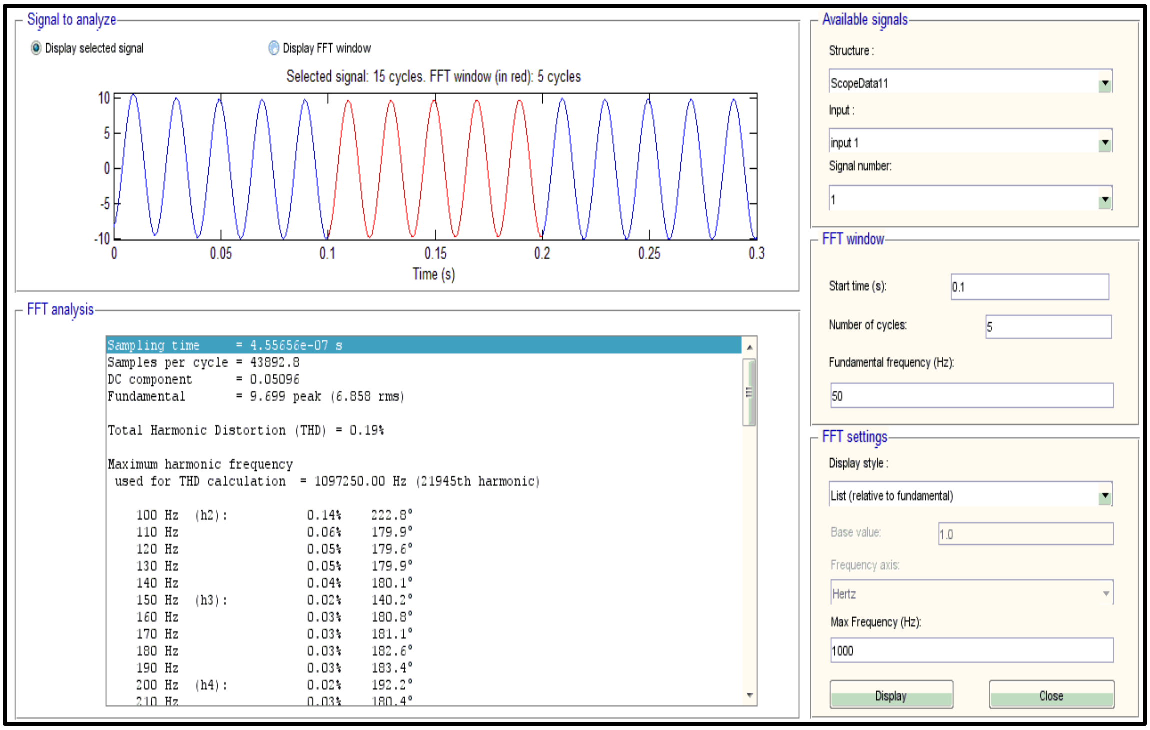

Figure 4.25: FFT analysis after Mitigation of Voltage Sag waveform for R-L load

4.5 Generation and Mitigation of Voltage Sag for Motor load

Here simulation of Voltage Sag Generation for Motor load is shown in below Figure 4.26

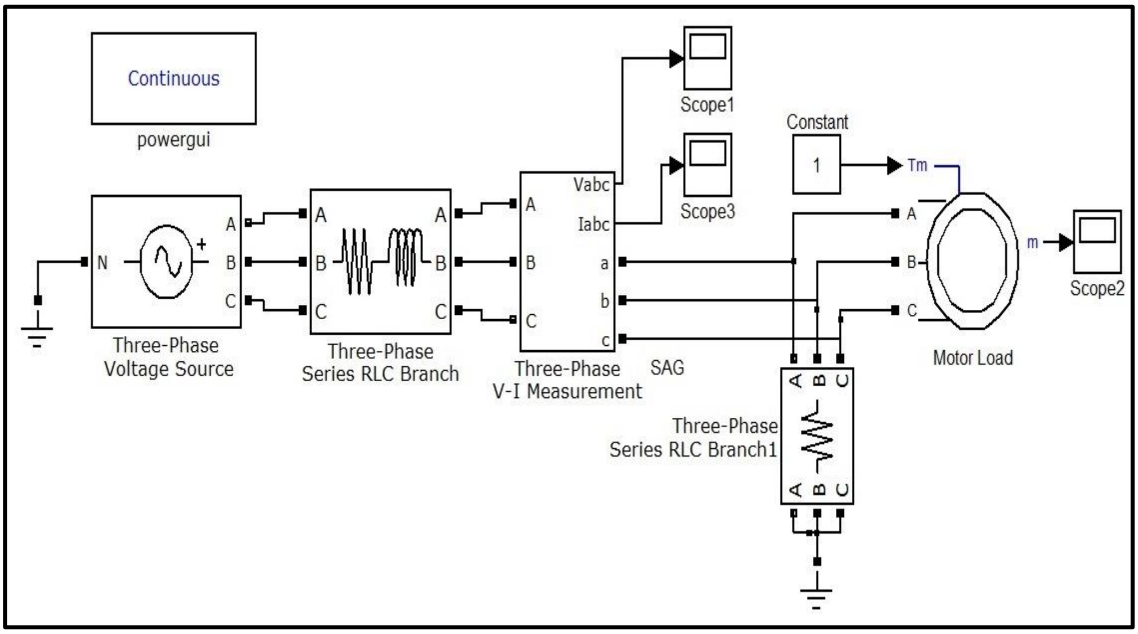

Figure 4.26: Simulation of Voltage Sag Generation for Motor load

Voltage Sag is generated with the help of programmable voltage source. For the motor load protection a small value of resistance is connected across motor load. Voltage Sag is occurring in between time from 0.1 to 0.2sec which is shown in below Figure 4.27.

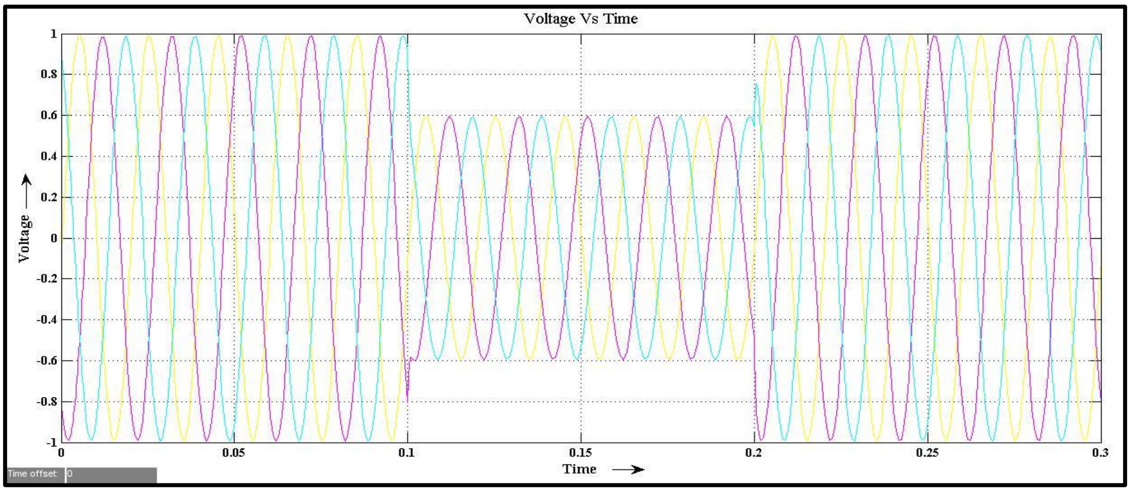

Figure 4.27: Waveform of Voltage Sag Generation for Motor load

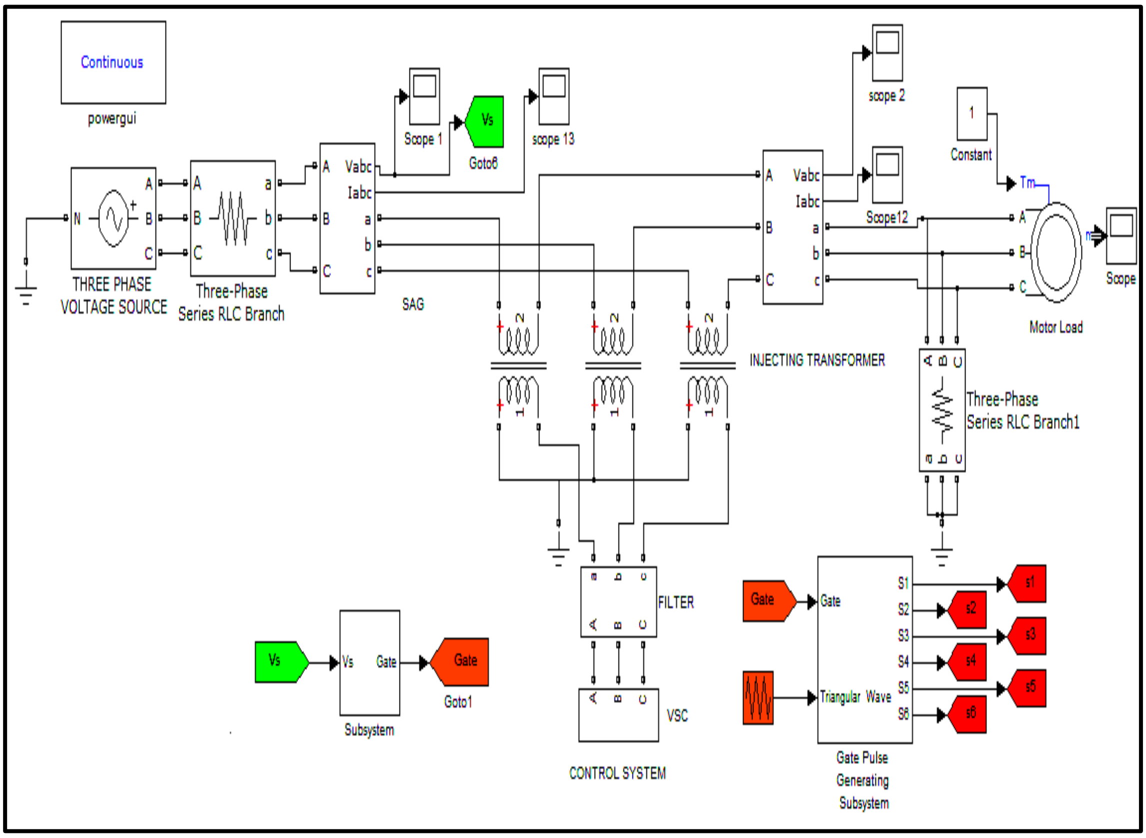

Figure 4.28: Simulation of Voltage Sag Mitigation for Motor load

Here control strategy for Voltage Sag with motor load is same as above used for R-L load. Error is generated with the help of control strategy that will be injected in the system through injecting transformer.

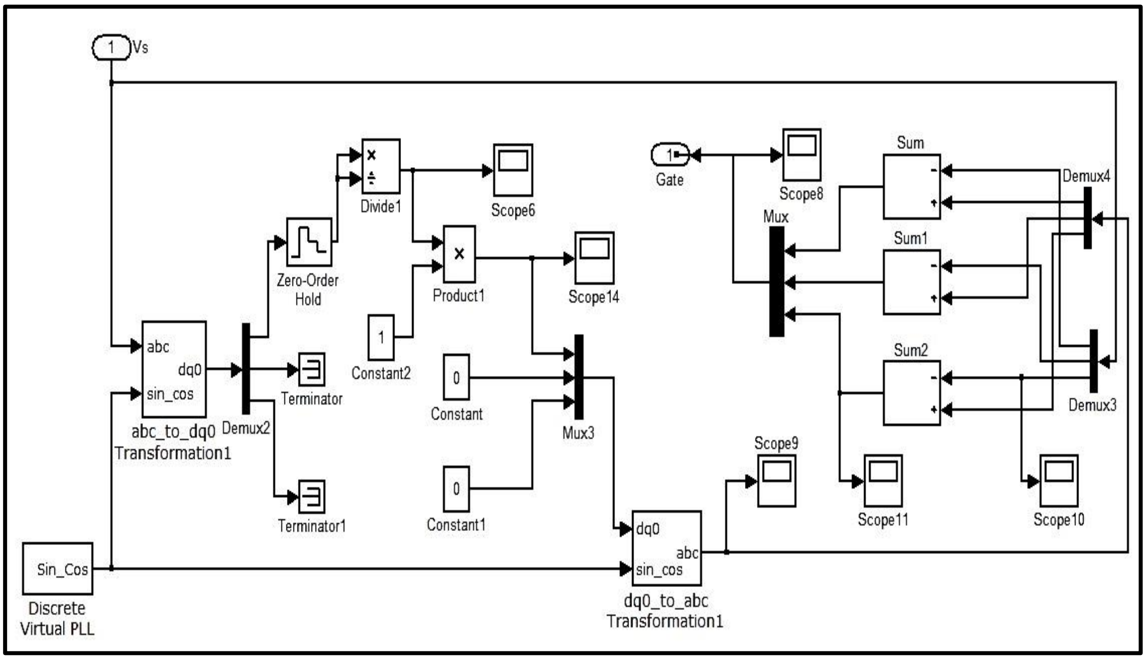

Figure 4.29: Control strategy for Voltage Sag

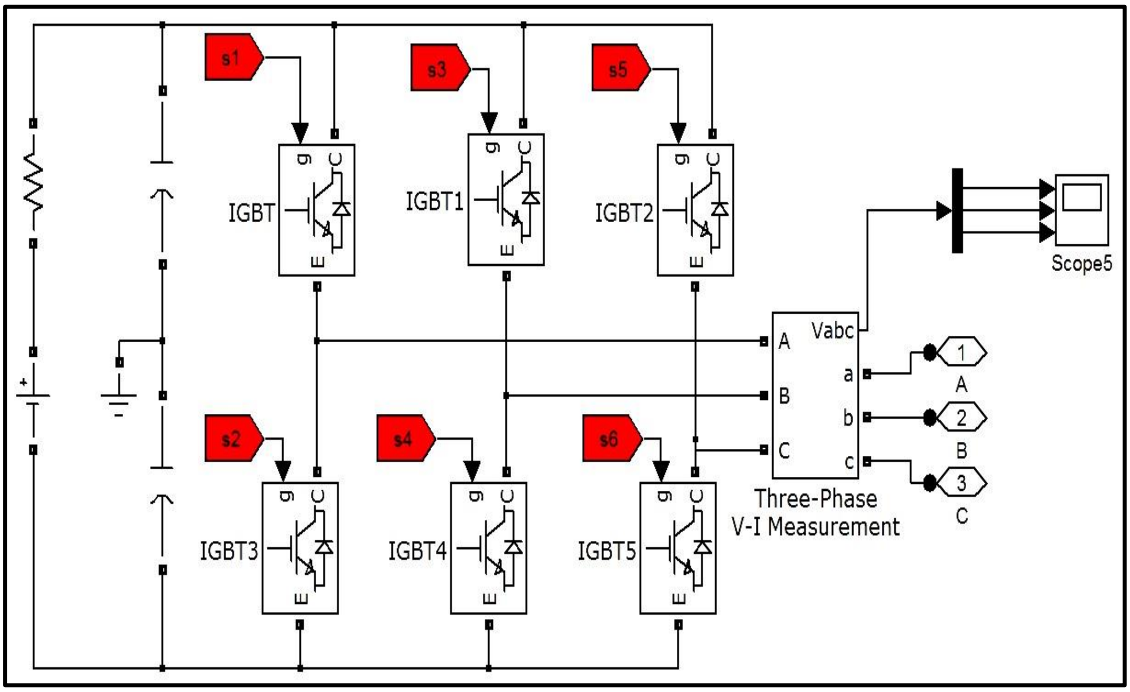

Figure 4.30: Voltage source converter

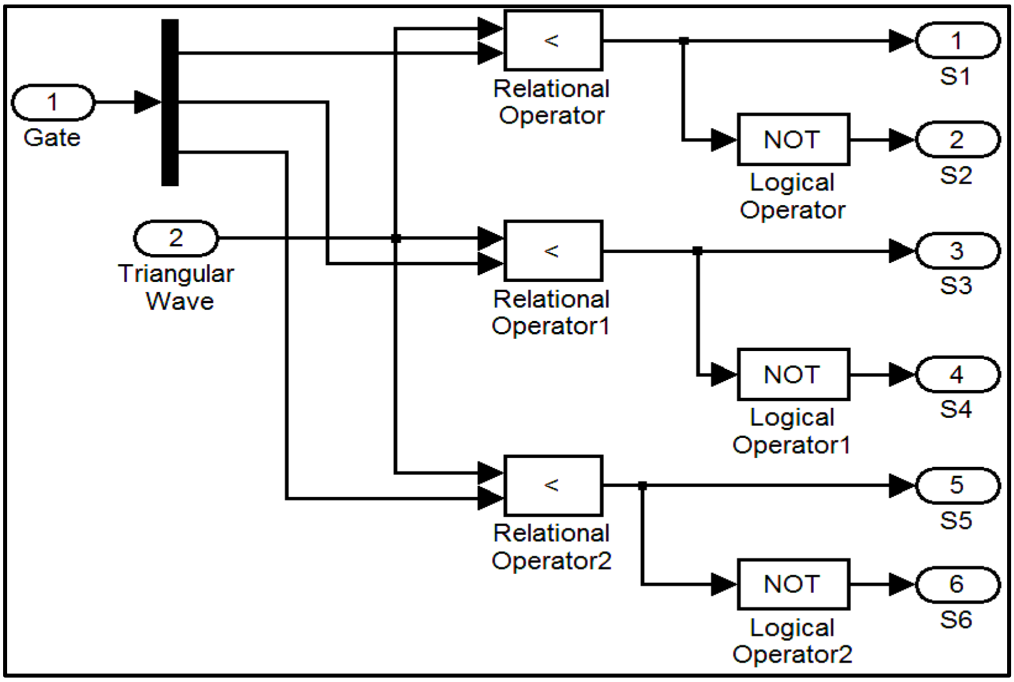

Figure 4.31: Gate pulse Controller

Simulation Rating

1. Supply Voltage = 3-Ø 1p.u. 50Hz
2. Voltage at Sag = 3-Ø 0.6p.u. 50Hz
3. Motor load = 5.4HP, 400V, 1430RPM, 50Hz
4. Injected Voltage = 3-Ø 0.4p.u. 50Hz

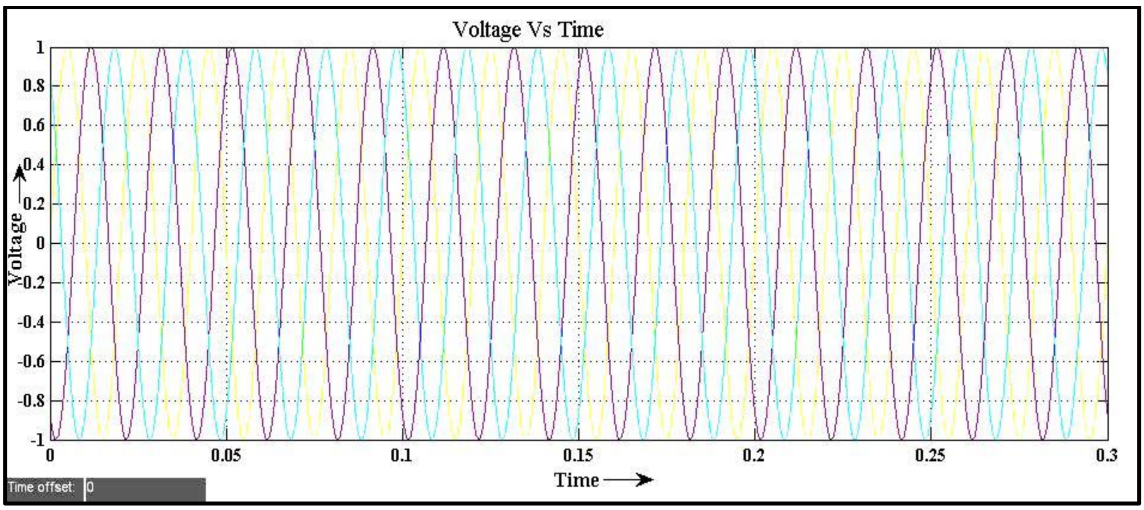

Figure 4.32: Waveform of Supply Voltage

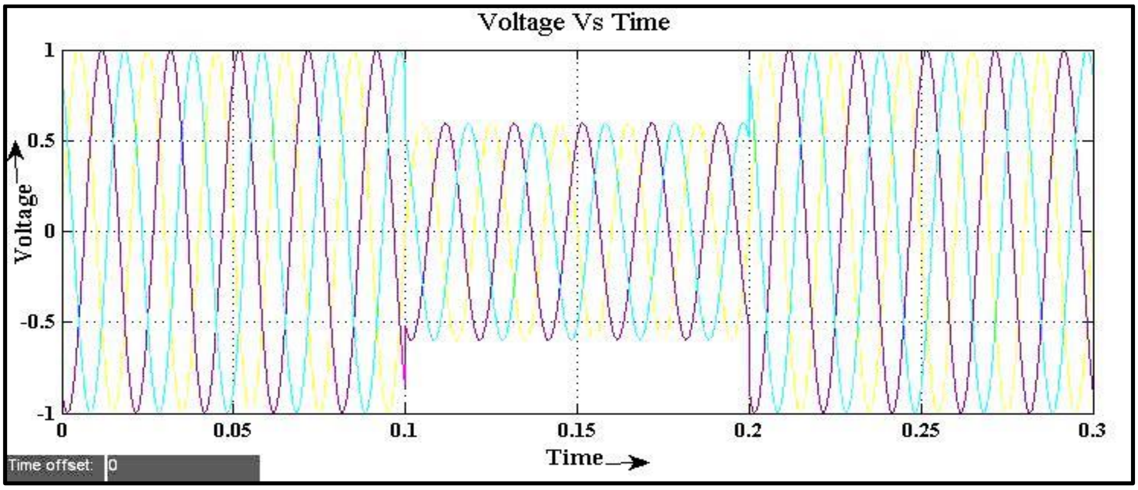

Figure 4.33: Waveform of Voltage Sag for Motor load

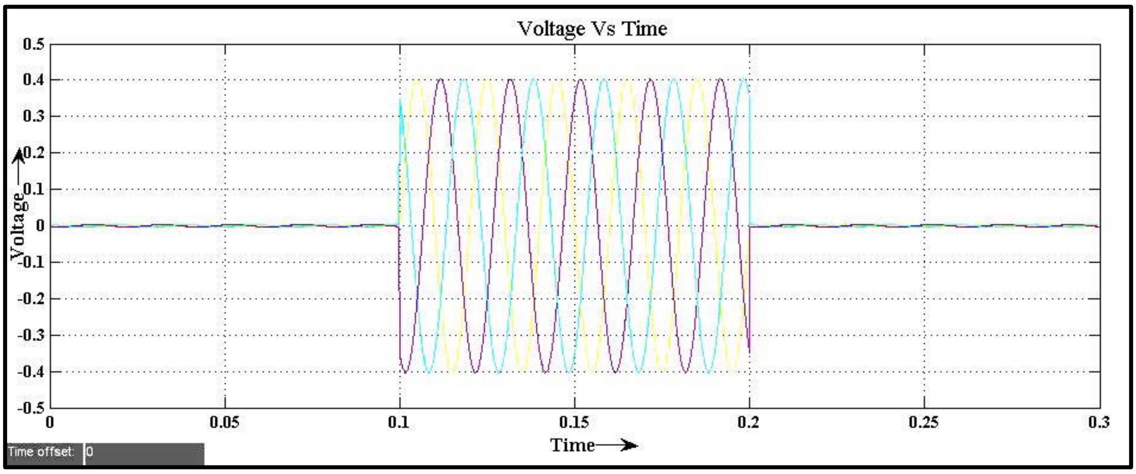

Figure 4.34: Waveform of injected voltage for Motor load

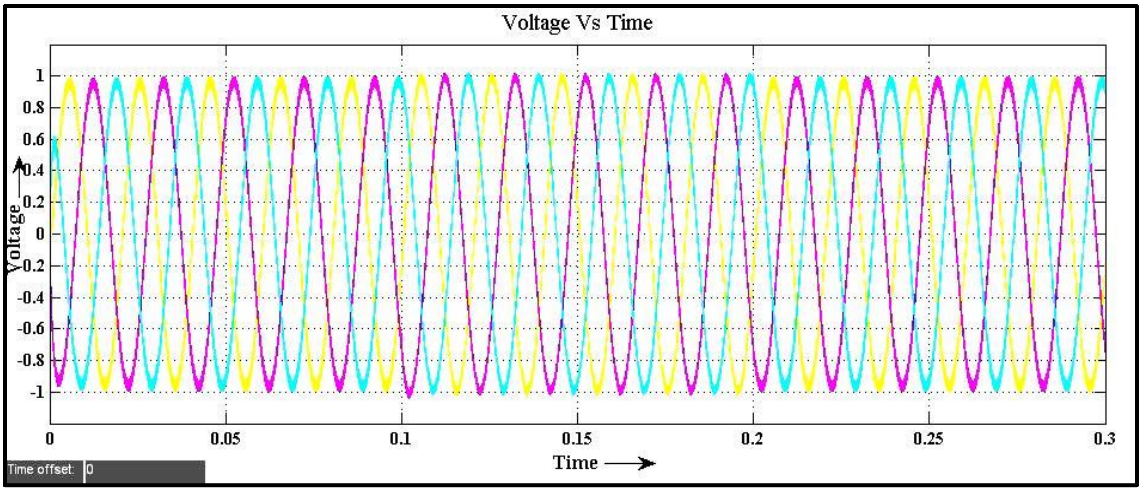

Figure 4.35: Waveform after Mitigation of Voltage Sag for Motor load

Here Figure 4.36 shows the FFT analysis of Voltage Sag waveform for Motor load. At Voltage Sag Total Harmonic Distortion in voltage is about 0.01% which is very less than acceptable limit of THD.

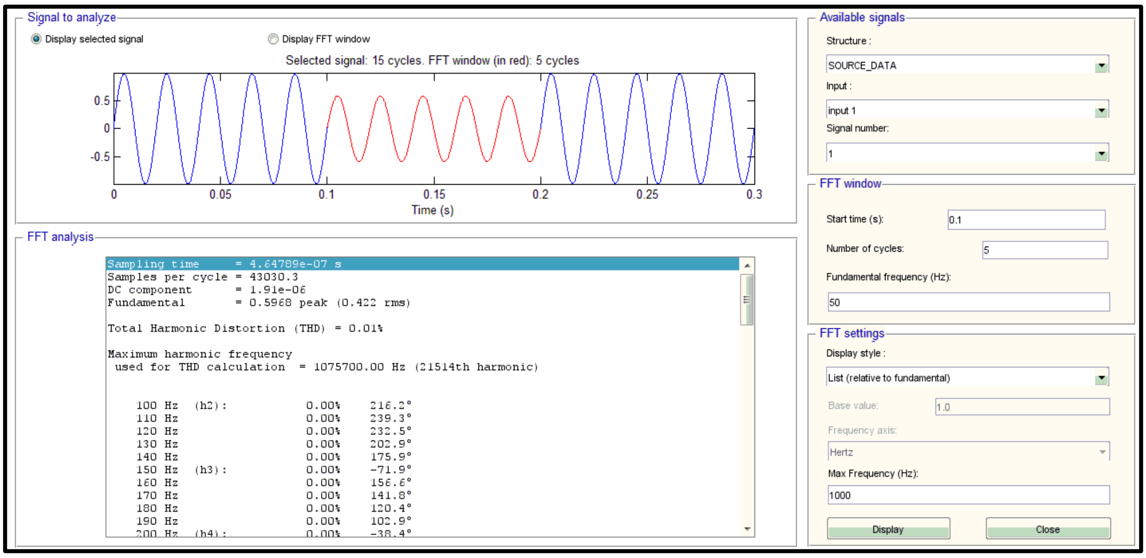

Figure 4.36: FFT analysis of Voltage Sag waveform for Motor load

FFT analysis after mitigation Voltage Sag waveform for Motor load i.e., Figure 4.37 shows that Total Harmonic Distortion in voltage rises to 2.49% because of voltage source converter, injecting transformer and motor load which are generally one type of harmonic generating sources, but here also THD is in acceptable limit of it.

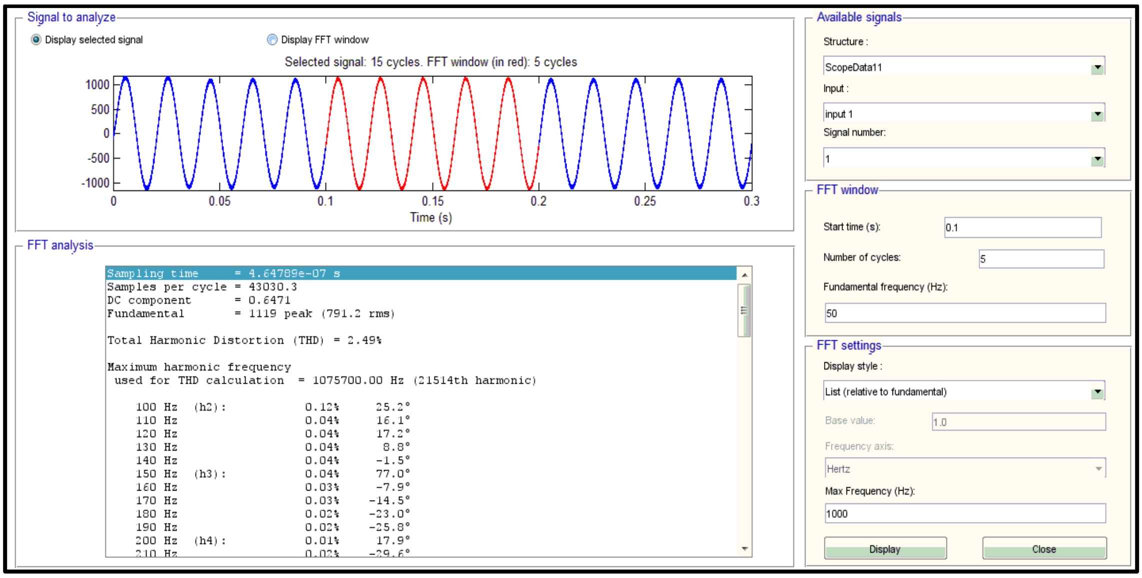

Figure 4.37: FFT analysis after Mitigation of Voltage Sag waveform for Motor load

4.6 Generation and Mitigation of Voltage Swell for R-L load

Here simulation of Voltage Swell Generation for R-L load is shown in below Figure 4.38

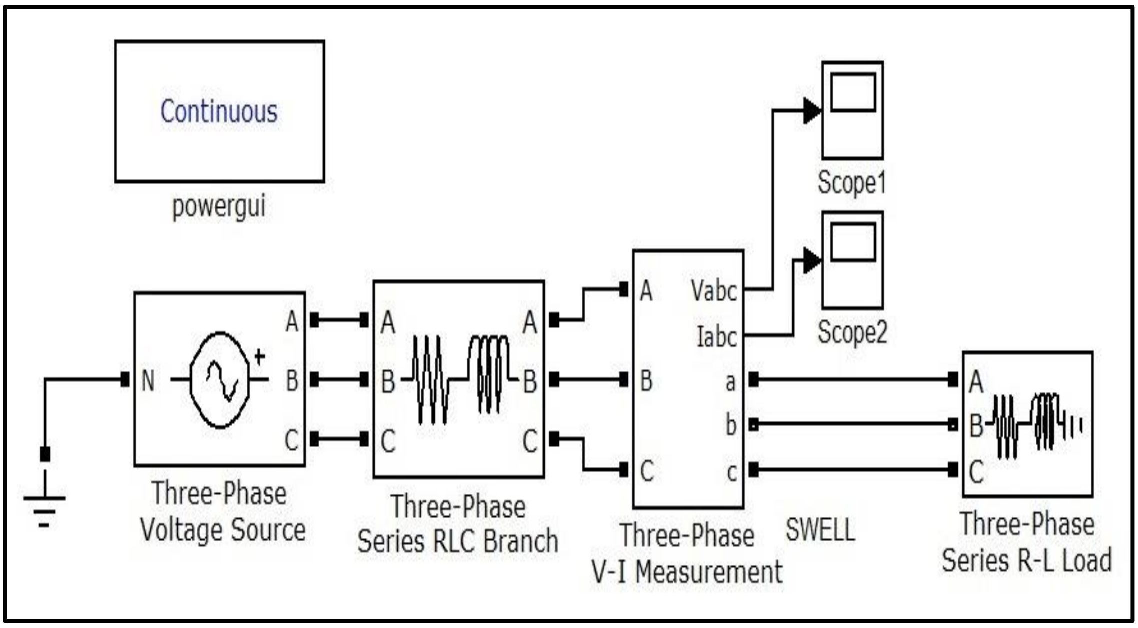

Figure 4.38: Simulation of Voltage Swell Generation for R-L load

Voltage Swell is generated with the help of programmable voltage source. Voltage Swell is occurring in between time from 0.1 to 0.2sec which is shown in below Figure 4.39.

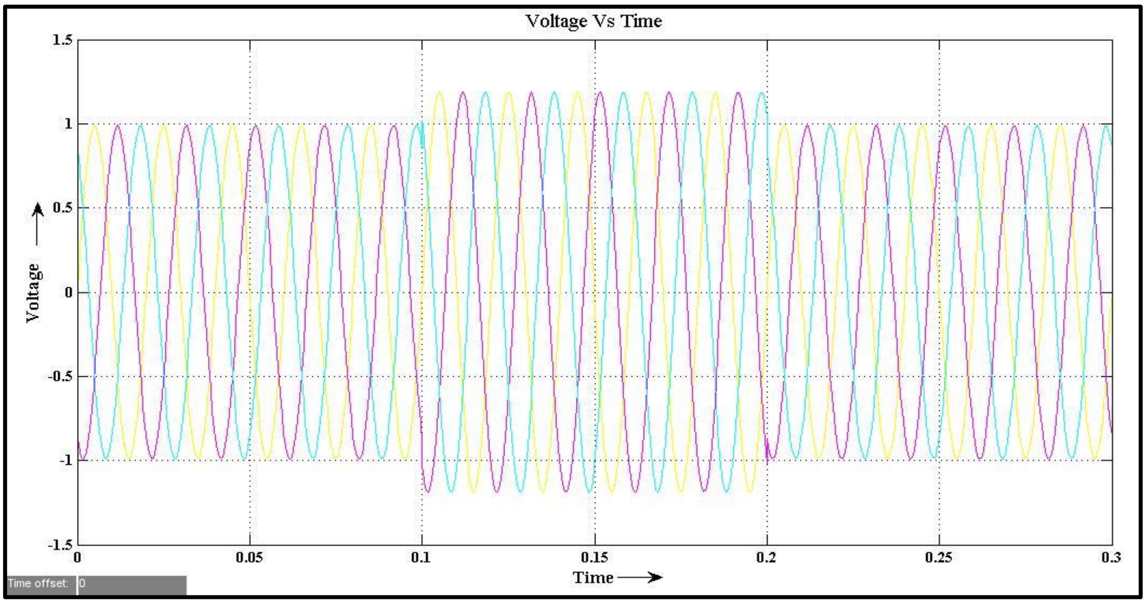

Figure 4.39: Waveform of Voltage Swell Generation for R-L Load

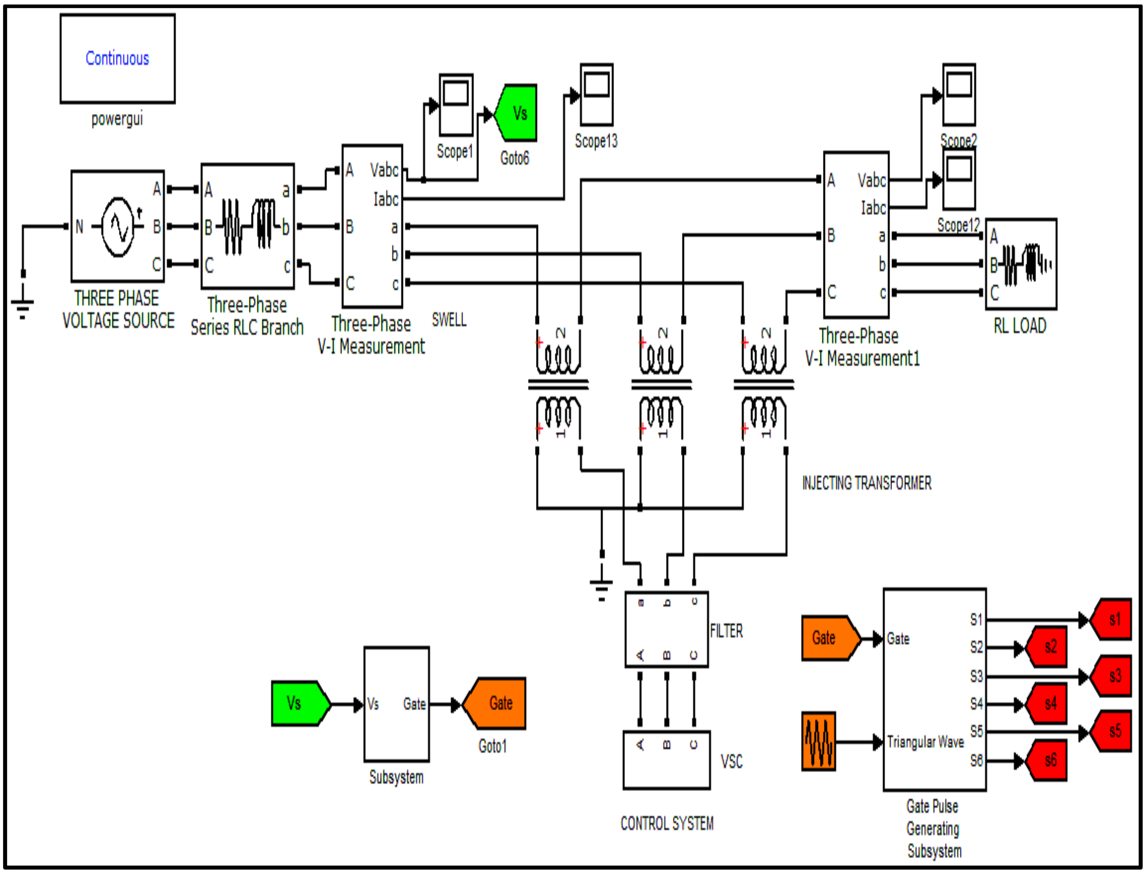

Figure 4.40: Simulation of Voltage Swell Mitigation for R-L load

To Mitigate Voltage Swell here basically three subsystems are used which are as follows

1. Control strategy of DVR
2. Voltage source converter
3. Generation of gate pulse for VSC

Here filter circuit is also used because when the DVR is suddenly restored the voltage to nominal value to the transmission line of distribution system with the help of injecting transformer at the time of instance some disturbances are occur which lead to spike in a load voltage. To reduce that spikes L-C filter circuit is used.

Control strategy for Voltage Swell is based on abc to dq0 transformation i.e., Clarke Park transformation and dq0 to abc transformation i.e., inverse Clarke Park transformation, which is shown in below Figure 4.41

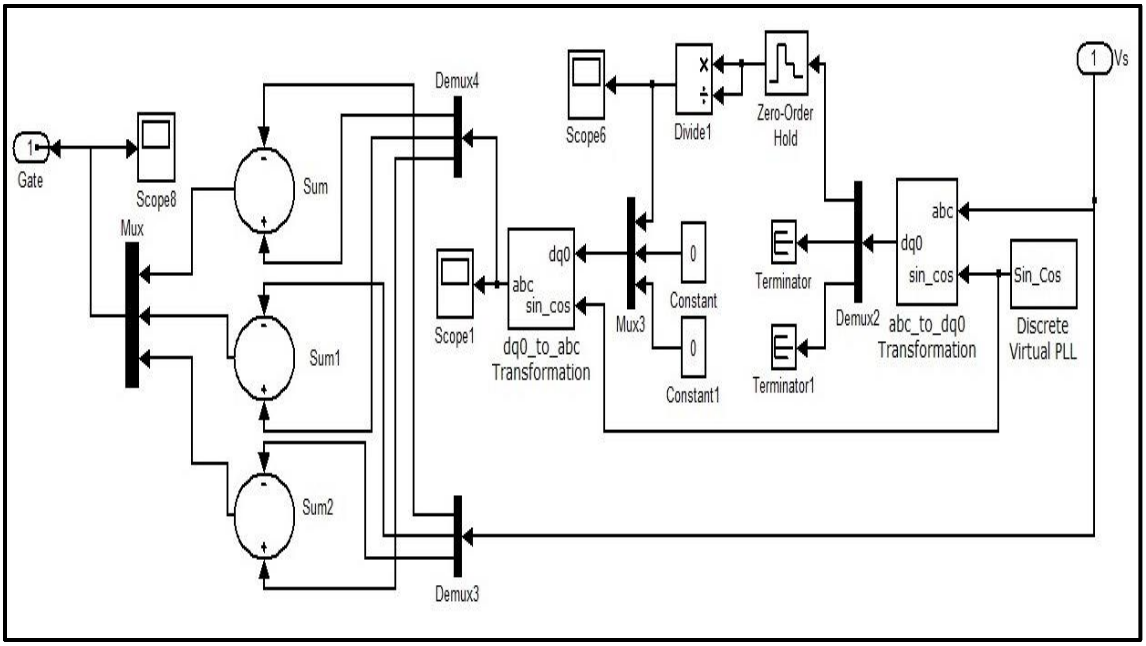

Figure 4.41: Control strategy for Voltage Swell

In a control strategy Voltage Swell is measured then after it is converted from abc to dq0 with the help abc to dq0 transformation block. Here reference sine wave, which is vectorized inputs in terms sine wave is provided for abc to dq0 transformation. After this transformation zero order hold is used to hold at Voltage Swell in the waveform of one axis either it is direct axis or quadrature axis. Here remaining two outputs of dq0 transformation is terminated to zero with the help of terminator, those two outputs are unconnected output.

After the zero order hold of Voltage Swell, signal will multiply and divided by itself due to that 1p.u. signal will be generated. That 1p.u. signal will be multiply with the constant 1 with the help of product block to generate 1p.u. signal. To generate 1p.u. in reference frame dq0 to abc transformation is performed. In this transformation two inputs are taken from terminator and remaining one input is taken from above generated 1p.u. in a stationary frame.

Here dq0 to abc transformation is done with the help of dq0 to abc transformation block in which stationary frame is converted into rotating frame. Due to that sine wave with the magnitude 1p.u. is generated. This 1p.u. reference sine wave is compared with the supply voltage (Voltage Swell) due to that error is generated in p.u., which is required to be restored to the nominal value in the system.

Magnitude of error in p.u., will be restored to the nominal value in the system with the help of injecting transformer. Here restored voltage is provided by voltage source converter.

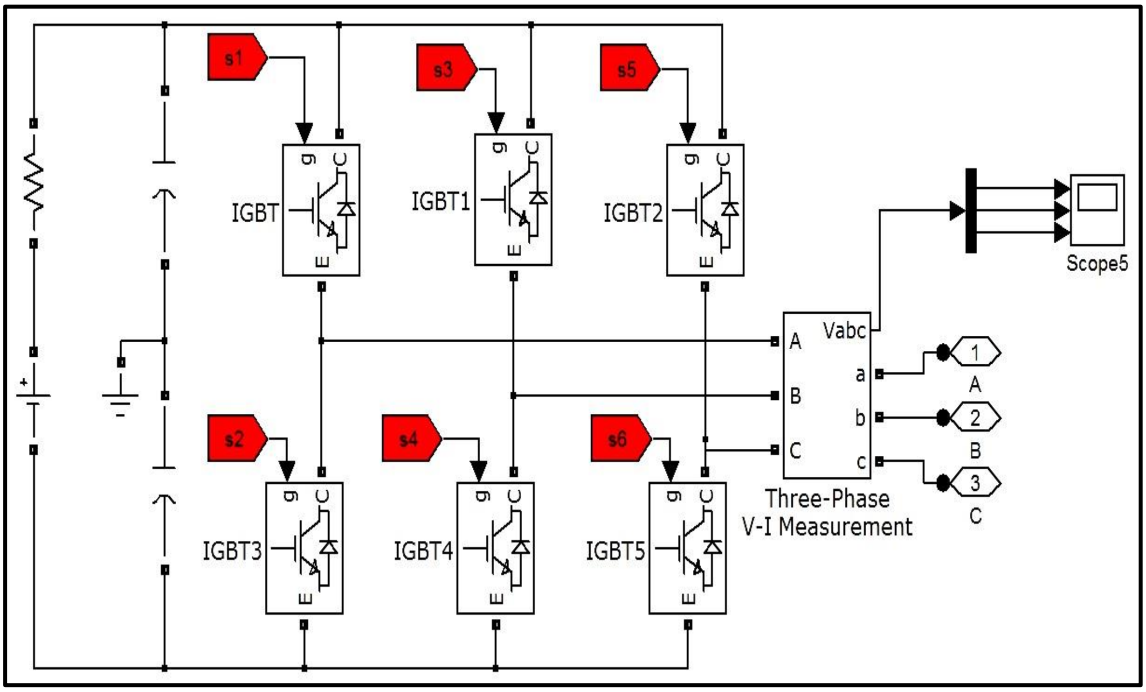

Figure 4.42: Voltage source converter

Voltage source converter is made up of combination of six IGBTs. Here separate gate signal is provided for each IGBT in voltage source converter. Each arm of voltage source converter consists of two IGBTs. Each IGBT is operated for 60° of conduction period. Two IGBTs in one arm cannot be operated simultaneously. Here gate pulse is generated with the comparison of two signals one is error signal which is generated in the control strategy of DVR and other one is triangular or carrier signal.

Here comparison of two signals is performed with the help of Boolean expression. According to this comparison gate pulse is generated in square wave which is given to the irrespective IGBTs. Comparison is made in between carrier signal which is in triangular form and modulating signal (error signal) which in sinusoidal form. Hence this voltage source converter is also known as sinusoidal pulse width inverter (SPWM). Gate pulse controlling mechanism is shown below in Figure 4.43. This gate pulse is fed to the irrespective IGBTs of voltage source converter

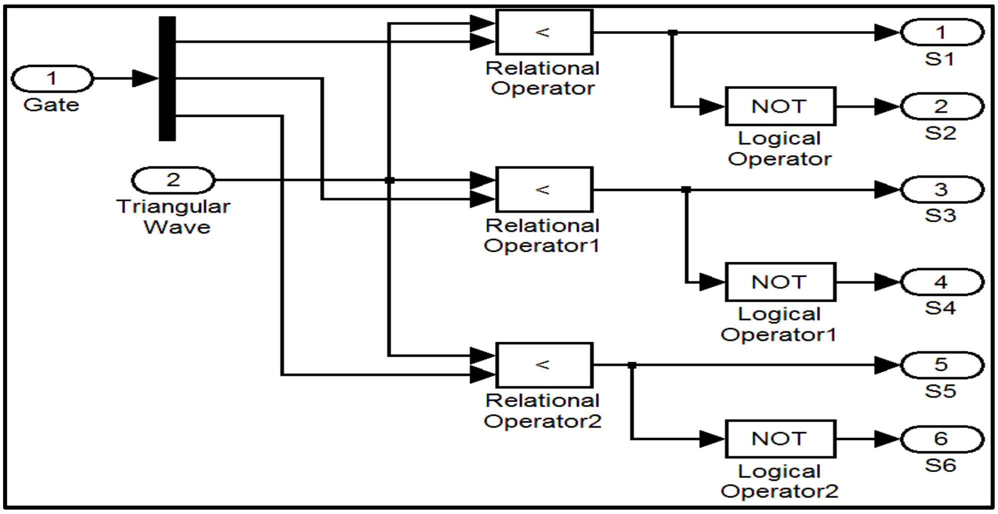

Figure 4.43: Gate pulse Controller

Due to that voltage source converter will generate error voltage in p.u., system, which is required to be restored to the nominal value in the system with the help of injecting transformer. After restoration operation Voltage Swell will be mitigated.

Simulation Rating

1. Supply Voltage = 3-Ø 1p.u. 50Hz
2. Voltage at Swell = 3-Ø 1.2p.u. 50Hz
3. R-L load
    - III. P_L = 1KW
    - IV. Q_L = 5000VAR
4. Restored Voltage = 3-Ø 0.2p.u. 50Hz

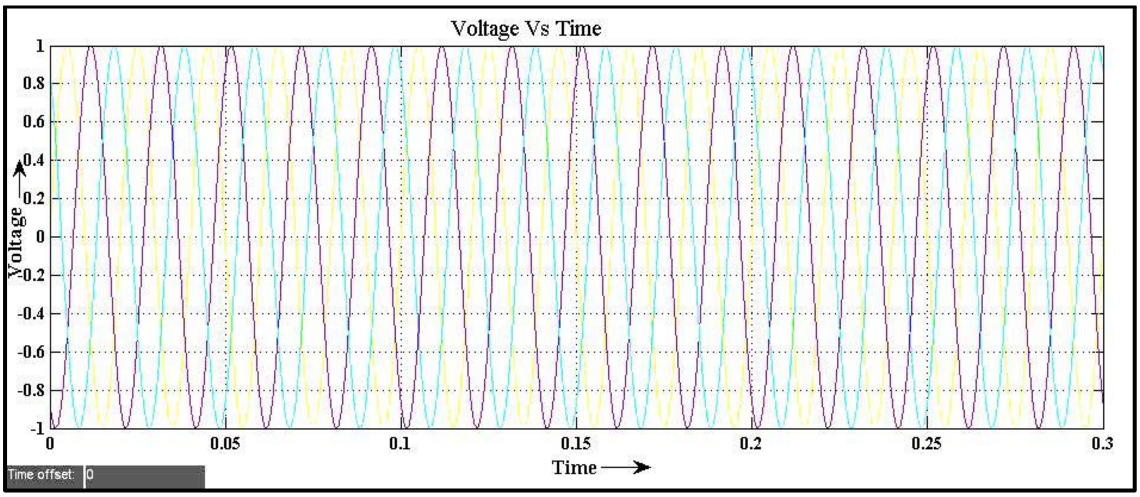

Figure 4.44: Waveform of supply voltage

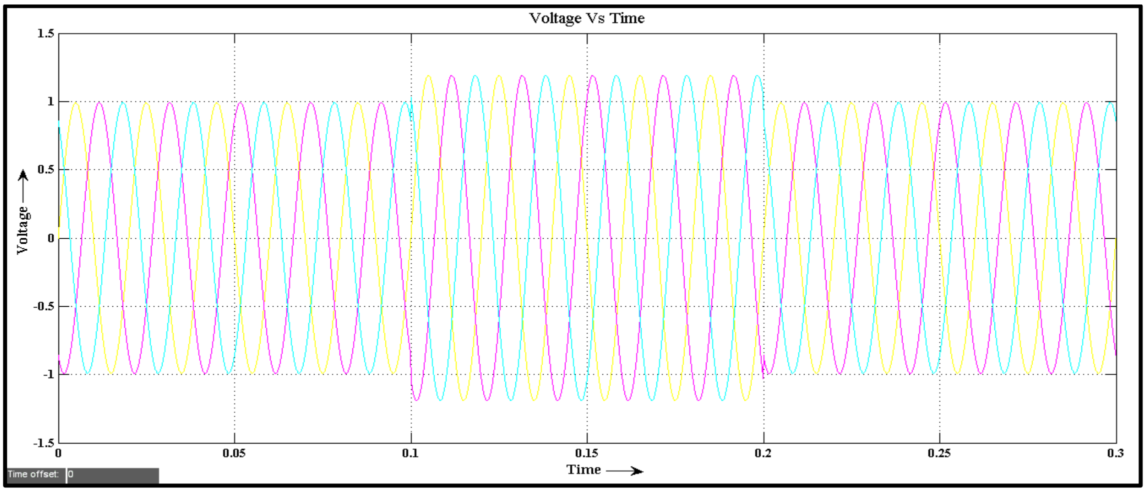

Figure 4.45: Waveform of Voltage Swell for R-L load

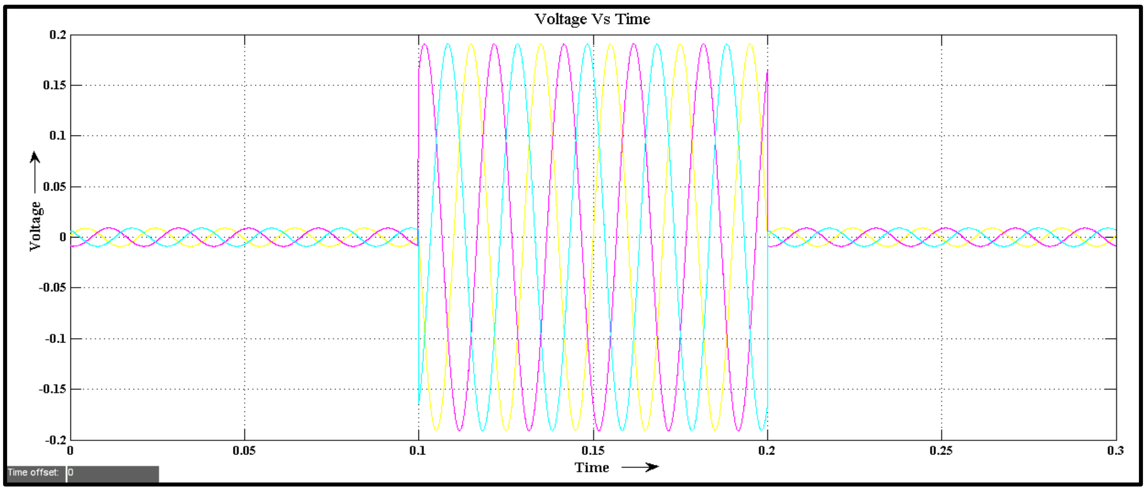

Figure 4.46: Waveform of restored voltage for R-L load

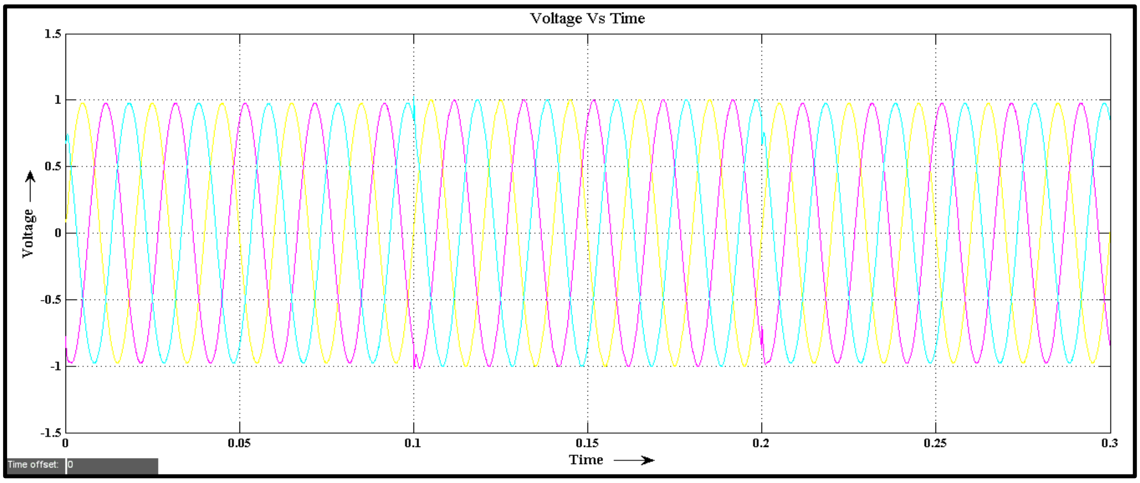

Figure 4.47: Waveform after Mitigation of Voltage Swell for R-L load

Here Figure 4.48 shows the FFT analysis of Voltage Swell waveform for R-L load. At Voltage Swell Total Harmonic Distortion in voltage is about 0.01% which is very less than acceptable limit of THD.

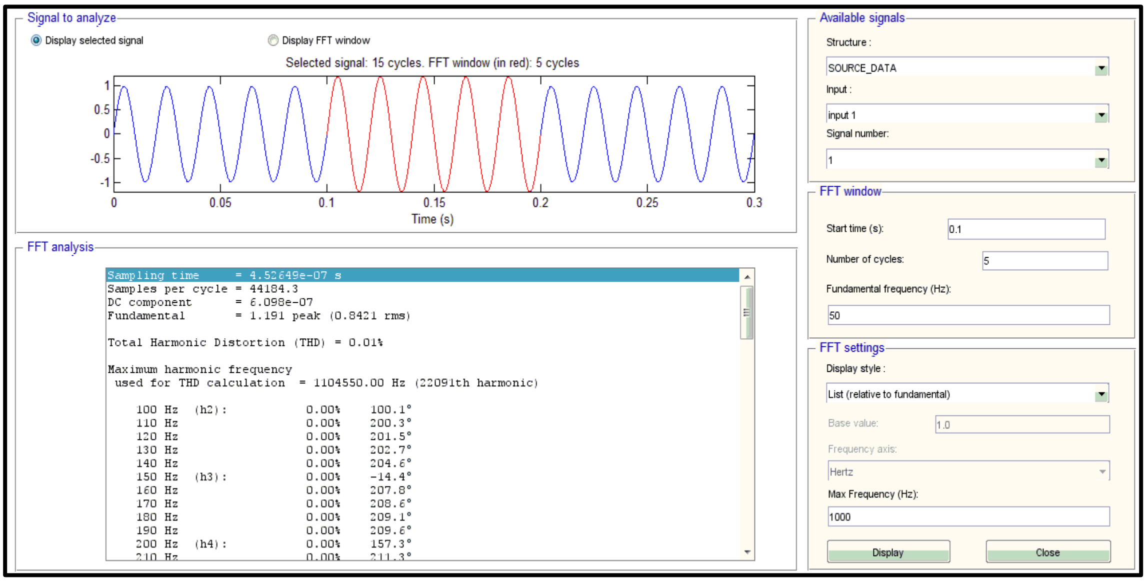

Figure 4.48: FFT analysis of Voltage Swell waveform for R-L load

FFT analysis after mitigation Voltage Swell waveform for R-L load i.e., Figure 4.49 shows that Total Harmonic Distortion in voltage rises to 0.15% because of voltage source converter and injecting transformer which are generally one type of harmonic generating sources, but here also THD is in acceptable limit of it.

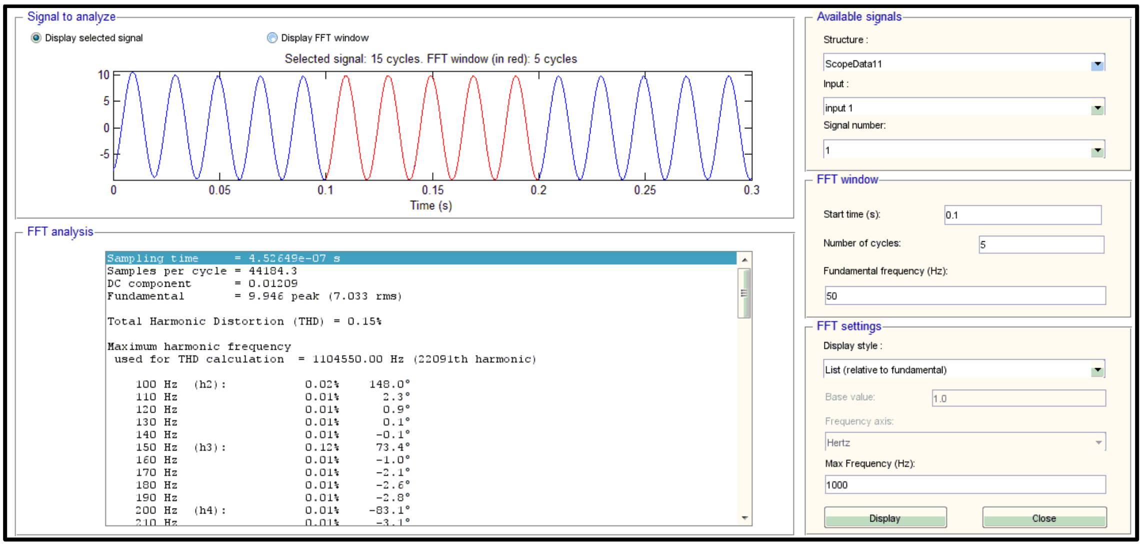

Figure 4.49: FFT analysis after Mitigation of Voltage Swell waveform for R-L load

4.7 Generation and Mitigation of Voltage Swell for Motor load

Here simulation of Voltage Swell Generation for Motor load is shown in below Figure 4.50

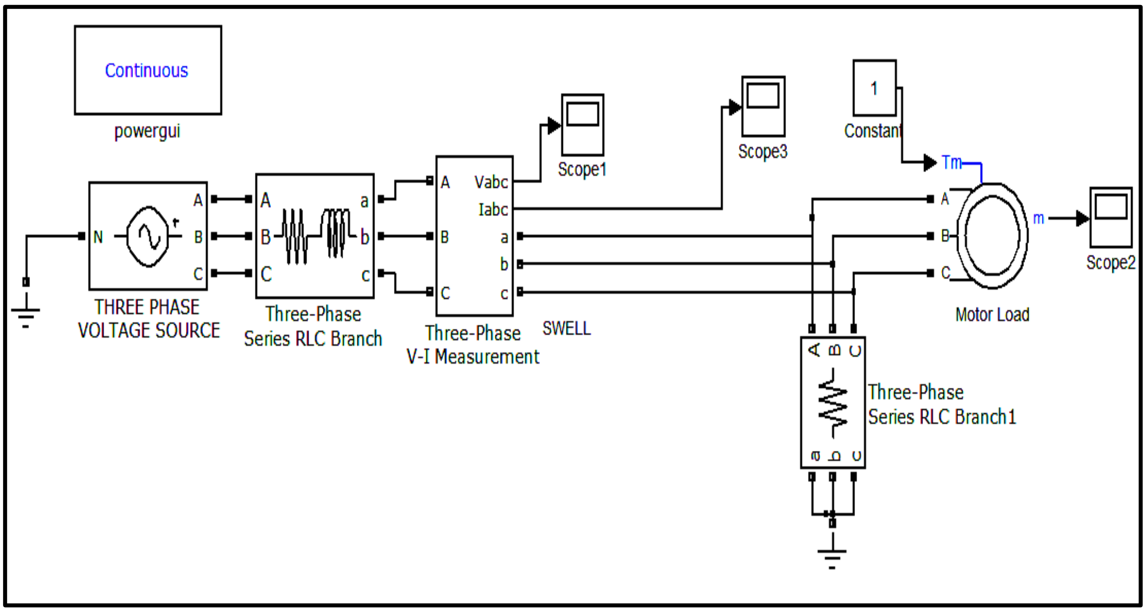

Figure 4.50: Simulation of Voltage Swell Generation for Motor load

Voltage Swell is generated with the help of programmable voltage source. For the motor protection a small value of resistance is connected across motor load. Voltage Swell is occurring in between time period from 0.1 to 0.2sec which is shown in below Figure 4.51.

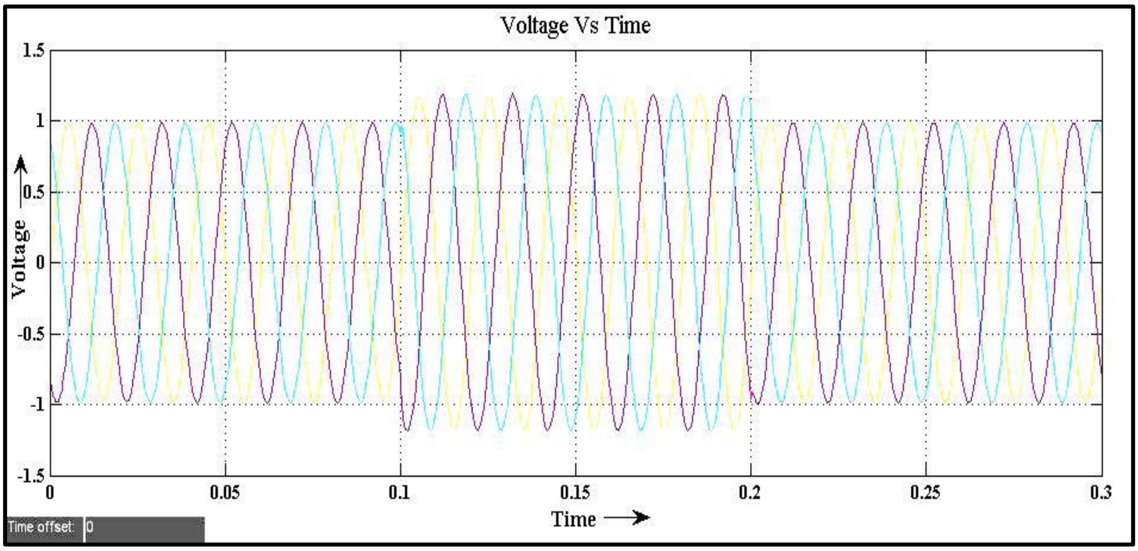

Figure 4.51: Waveform of Voltage Swell Generation for Motor load

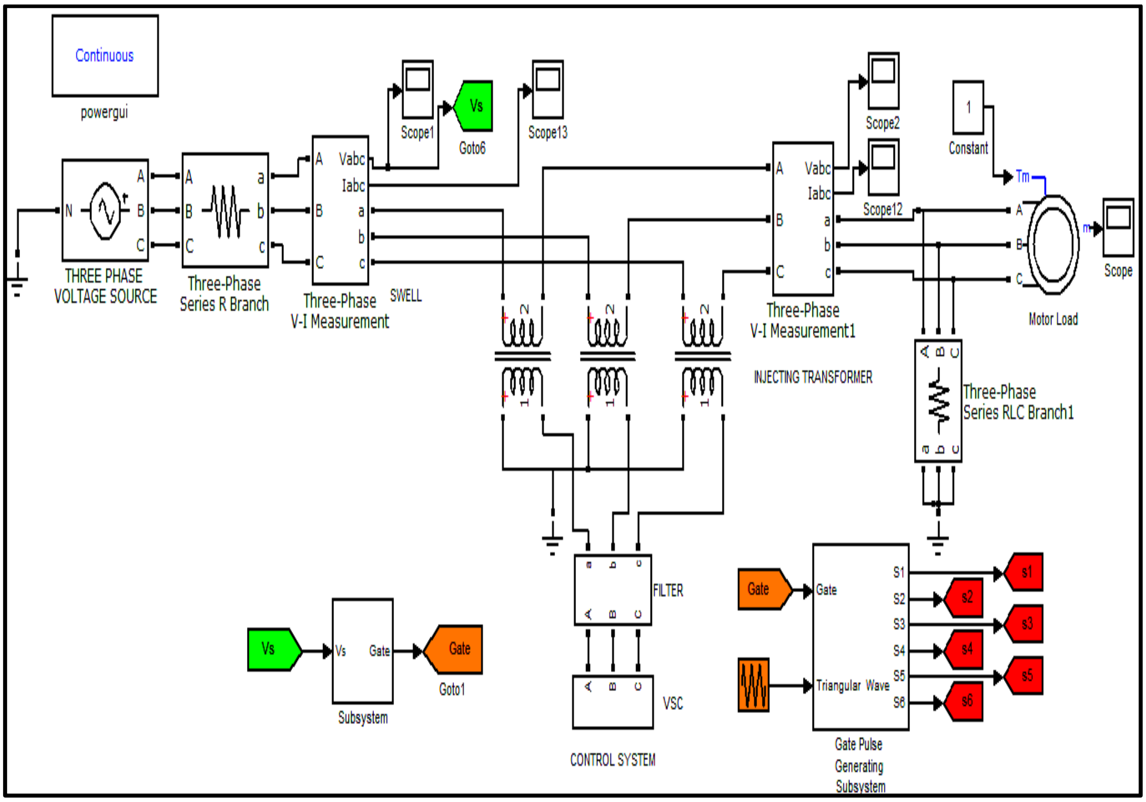

Figure 4.52: Simulation of Voltage Swell Mitigation for Motor load

Here control strategy for Voltage Swell with motor load is same as above used for R-L load. Error is generated with the help of control strategy that will be restored in the system through injecting transformer.

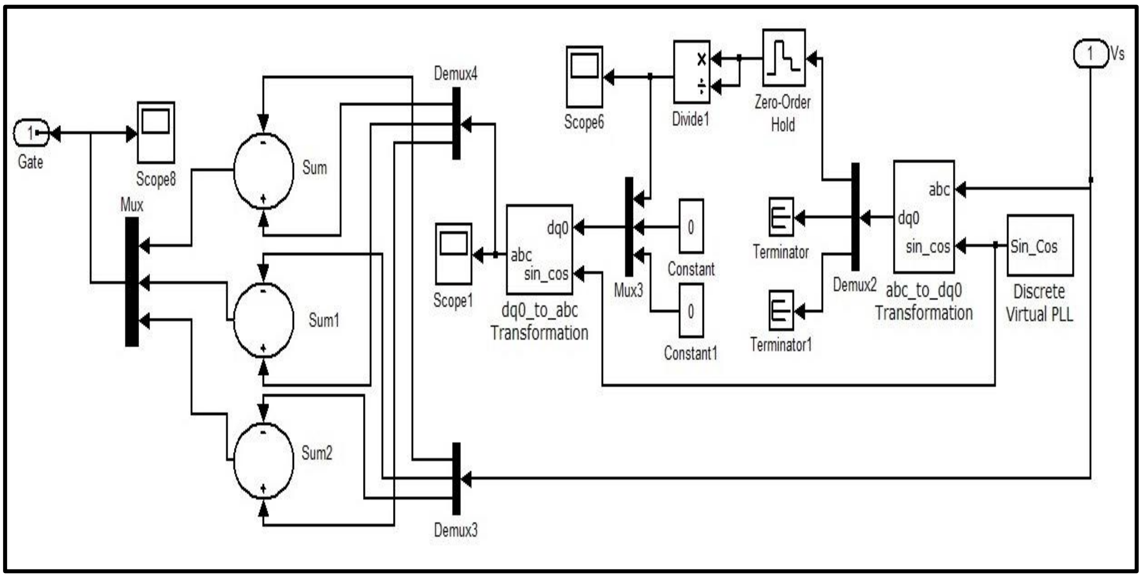

Figure 4.53: Control strategy for Voltage Swell

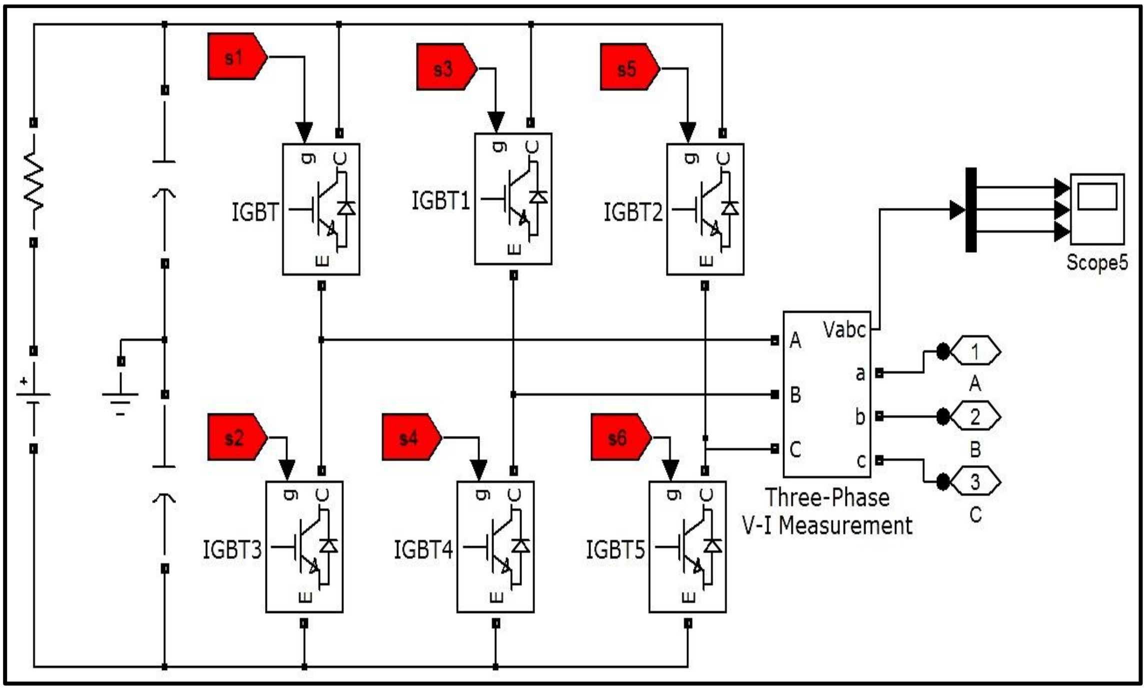

Figure 4.54: Voltage source converter

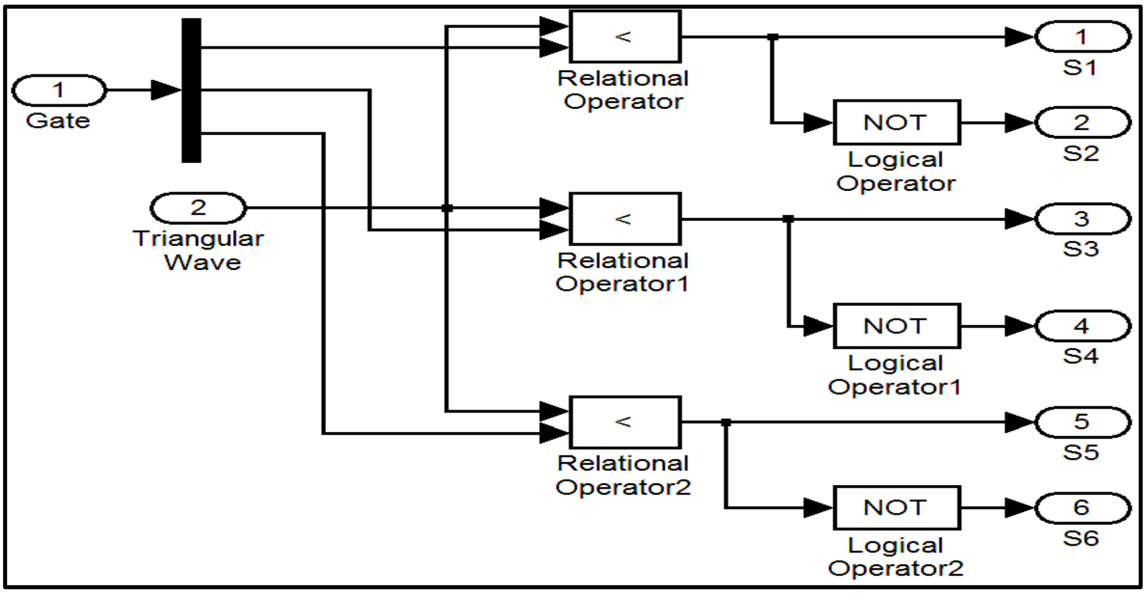

Figure 4.55: Gate pulse Controller

Simulation Rating

1. Supply Voltage = 3-Ø 1p.u. 50Hz
2. Voltage at Swell = 3-Ø 1.2p.u. 50Hz
3. Motor load = 5.4HP, 400V, 1430RPM, 50Hz
4. Restored Voltage = 3-Ø 0.2p.u. 50Hz

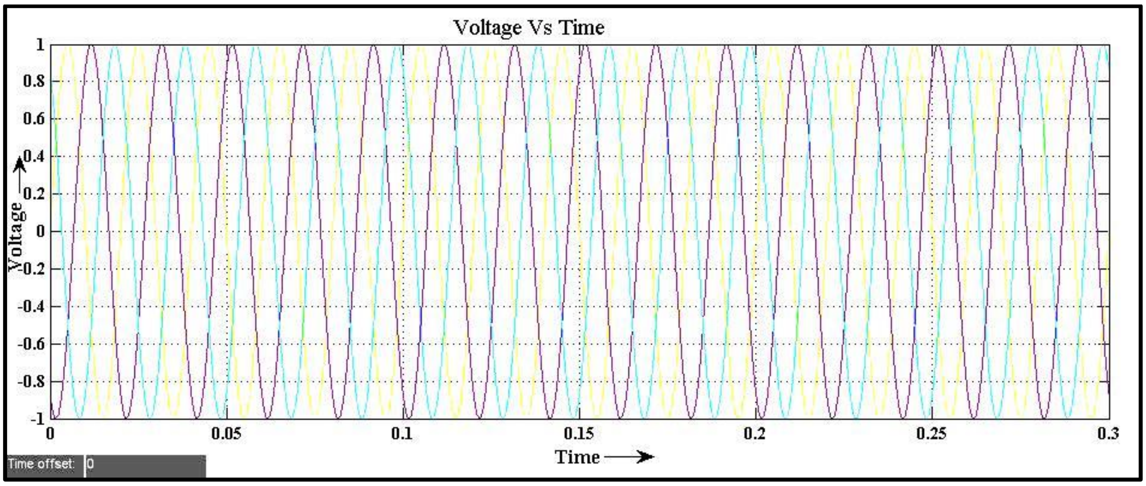

Figure 4.56: Waveform of Supply Voltage

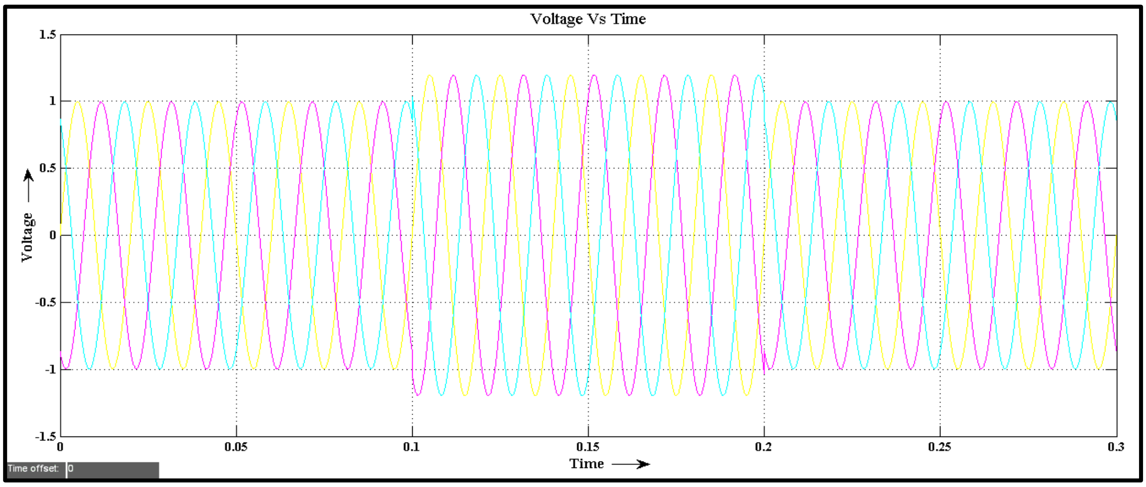

Figure 4.57: Waveform of Voltage Swell for Motor load

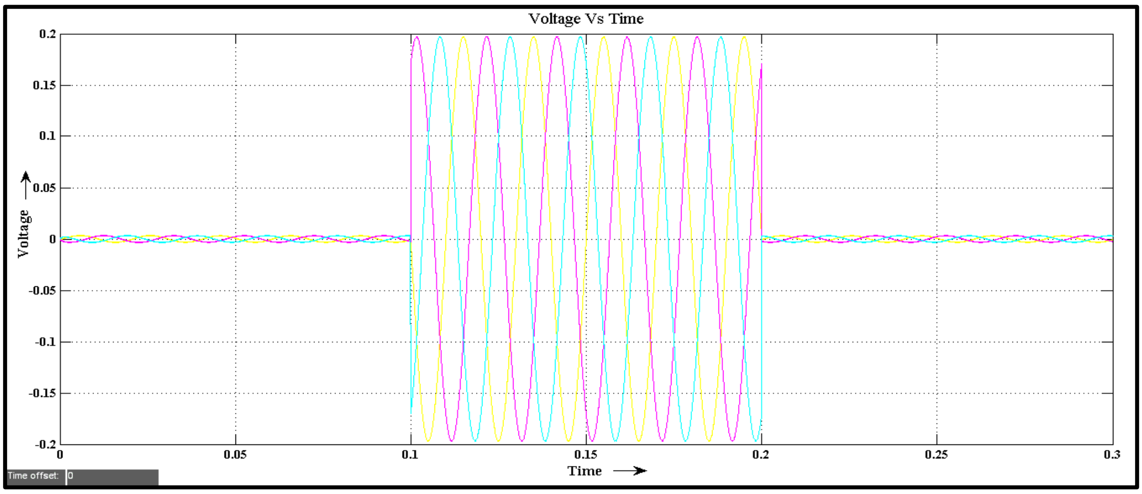

Figure 4.58: Waveform of restored voltage for Motor load

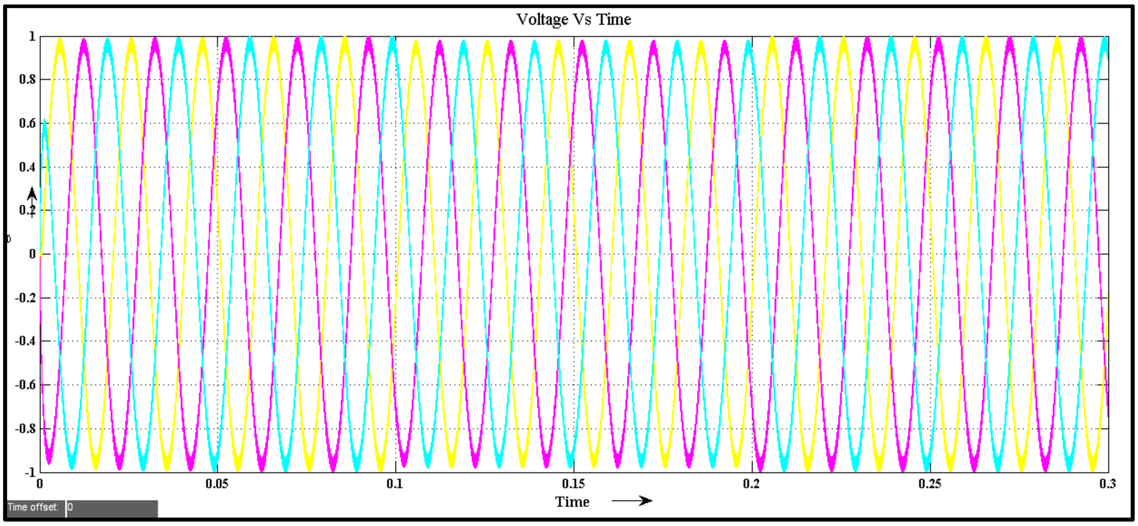

Figure 4.59: Waveform after Mitigation of Voltage Swell for Motor load

Here Figure 4.60 shows the FFT analysis of Voltage Swell waveform for Motor load. At Voltage Swell Total Harmonic Distortion in voltage is about 0.01% which is very less than acceptable limit of THD.

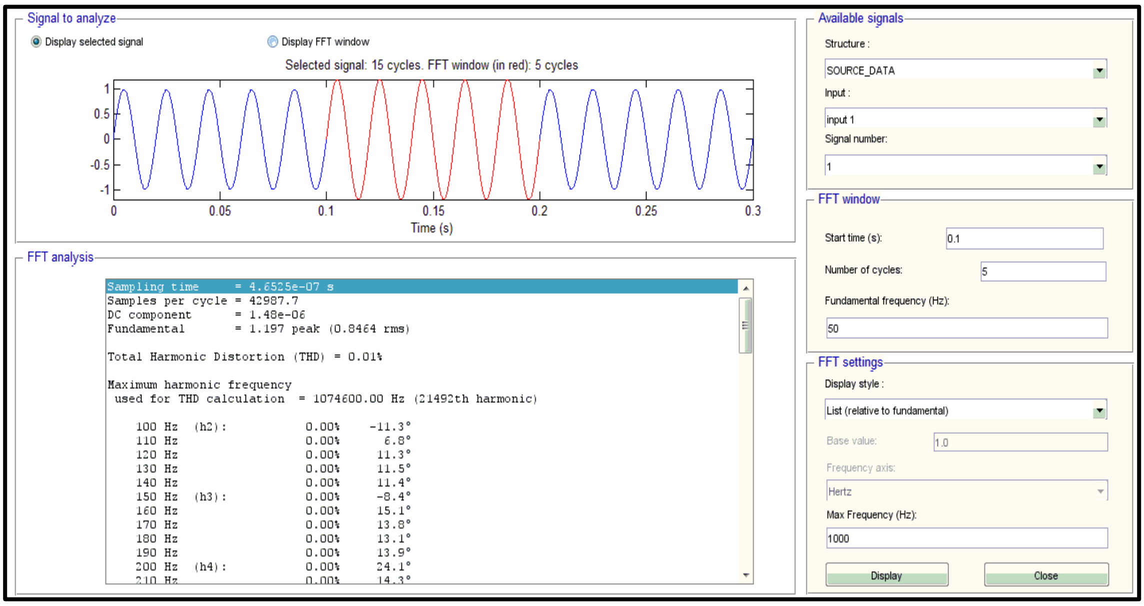

Figure 4.60: FFT analysis of Voltage Swell waveform for Motor load

FFT analysis after mitigation Voltage Swell waveform for Motor load i.e., Figure 4.61 shows that Total Harmonic Distortion in voltage rises to 3.31% because of voltage source converter, injecting transformer and motor load which are generally one type of harmonic generating sources, but here also THD is in acceptable limit of it.

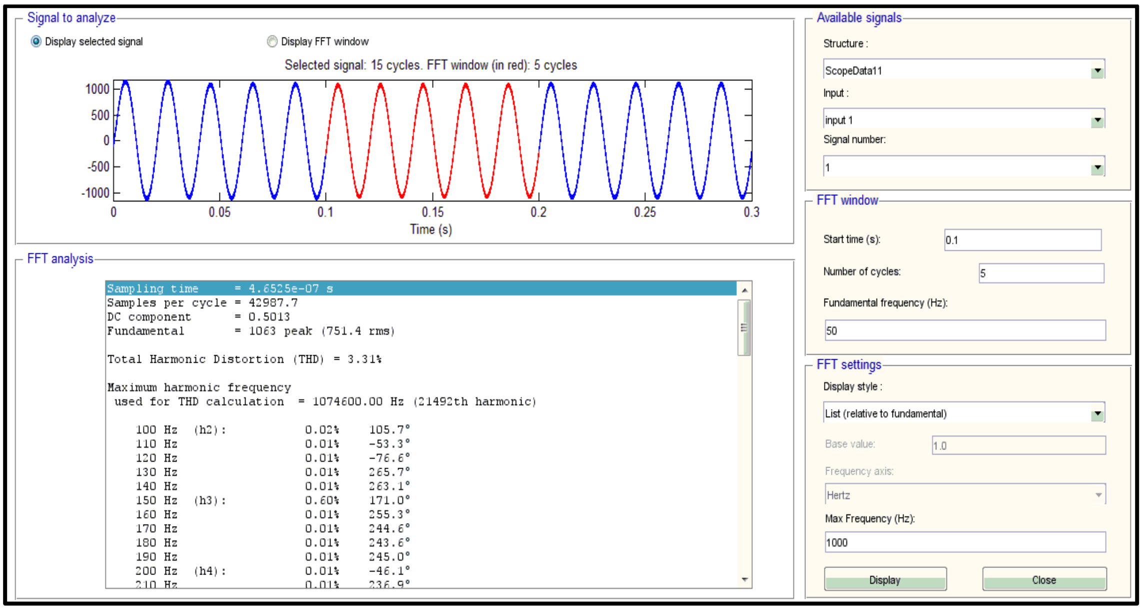

Figure 4.61: FFT analysis after Mitigation of Voltage Swell waveform for Motor load

4.8 Mitigation of Voltage Sag and Swell for R-L load

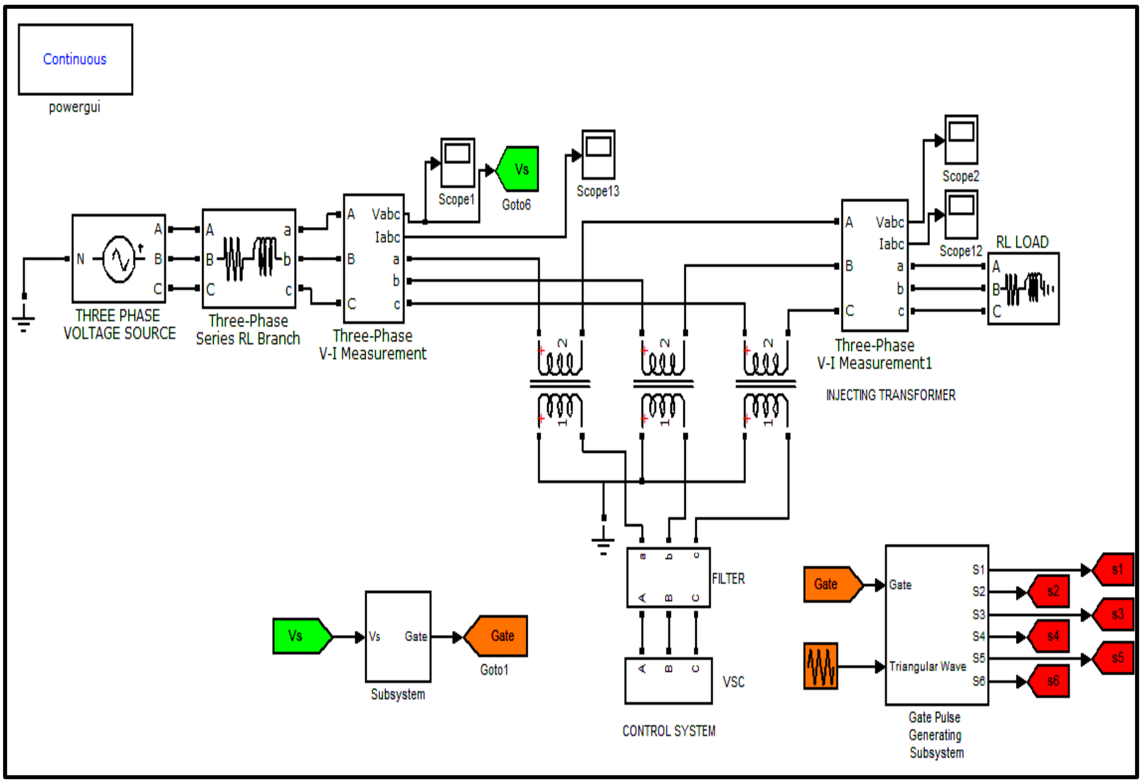

Figure 4.62: Simulation of Voltage Sag and Swell Mitigation for R-L load

DVR is capable to mitigate Voltage Sag and Swell simultaneously in the same system. Simulation for both Voltage Sag and Swell mitigation for R-L load is shown above Figure 4.62. Here control strategy is same as used in above simulation of Voltage Sag and Swell mitigation for R-L load. With the help of control strategy error signal is generated for both Voltage Sag and Swell which is required to be injected and restored to the system simultaneously.

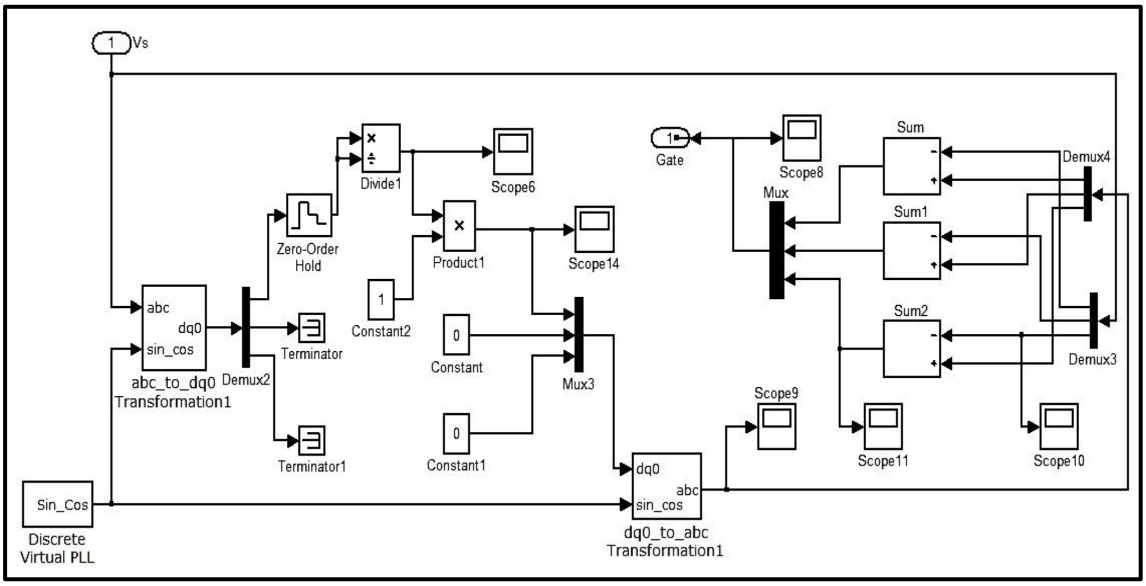

Figure 4.63: Control strategy for Voltage Sag and Swell

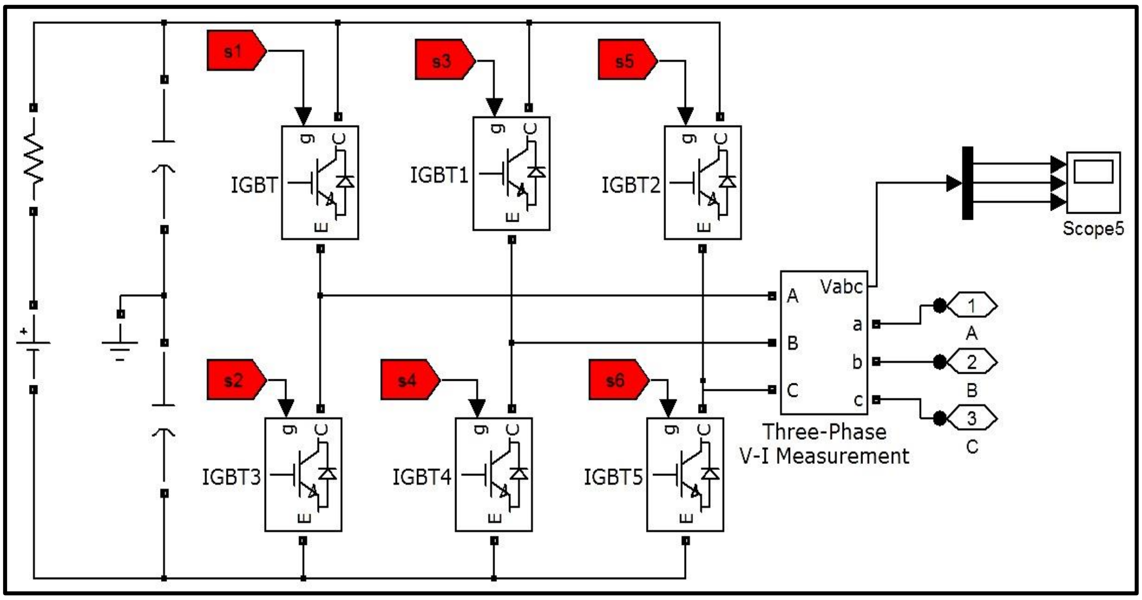

Figure 4.64: Voltage source converter

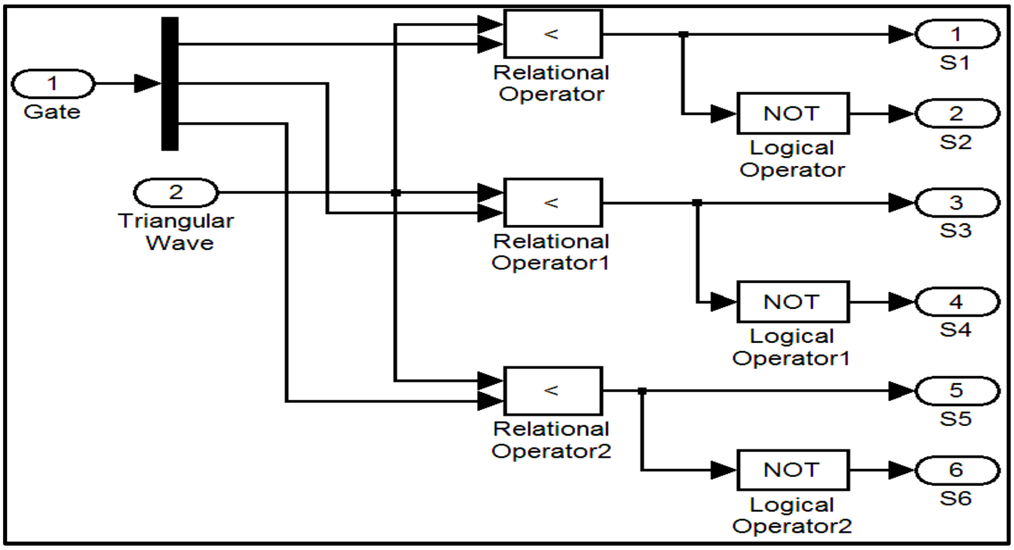

Figure 4.65: Gate pulse Controller

Simulation Rating

1. Supply Voltage = 3-Ø 1p.u. 50Hz
2. Voltage at Sag = 3-Ø 0.6p.u. 50Hz
3. Voltage at Swell = 3-Ø 1.2p.u. 50Hz
4. R-L load
   V. P_L = 1KW
   VI. Q_L = 5000VAR
5. Injected Voltage = 3-Ø 0.4p.u. 50Hz
6. Restored Voltage = 3-Ø 0.2p.u. 50Hz

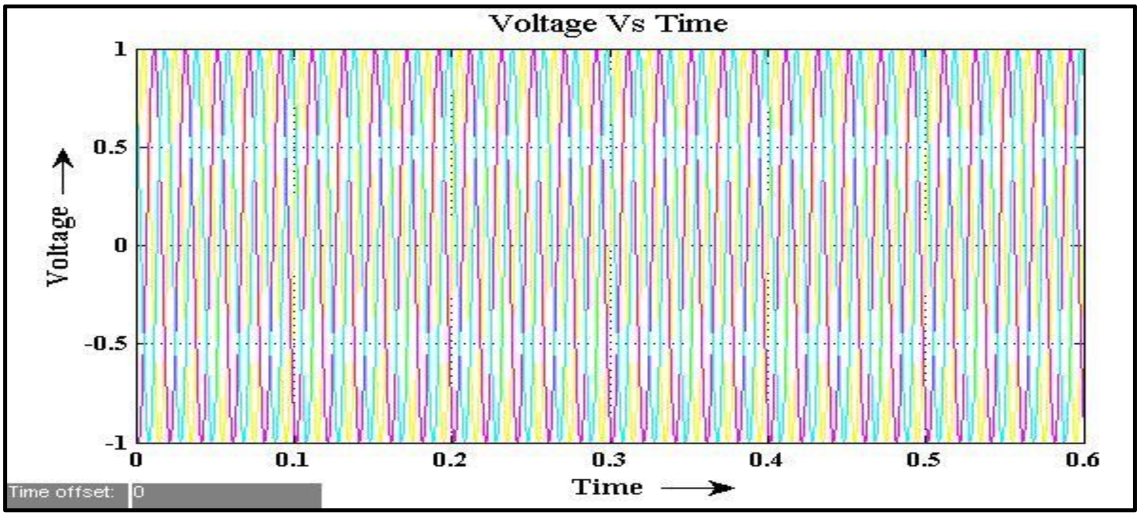

Figure 4.66: Waveform of Supply Voltage

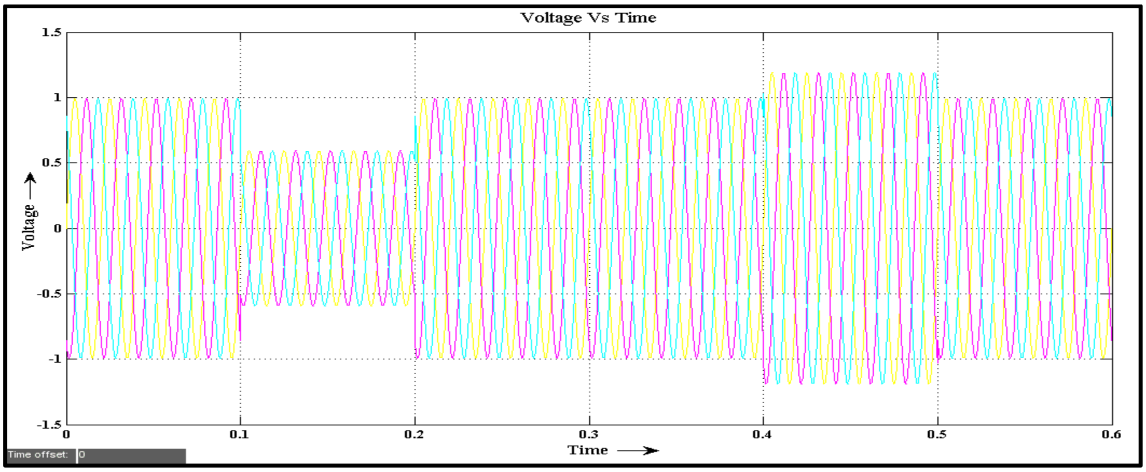

Figure 4.67: Waveform of Voltage Sag and Swell for R-L load

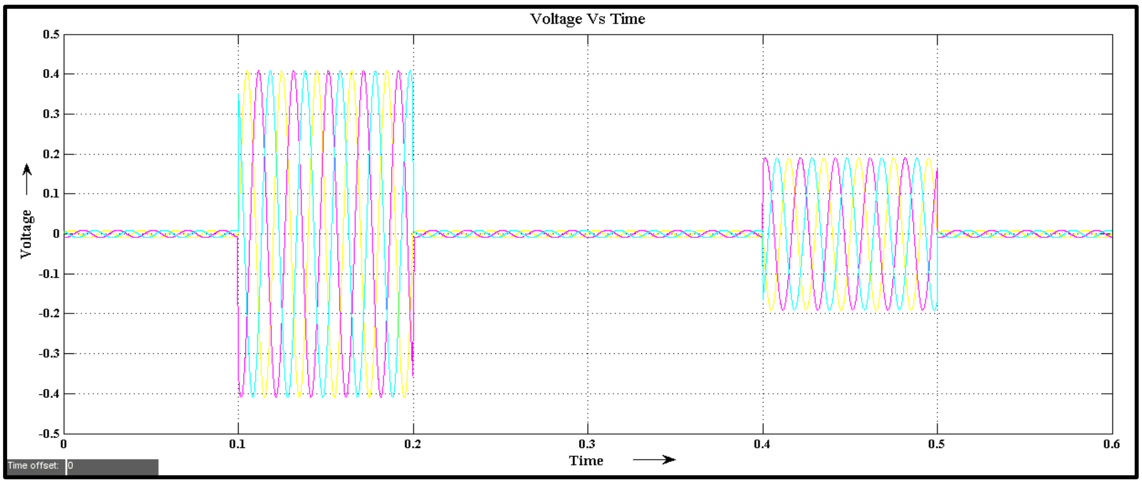

Figure 4.68: Waveform of injected and restored voltage for R-L load

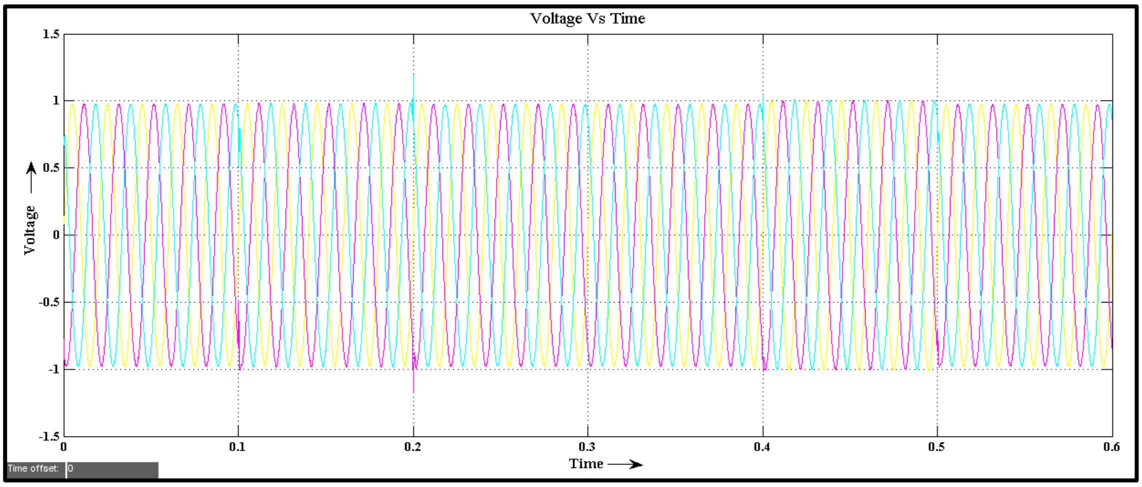

Figure 4.69: Waveform after Mitigation of Voltage Sag and Swell for R-L load

Here Figure 4.70 shows the FFT analysis of Voltage Sag and Swell waveform for R-L load. At Voltage Sag and Swell Total Harmonic Distortion in voltage is about 0.01% which is very less than acceptable limit of THD.

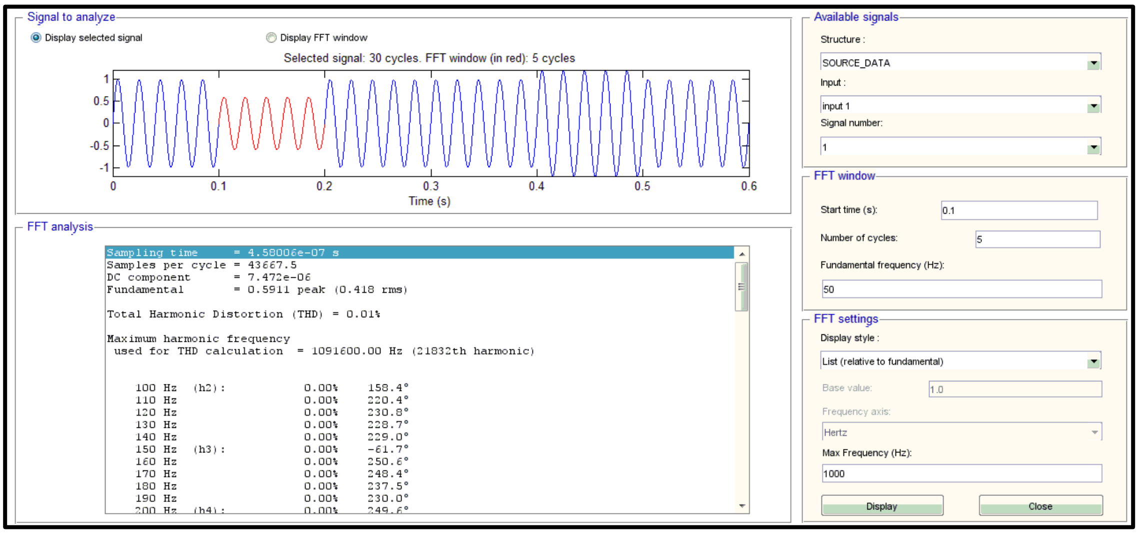

Figure 4.70: FFT analysis of Voltage Sag and Swell waveform for R-L load

FFT analysis after mitigation Voltage Sag and Swell waveform for R-L load i.e., Figure 4.71 shows that Total Harmonic Distortion in voltage rises to 0.19% because of voltage source converter and injecting transformer which are generally one type of harmonic generating sources, but here also THD is in acceptable limit of it.

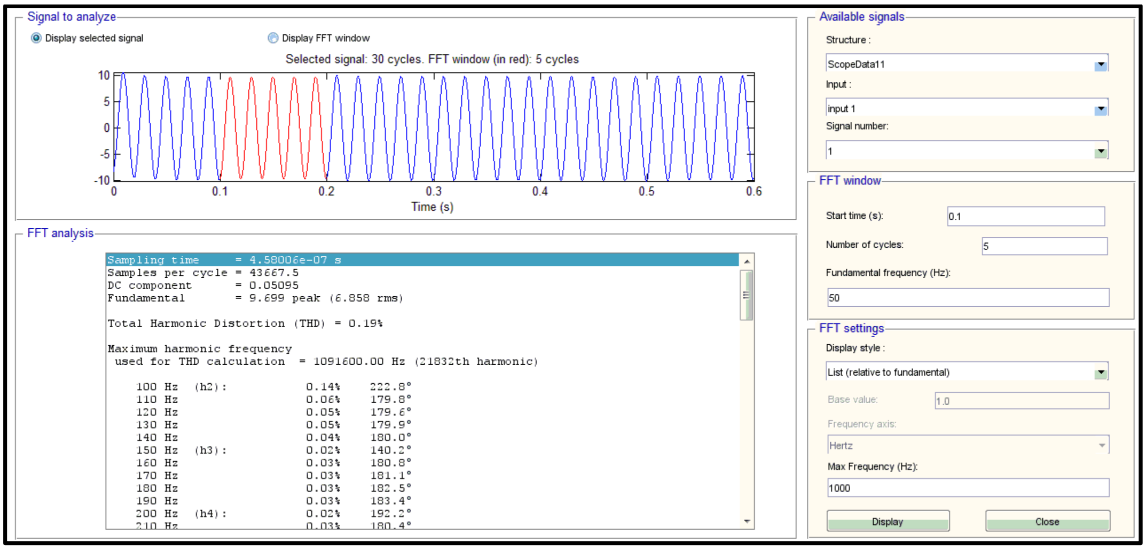

Figure 4.71: FFT analysis after Mitigation of Voltage Sag and Swell waveform for R-L load

4.9 Mitigation of Voltage Sag and Swell for Motor load

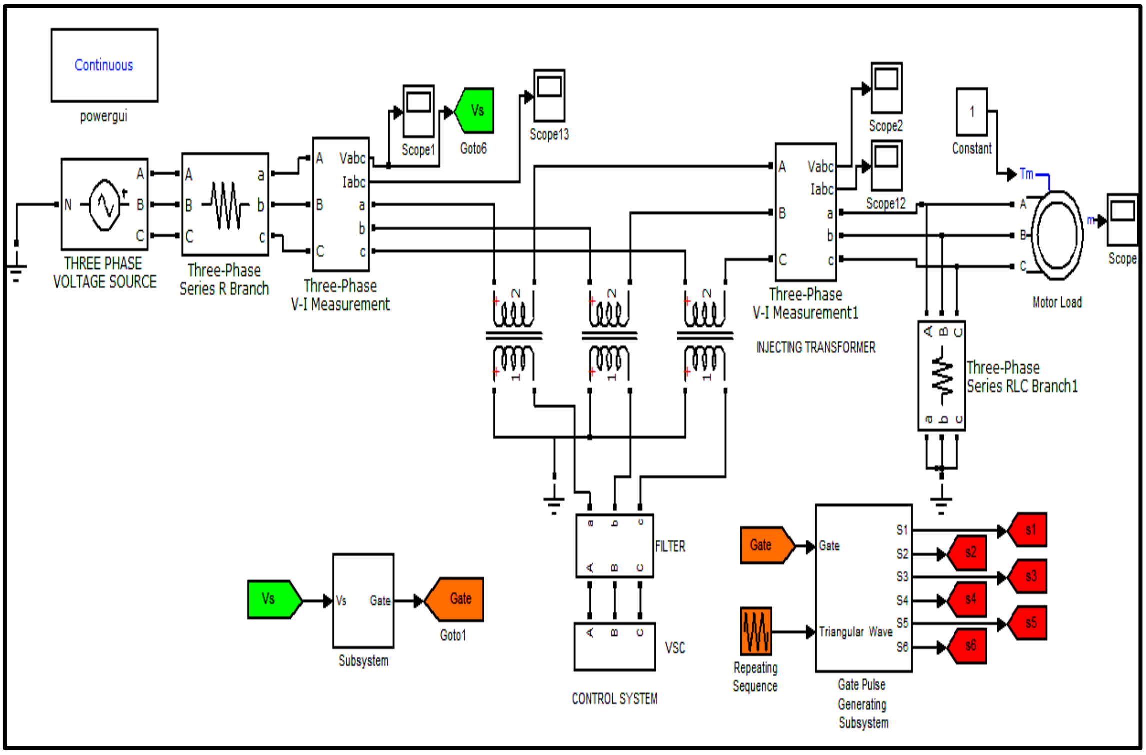

Figure 4.72: Simulation of Voltage Sag and Swell Mitigation for Motor load

DVR is capable to mitigate Voltage Sag and Swell simultaneously in the same system. Simulation for both Voltage Sag and Swell mitigation for motor load is shown above Figure 4.72.

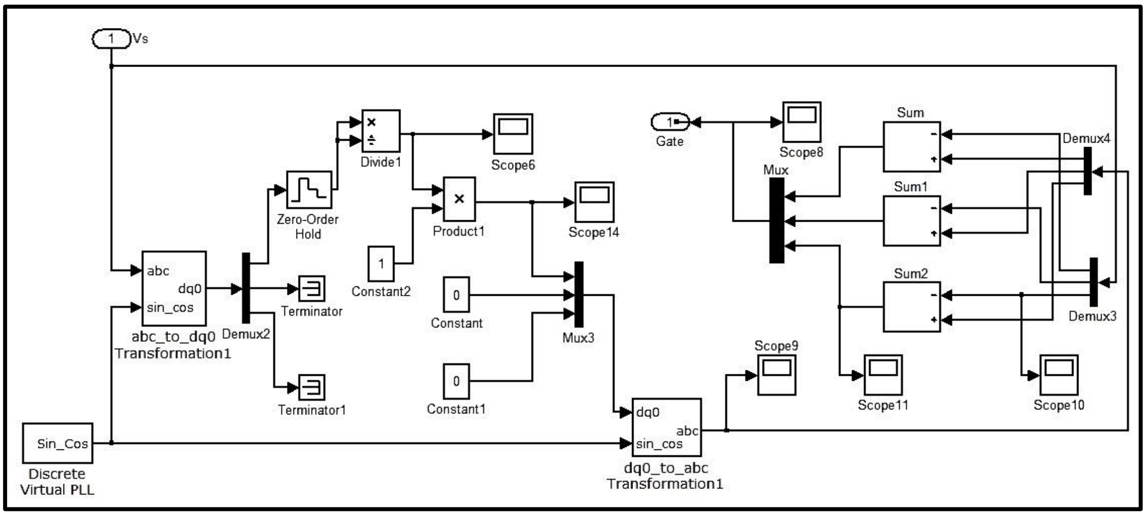

Figure 4.73: Control strategy for Voltage Sag and Swell

Here control strategy is same as used in above simulation of Voltage Sag and Swell mitigation for motor load. With the help of control strategy error signal is generated for both Voltage Sag and Swell which is required to be injected and restored to the system simultaneously.

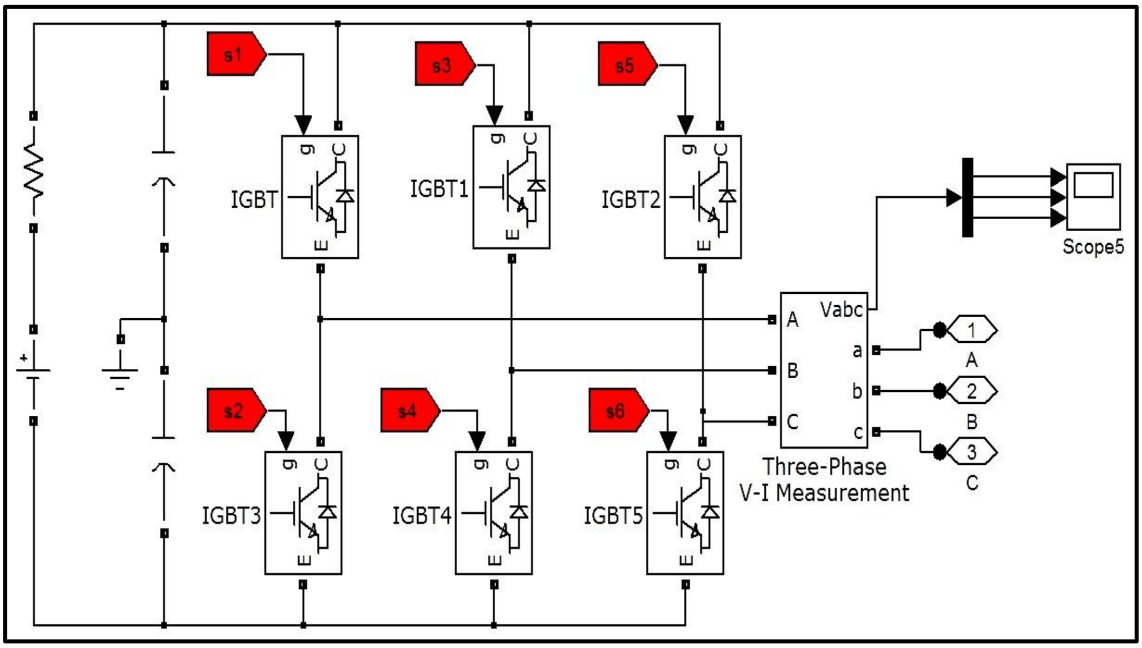

Figure 4.74: Voltage source converter

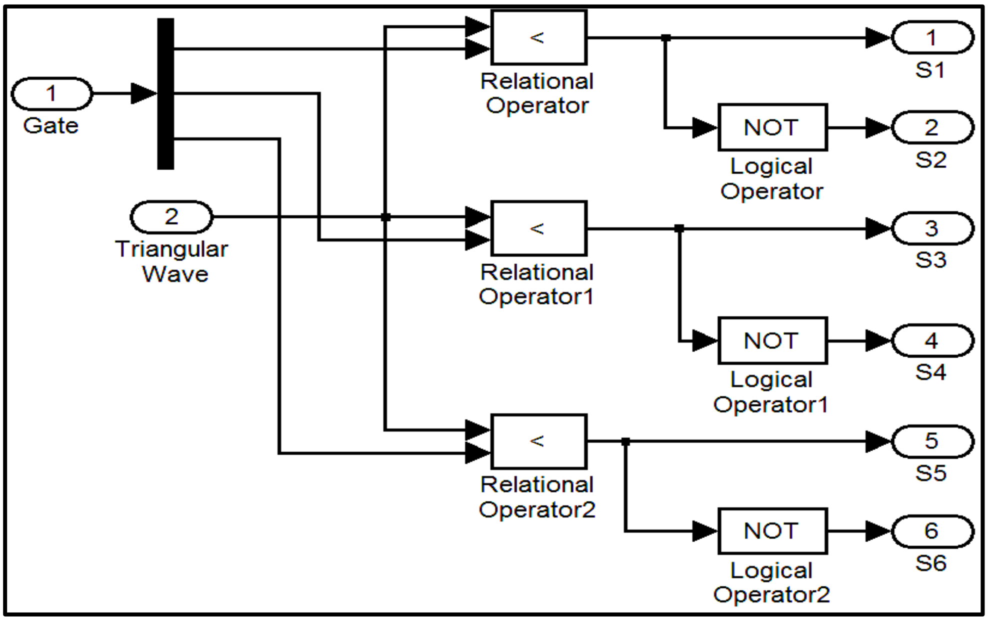

Figure 4.75: Gate pulse Controller

Simulation Rating

1. Supply Voltage = 3-Ø 1p.u. 50Hz
2. Voltage at Sag = 3-Ø 0.6p.u. 50Hz
3. Voltage at Swell = 3-Ø 1.2p.u. 50Hz
4. Motor load = 5.4HP, 400V, 1430RPM, 50Hz
5. Injected Voltage = 3-Ø 0.4p.u. 50Hz
6. Restored Voltage = 3-Ø 0.2p.u. 50Hz

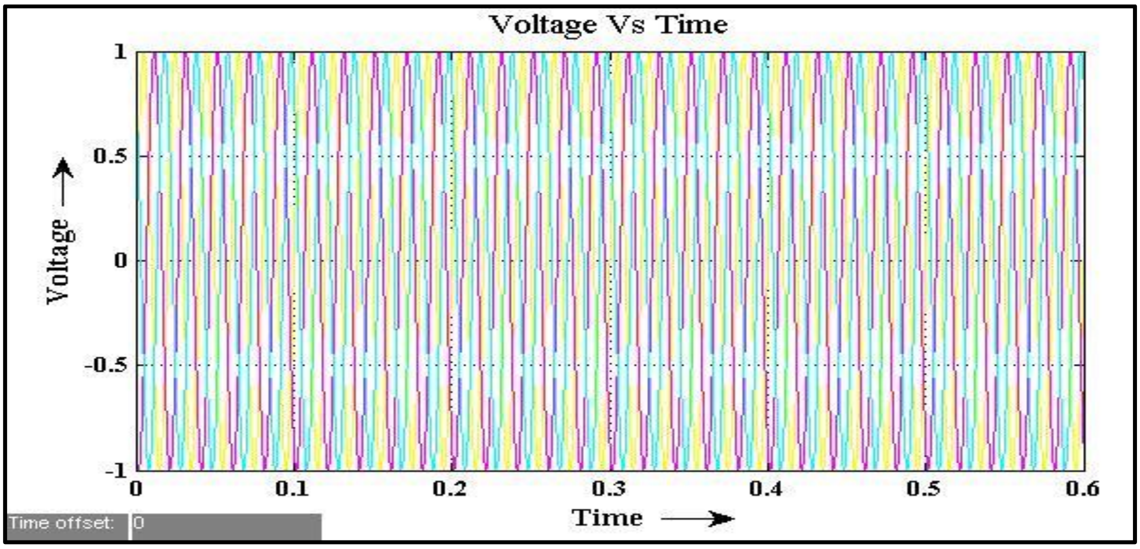

Figure 4.76: Waveform of Supply Voltage

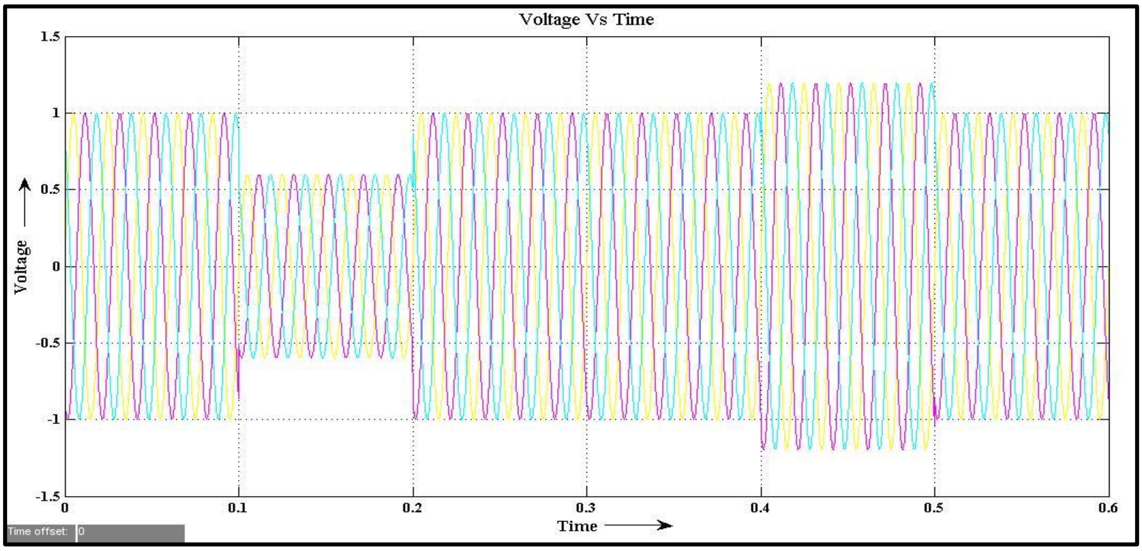

Figure 4.77: Waveform of Voltage Sag and Swell for Motor load

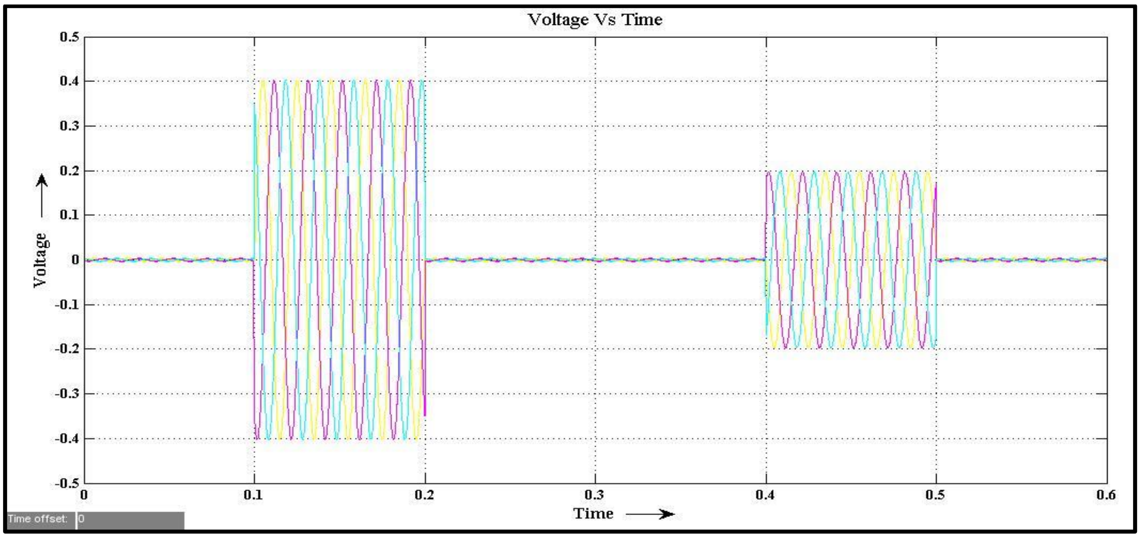

Figure 4.78: Waveform of injected and restored voltage for Motor load

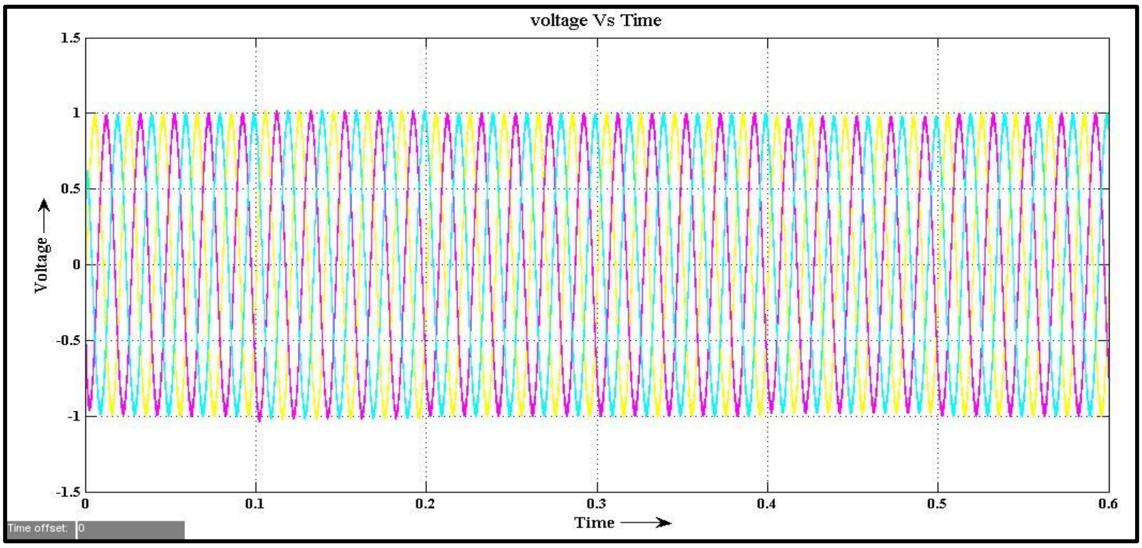

Figure 4.79: Waveform after Mitigation of Voltage Sag and Swell for Motor load

Here Figure 4.80 shows the FFT analysis of Voltage Sag and Swell waveform for Motor load. At Voltage Sag and Swell Total Harmonic Distortion in voltage is about 0.01% which is very less than acceptable limit of THD.

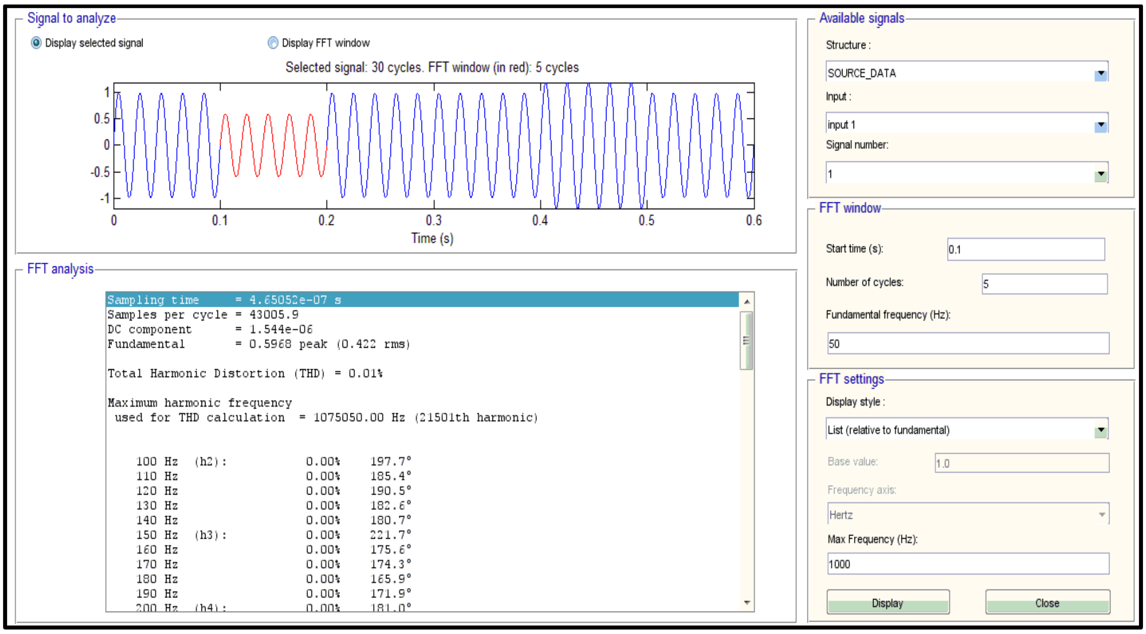

Figure 4.80: FFT analysis of Voltage Sag and Swell waveform for Motor load

FFT analysis after mitigation Voltage Sag and Swell waveform for Motor load i.e., Figure 4.81 shows that Total Harmonic Distortion in voltage rises to 2.48% because of voltage source converter, injecting transformer and motor load which are generally one type of harmonic generating sources, but here also THD is in acceptable limit of it.

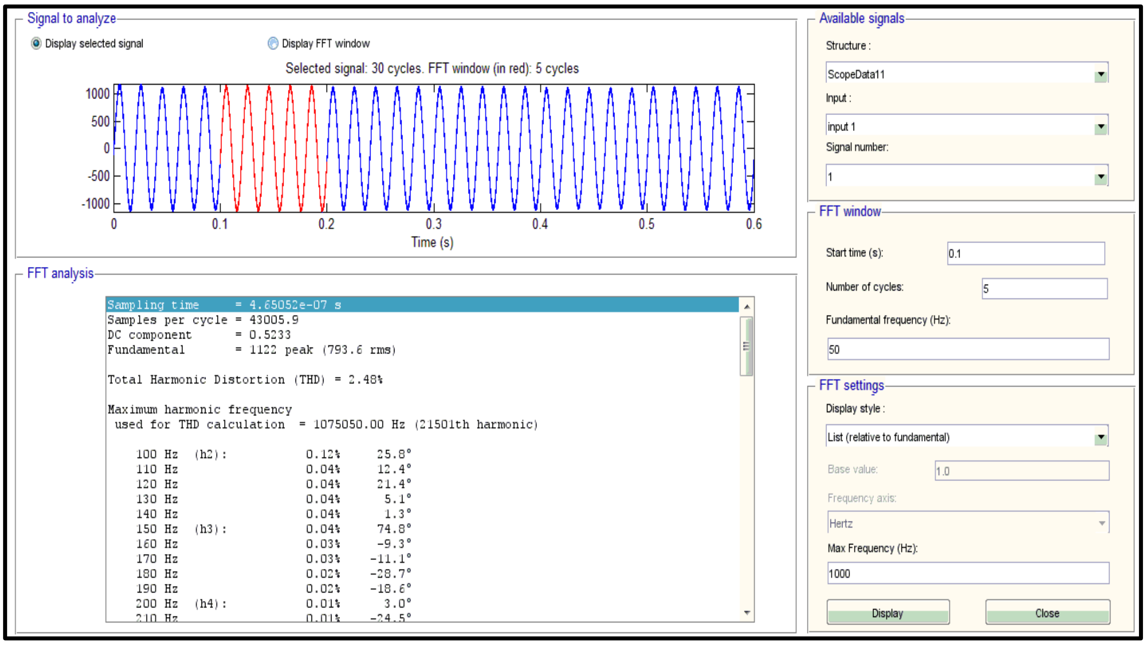

Figure 4.81: FFT analysis after Mitigation of Voltage Sag and Swell waveform for Motor load

Chapter – 5

CONCLUSION AND FUTURE SCOPE OF WORK

5.1 Conclusion

The modeling and simulation of a DVR using MATLAB/SIMULINK has been presented. A control system based on dq0 technique which is detect error between source side of the DVR and its reference for Voltage Sag and Swell correction. The simulation shows that the DVR performance is satisfactory in mitigating Voltage Sag and Swell for R-L load as well as motor load.

From simulation results also show that the DVR compensates the Voltage Sag and Swell quickly and provides excellent voltage regulation. The DVR handles balanced situation without any difficulties and injects as well as absorbs the appropriate voltage component to correct quickly any deviation in the supply voltage to keep the load voltage balanced and constant at the nominal value.

5.2 Future Scope of Work

It can be seen from the simulation results that Voltage Sag and Swell is mitigated by the DVR. But at the same time reactive power compensation was not achieved. However this was within the acceptable limit in this study, when the DVR rating is increased then the drop increases and thus affects the load voltage. The reason for this is there is no continuous monitoring and feedback is carried out at the load voltage. This problem can be eliminated by introducing another separate feedback control loop for checking the load voltage magnitude the load magnitude compensation to improve reactive power compensation.

The prototype model of DVR can be implemented using electronics components and power electronic switches can be used to generate injected voltage and restored voltage to mitigate Voltage Sag and Swell. Then simulation results can be compared with that of prototype model and the effectiveness of the simulated model can be ensured.

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[1] C. SANKARAN, "Power Quality" handbook, CRC Press, 2002.

[2] Dr. Vic Smith, "Voltage Sag Mitigation," Endeavour Energy Power Quality & Reliability Center, University of Wollongong, Australia, August, 2012.

[3] F. Ghezal; S. Hadjeri; M. Benghanem and S. Zidi, "Dynamic Voltage Restorer behaviour" from Intelligent Control and Electrical Power Systems Laboratory ICEPS Electrical Engineering Department Djillali Liabes university, Sidi Bel Abbes, Algeria, March, 2014.

[4] H.P. Tiwari and Sunil Kumar Gupta, "Dynamic Voltage Restorer against Voltage Sag," International Journal of Innovation, Management and Technology, Vol. 1, No. 3, ISSN: 2010-0248, August 2010.

[5] John Godsk Nielsen, "Design and Control of a Dynamic voltage Restorer", Aalborg University, Denmark Institute of Energy Technology, March, 2002.

[6] K. R. Padiyar, "FACTS Controllers in Power Transmission and Distribution," New AGE International Publishers hand book, 2007.

[7] Rosli Omar, N.A. Rahim and Marizan Sulaiman, "Dynamic Voltage Restorer for Application of Power Quality Improvement in Electrical Distribution System: An Overview", Australian Journal of Basic and Applied Sciences, 5(12): 379-396, ISSN 1991-8178, 2011.

[8] Ravilla Madhusudan and G.Ramamohan Rao, "Modeling and Simulation of a DVR for Power Quality Problems Voltage Sags and Swells", IEEE student member, International Conference on Advances in Engineering, Science and Management (ICAESM -2012) March 30, 31, 2012.

[9] Sanjay Haribhai Chaudhary and Mr. Gaurav gangil, "Mitigation of voltage Sag/Swell using DVR", IOSR Journal of Electrical and Electronics Engineering (IOSR-JEEE) e-ISSN: 2278-1676, p-ISSN: 2320-3331, Volume 8, Issue 4, PP 21-38, (Nov. – Dec.), 2004.

APPENDIX

Periodic Progess Report : **First PPR**

Project : "Mitigation Of Voltage Sag And Swell Using Dynamic Voltage Restorer"

Status : Reviewed (Freeze)

What Progress you have made in the Project ?

This project consults with MATLAB Simulation of Mitigation Voltage Sag and Swell using DVR. As we have completed Generation and Mitigation of Voltage Sag with R-L load in last phase of dissertation. Currently, Mitigation of Voltage Swell with R-L as well as motor Load. Just in a last week we have completed Mitigation of Voltage Sag with motor load. In next coming days we will perform FFT analysis.

What challenge you have faced ?

Following challenges we have faced. I. Characteristics of motor load and R-L load are different II. Changes in rating of filter unit as well as series branch for motor loading condition III. Changes in capacitor rating connected across VSC for motor loading condition IV. Shunt resistance have to connect across motor load Etc.

What support you need ?

As concern as motor loading condition for Voltage Sag mitigation we need support of our guide regarding the change in rating of filter unit as well as series branch.

Which literature you have referred ?

1. John Godsk Nielsen, “Design and Control of a Dynamic voltage Restorer,” Aalborg University, Denmark Institute of Energy Technology, March, 2002. 2. C. SANKARAN, “Power Quality” handbook, CRC Press, 2002. 3. K. R. Padiyar, “FACTS Controllers in Power Transmission and Distribution,” New AGE International Publishers hand book, 2007. 4. Dr. Vic Smith, “Voltage Sag Mitigation,” Endeavour Energy Power Quality & Reliability Center, University of Wollongong, Australia, August, 2012. 5. Sanjay Haribhai Chaudhary and Mr. Gaurav gangil, “Mitigation of voltage Sag/Swell using DVR,” IOSR Journal of Electrical and Electronics Engineering (IOSR-JEEE) e-ISSN: 2278-1676, p-ISSN: 2320-3331, Volume 8, Issue 4, PP 21-38, (Nov. – Dec.), 2004. 6. Ravilla Madhusudan and G.Ramamohan Rao, “Modeling and Simulation of a DVR for Power Quality Problems Voltage Sags and Swells,” IEEE student member, International Conference on Advances in Engineering, Science and Management (ICAESM -2012) March 30, 31, 2012. 7. F. Ghezal; S. Hadjeri; M. Benghanem and S. Zidi, “Dynamic Voltage Restorer behaviour” from Intelligent Control and Electrical Power Systems Laboratory ICEPS Electrical Engineering Department Djillali Liabes university, Sidi Bel Abbes, Algeria, March, 2014. 8. Rosli Omar, N.A. Rahim and Marizan Sulaiman, “Dynamic Voltage Restorer for Application of Power Quality Improvement in Electrical Distribution System: An Overview,” Australian Journal of Basic and Applied Sciences, 5(12): 379-396, ISSN 1991-8178, 2011. 9. H.P. Tiwari and Sunil Kumar Gupta, “Dynamic Voltage Restorer against Voltage Sag,” International Journal of Innovation, Management and Technology, Vol. 1, No. 3, ISSN: 2010-0248, August 2010.

Comment by Internal Guide :

This project consult with power quality problem like voltage sag and voltage swell. Voltage sags are brief reductions in voltage, typically lasting from a cycle to a second or so. Voltage swells surges are brief increases in voltage over the same time range.

Periodic Progess Report : **Second PPR**

Project : "Mitigation Of Voltage Sag And Swell Using Dynamic Voltage Restorer"

Status : Reviewed (Freeze)

What Progress you have made in the Project ?

I have completed the FFT analysis for mitigation of Voltage Sag with R-L load as well as motor load.

What challenge you have faced ?

FFT analysis shows the THD in percentage without DVR system and with DVR system. It shows lower value of percentage. So, list wise values are shown instead of Bar chart.

What support you need ?

No support needed.

Which literature you have referred ?

I. John Godsk Nielsen, "Design and Control of a Dynamic voltage Restorer," Aalborg University, Denmark Institute of Energy Technology, March, 2002. II. C. SANKARAN, "Power Quality" handbook, CRC Press, 2002. III. K. R. Padiyar, "FACTS Controllers in Power Transmission and Distribution," New AGE International Publishers hand book, 2007. IV. Dr. Vic Smith, "Voltage Sag Mitigation," Endeavour Energy Power Quality & Reliability Center, University of Wollongong, Australia, August, 2012. V. Sanjay Haribhai Chaudhary and Mr. Gaurav gangil, "Mitigation of voltage Sag/Swell using DVR," IOSR Journal of Electrical and Electronics Engineering (IOSR-JEEE) e-ISSN: 2278-1676, p-ISSN: 2320-3331, Volume 8, Issue 4, PP 21-38, (Nov. – Dec.), 2004. VI. Ravilla Madhusudan and G.Ramamohan Rao, "Modeling and Simulation of a DVR for Power Quality Problems Voltage Sags and Swells," IEEE student member, International Conference on Advances in Engineering, Science and Management (ICAESM -2012) March 30, 31, 2012. VII. F. Ghezal; S. Hadjeri; M. Benghanem and S. Zidi, "Dynamic Voltage Restorer behaviour" from Intelligent Control and Electrical Power Systems Laboratory ICEPS Electrical Engineering Department Djillali Liabes university, Sidi Bel Abbes, Algeria, March, 2014. VIII. Rosli Omar, N.A. Rahim and Marizan Sulaiman, "Dynamic Voltage Restorer for Application of Power Quality Improvement in Electrical Distribution System: An Overview," Australian Journal of Basic and Applied Sciences, 5(12): 379-396, ISSN 1991-8178, 2011. IX. H.P. Tiwari and Sunil Kumar Gupta, "Dynamic Voltage Restorer against Voltage Sag," International Journal of Innovation, Management and Technology, Vol. 1, No. 3, ISSN: 2010-0248, August 2010.

Comment by Internal Guide :

Voltage Sags are caused by abrupt increases in loads such as short circuits or faults, motor starting, or they are caused by abrupt increases in source impedance. We have successfully achieved the results for voltage sag with RL load and motor load.

Periodic Progess Report : **Third PPR**

Project : "Mitigation Of Voltage Sag And Swell Using Dynamic Voltage Restorer"

Status : Reviewed (Freeze)

What Progress you have made in the Project ?

I have completed our new simulation Voltage Swell with R-L load as concern to our project topic.

What challenge you have faced ?

I. For Voltage Swell control strategy shows the restored voltage as error signal which is require to be restored to nominal value in the system. That point I was understood while simulating Dynamic Voltage Restorer for Voltage Swell with R-L Load. II. Changes in R-L-C branch ratings for Voltage Sag with R-L Load. III. Changes in Filter ratings

What support you need ?

No support needed.

Which literature you have referred ?

I. John Godsk Nielsen, “Design and Control of a Dynamic voltage Restorer,” Aalborg University, Denmark Institute of Energy Technology, March, 2002. II. C. SANKARAN, “Power Quality” handbook, CRC Press, 2002. III. K. R. Padiyar, “FACTS Controllers in Power Transmission and Distribution,” New AGE International Publishers hand book, 2007. IV. Dr. Vic Smith, “Voltage Sag Mitigation,” Endeavour Energy Power Quality & Reliability Center, University of Wollongong, Australia, August, 2012. V. Sanjay Haribhai Chaudhary and Mr. Gaurav gangil, “Mitigation of voltage Sag/Swell using DVR,” IOSR Journal of Electrical and Electronics Engineering (IOSR-JEEE) e-ISSN: 2278-1676, p-ISSN: 2320-3331, Volume 8, Issue 4, PP 21-38, (Nov. – Dec.), 2004. VI. Ravilla Madhusudan and G.Ramamohan Rao, “Modeling and Simulation of a DVR for Power Quality Problems Voltage Sags and Swells,” IEEE student member, International Conference on Advances in Engineering, Science and Management (ICAESM -2012) March 30, 31, 2012. VII. F. Ghezal; S. Hadjeri; M. Benghanem and S. Zidi, “Dynamic Voltage Restorer behaviour” from Intelligent Control and Electrical Power Systems Laboratory ICEPS Electrical Engineering Department Djillali Liabes university, Sidi Bel Abbes, Algeria, March, 2014. VIII. Rosli Omar, N.A. Rahim and Marizan Sulaiman, “Dynamic Voltage Restorer for Application of Power Quality Improvement in Electrical Distribution System: An Overview,” Australian Journal of Basic and Applied Sciences, 5(12): 379-396, ISSN 1991-8178, 2011. IX. H.P. Tiwari and Sunil Kumar Gupta, “Dynamic Voltage Restorer against Voltage Sag,” International Journal of Innovation, Management and Technology, Vol. 1, No. 3, ISSN: 2010-0248, August 2010.

Comment by Internal Guide :

We have successfully achieved the results for voltage swell with RL load using dqo transformation.

Periodic Progess Report : Forth PPR

Project : "Mitigation Of Voltage Sag And Swell Using Dynamic Voltage Restorer"

Status : Reviewed (Freeze)

What Progress you have made in the Project ?

I have completed our new simulation Voltage Swell with motor load as concern to our project topic.

What challenge you have faced ?

I. For Voltage Swell control strategy shows the restored voltage as error signal which is require to be restored to nominal value in the system. That point I was understood while simulating Dynamic Voltage Restorer for Voltage Swell with motor Load. II. Changes in R-L-C branch ratings for Voltage Swell with motor Load. III. Changes in Filter ratings

What support you need ?

No support needed.

Which literature you have referred ?

I. John Godsk Nielsen, “Design and Control of a Dynamic voltage Restorer,” Aalborg University, Denmark Institute of Energy Technology, March, 2002. II. C. SANKARAN, “Power Quality” handbook, CRC Press, 2002. III. K. R. Padiyar, “FACTS Controllers in Power Transmission and Distribution,” New AGE International Publishers hand book, 2007. IV. Dr. Vic Smith, “Voltage Sag Mitigation,” Endeavour Energy Power Quality & Reliability Center, University of Wollongong, Australia, August, 2012. V. Sanjay Haribhai Chaudhary and Mr. Gaurav gangil, “Mitigation of voltage Sag/Swell using DVR,” IOSR Journal of Electrical and Electronics Engineering (IOSR-JEEE) e-ISSN: 2278-1676, p-ISSN: 2320-3331, Volume 8, Issue 4, PP 21-38, (Nov. – Dec.), 2004. VI. Ravilla Madhusudan and G.Ramamohan Rao, “Modeling and Simulation of a DVR for Power Quality Problems Voltage Sags and Swells,” IEEE student member, International Conference on Advances in Engineering, Science and Management (ICAESM -2012) March 30, 31, 2012. VII. F. Ghezal; S. Hadjeri; M. Benghanem and S. Zidi, “Dynamic Voltage Restorer behaviour” from Intelligent Control and Electrical Power Systems Laboratory ICEPS Electrical Engineering Department Djillali Liabes university, Sidi Bel Abbes, Algeria, March, 2014. VIII. Rosli Omar, N.A. Rahim and Marizan Sulaiman, “Dynamic Voltage Restorer for Application of Power Quality Improvement in Electrical Distribution System: An Overview,” Australian Journal of Basic and Applied Sciences, 5(12): 379-396, ISSN 1991-8178, 2011. IX. H.P. Tiwari and Sunil Kumar Gupta, “Dynamic Voltage Restorer against Voltage Sag,” International Journal of Innovation, Management and Technology, Vol. 1, No. 3, ISSN: 2010-0248, August 2010.

Comment by Internal Guide :

We have successfully achieved the results for voltage swell with motor load using dqo transformation.

Periodic Progess Report : **Additional PPR_1**

Project : "Mitigation Of Voltage Sag And Swell Using Dynamic Voltage Restorer"

Status : Reviewed (Freeze)

What Progress you have made in the Project ?

I have completed the FFT analysis for mitigation of Voltage Swell with R-L load as well as motor load.

What challenge you have faced ?

FFT analysis shows the THD in percentage without DVR system and with DVR system. It shows lower value of percentage. So, list wise values are shown instead of Bar chart.

What support you need ?

No support needed.

Which literature you have referred ?

I. John Godsk Nielsen, “Design and Control of a Dynamic voltage Restorer,” Aalborg University, Denmark Institute of Energy Technology, March, 2002. II. C. SANKARAN, “Power Quality” handbook, CRC Press, 2002. III. K. R. Padiyar, “FACTS Controllers in Power Transmission and Distribution,” New AGE International Publishers hand book, 2007. IV. Dr. Vic Smith, “Voltage Sag Mitigation,” Endeavour Energy Power Quality & Reliability Center, University of Wollongong, Australia, August, 2012. V. Sanjay Haribhai Chaudhary and Mr. Gaurav gangil, “Mitigation of voltage Sag/Swell using DVR,” IOSR Journal of Electrical and Electronics Engineering (IOSR-JEEE) e-ISSN: 2278-1676, p-ISSN: 2320-3331, Volume 8, Issue 4, PP 21-38, (Nov. – Dec.), 2004. VI. Ravilla Madhusudan and G.Ramamohan Rao, “Modeling and Simulation of a DVR for Power Quality Problems Voltage Sags and Swells,” IEEE student member, International Conference on Advances in Engineering, Science and Management (ICAESM -2012) March 30, 31, 2012. VII. F. Ghezal; S. Hadjeri; M. Benghanem and S. Zidi, “Dynamic Voltage Restorer behaviour” from Intelligent Control and Electrical Power Systems Laboratory ICEPS Electrical Engineering Department Djillali Liabes university, Sidi Bel Abbes, Algeria, March, 2014. VIII. Rosli Omar, N.A. Rahim and Marizan Sulaiman, “Dynamic Voltage Restorer for Application of Power Quality Improvement in Electrical Distribution System: An Overview,” Australian Journal of Basic and Applied Sciences, 5(12): 379-396, ISSN 1991-8178, 2011. IX. H.P. Tiwari and Sunil Kumar Gupta, “Dynamic Voltage Restorer against Voltage Sag,” International Journal of Innovation, Management and Technology, Vol. 1, No. 3, ISSN: 2010-0248, August 2010.

Comment by Internal Guide :

Voltage Swells are almost always caused by an abrupt reduction in load on a circuit with a poor or damaged voltage regulator, although they can also be caused by a damaged or loose neutral connection. We have successfully achieved the results for voltage swell with RL load and motor load.

Business Model Canvas

In this type of canvas there are mainly nine blocks are available on which different sheet is stick with the appropriate answer.

1. Key Parameters
2. Key Activities
3. Key Resources
4. Value Propositions
5. Customer Relationships
6. Channels
7. Customers Segments
8. Cost Structure
9. Revenue Streams

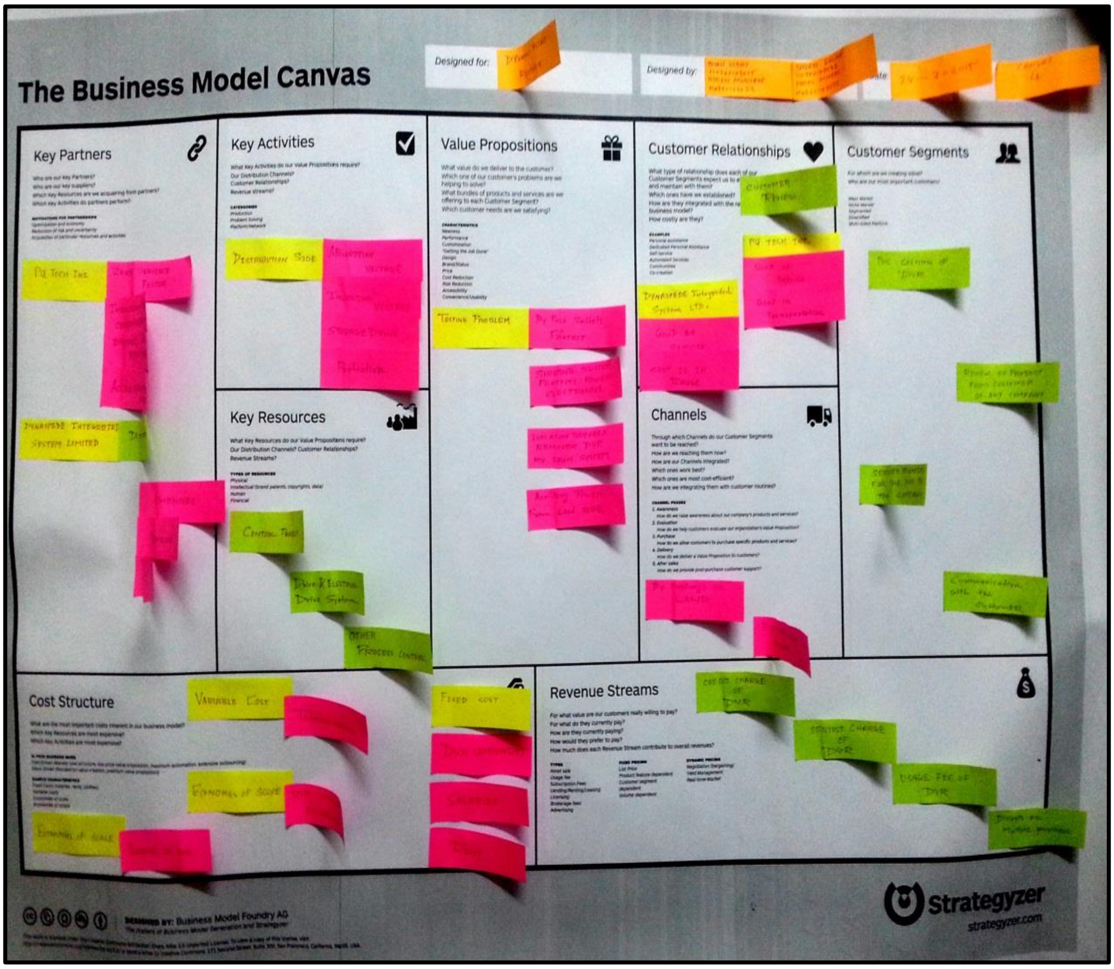

Figure: Business Model Canvas

DVR is used according to different purposes which are included in business model canvas. Here in Key parameter block two major industries i.e., PQ TECH INC and Dynaspede Integrated System Limited, which are selling the DVR is included. Here also describes the other products which are sold by these companies like Zero Sequence Filter, Intelligent VAR Compensator (IVC), and Active Harmonic Filter. Distribution City of Dynaspede Integrated System Limited that is Chennai, Bangalore, and New Delhi is also mentioned.

After that in the second block key activity of DVR at distribution side that is absorption voltage, injecting voltage, storage device, protection is mentioned. In the third block the key resources of the DVR that is Drive & Drive System, Control Panels and other Process Control is included. In the fourth block Value propositions problem at the time of testing of DVR which is Bypass Switch Protection, Shorting Switch Protect the power electronics, Isolation breaker remove DVR MV from System, Auxiliary Power from load side are mentioned. In the fifth block the channels by which DVR is taken away to install at location is described very well i.e., two channel by roadways and by streamer.

In the Sixth block cost structure about the different cost like fixed cost, variable cost, Economics of Scale and Economics of Scope is mentioned. In the eighth block the different types of revenue streams like Credit charge of DVR, Service charge of DVR, Usage fee of DVR, Discounts on multiple purchase is mentioned. In the last block customer segment in pre costing of DVR, Review of product from customer of any company, service provided for the DVR by the company, and communication with the customer is mentioned.

GTU Innovation Council

Patent Drafting Exercise (PDE)

FORM 1 THE PATENTS ACT 1970 (39 OF 1970) & THE PATENTS RULES, 2003 APPLICATION FOR GRANT OF PATENT	(FOR OFFICE USE ONLY) Application No: Filing Date: Amount of Fee paid: CBR No:

1. Applicant(s) :

ID	Name	Nationality	Address	Mobile No.	Email
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4	Miteshkumar Parbhubhai Patel	Indian	Electrical Engineering , Shri Swami Atmanand Saraswati Institute Of Technology, Surat , Gujarat Technologycal University.	9033588965	mitesh821993@gmail.com

2. Inventor(s):

Note : This is just a mock Patent Drafting Exercise (PDE) for semester 8, BE students of GTU. These documents are not to be submitted with any patent office.

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1	Vishvkumar Sanjaybhai Shah	Indian	Electrical Engineering , Shri Swami Atmanand Saraswati Institute Of Technology, Surat , Gujarat Technologycal University.	8866207917	vishvshah705@gmail.com
2	Hiren Arjanbhai Munjani	Indian	Electrical Engineering , Shri Swami Atmanand Saraswati Institute Of Technology, Surat , Gujarat Technologycal University.	9033669476	hiren.munjani1994@gmail.com
3	Sagar Parsotambhai Galani	Indian	Electrical Engineering , Shri Swami Atmanand Saraswati Institute Of Technology, Surat , Gujarat Technologycal University.	9173898778	galanisagar1@gmail.com
4	Miteshkumar Parbhubhai Patel	Indian	Electrical Engineering , Shri Swami Atmanand Saraswati Institute Of Technology, Surat , Gujarat Technologycal University.	9033588965	mitesh821993@gmail.com

3. Title of Invention/Project:

"Mitigation Of Voltage Sag And Swell Using Dynamic Voltage Restorer"

4. Address for correspondence of applicant/authorized patent agent in india

Name: Vishvkumar Sanjaybhai Shah

Address: Electrical Engineering , Shri Swami Atmanand Saraswati Institute Of Technology, Surat , Gujarat Technological University.

Mobile: 8866207917

Email ID: vishvshah705@gmail.com

5. Priority particulars of the application(S) field in convention country

Country	Application No.	Filing Date	Name of the Applicant	Title of the Invention
N/A	*N/A*	*N/A*	*N/A*	*N/A*

6. Particulars for filing patent co-operation treaty (pct) national phase Application

International application number	International filing date as alloted by the receiving office
N/A	N/A

7. Particulars for filing divisional application

Original(First) Application Number	Date of filing of Original (first) application
N/A	N/A

8. Particulars for filing patent of addition

Original(First) Application Number	Date of filing of Original (first) application
N/A	N/A

9. DECLARATIONS:

(i) Declaration by the inventor(s)

I/We, the above named inventor(s) is/are true & first inventor(s) for this invention and declare that the applicant(s).
herein is/are my/our assignee or legal representative.
Date : 19 - May - 2015

	Name	Signature & Date
1	Vishvkumar Sanjaybhai Shah	
2	Hiren Arjanbhai Munjani	
3	Sagar Parsotambhai Galani	
4	Miteshkumar Parbhubhai Patel	

(ii) Declaration by the applicant(s) in the convention country

I/We, the applicant (s) in the convention country declare that the applicant(s) herein is/are my/our assignee or legal representative.applicant(s)

(iii) Declaration by the applicant(s)

I/We, the applicant(s) hereby declare(s) that:-

✓ I am/We in possession of the above mentioned invention.

✓ The provisional/complete specification relating to the invention is filed with this aplication.

✗ The invention as disclosed in the spcification uses the biological material from India and the necessary permission from the competent authority shall be submitted by me/us before the grant of patent to me/us.

✗ There is no lawful ground of objection to the grant of the patent to me/us.

✓ I am/we are the assignee or the legal representative of true & first inventors.

✗ The application or each of the application,particulars of each are given in the para 5 was the first applicatin in the convention country/countries in respect of my/our invention.

✗ The application or each of the application,particulars of each are given in the para 5 was the first applicatin in the convention country/countries in respect of my/our invention.

✗ I/we claim the priority from the above mentioned applications(s) filed in the convention country/countries & state that no application for protection in respect of invention had been made in a convention country before that date by me/us or by any person

✗ My/Our application in india is based on international application under Patent Cooperation Treaty (PCT) as mentioned in para 6

✗ The application is divided out of my/our application(s) particulars of which are given in para 7 and pray that this application may be treated as deemed to have been filed on ___________under section 16 of the Act.

✗ The said invention is an improvement in or modification of the invention particulars of ehivh are given in para 8.

10. Following are the attachments with the application:

✓ (a) Provisional specification/Complete specification

✗ (b) Complete specification(In confirmation with the international application) / as amended befo international Preliminary Examination Authority (IPEA),as applicable(2 copies),No.of pages.. claims.....

✓ (c) Drawings (In confirmation with the international application)/as amended before the interr Preliminary Examination Authority(IPEA),as applicable(2 copies),No.of sheets....

✗ (d) Priority documents

✗ (e) Translations of priority documents/specification/international search reports

✓ (f) Statement and undertaking on Form 3

✗ (g) Power of Authority

✗ (h) Declaration of inventorship on Form 5

✗ (i) Sequence listing in electronic Form

✗ (j) .... Fees Rs.XXX in Cash /Cheque/Bank Draft bearin No.XXX Date: XXX o Bank.

I/We hereby declare that to the best of my /our knowledge, information and belief the fact and mtters stated herein are correct and I/We request that a patent may be granted to me/us for the said invention.

Dated this **19** day of **May** , **2015**

	Name	Signature & Date
1	Vishvkumar Sanjaybhai Shah	______________
2	Hiren Arjanbhai Munjani	______________
3	Sagar Parsotambhai Galani	______________
4	Miteshkumar Parbhubhai Patel	______________

FORM 2
THE PATENTS ACT, 1970
(39 OF 1970)
&
THE PATENTS RULES, 2003
PROVISIONAL SPECIFICATION

1. Title of the project/invention :

"Mitigation Of Voltage Sag And Swell Using Dynamic Voltage Restorer"

2. Applicant(s) :

Vishvkumar Sanjaybhai Shah , (Indian)
Address :Electrical Engineering , Shri Swami Atmanand Saraswati Institute Of Technology, Surat , Gujarat Technologycal University.

Hiren Arjanbhai Munjani , (Indian)
Address :Electrical Engineering , Shri Swami Atmanand Saraswati Institute Of Technology, Surat , Gujarat Technologycal University.

Sagar Parsotambhai Galani , (Indian)
Address :Electrical Engineering , Shri Swami Atmanand Saraswati Institute Of Technology, Surat , Gujarat Technologycal University.

Miteshkumar Parbhubhai Patel , (Indian)
Address :Electrical Engineering , Shri Swami Atmanand Saraswati Institute Of Technology, Surat , Gujarat Technologycal University.

3. Preamble to the description :

The following specification describes the invention.

4. Description :

a. Field of Application / Project / Invention :

Power System

b. Prior Art / Background of the Invention / References :

Power quality is one of major concerns in the present era.Some of the major problems comes here are voltage sag, voltage swell, harmonics, and transient conditions in three-phase power system.This Project helps to remove such conditon like voltage sag and swell for R-L load as well as Motor load.

c. Summary of the Invention/Project :

From simulation results show that the DVR compensates the Voltage Sag and Swell quickly and provides excellent voltage regulation. The DVR handles balanced situation without any difficulties and injects as well as restores the appropriate voltage component to correct quickly any deviation in the supply voltage to keep the load voltage balanced and constant at the nominal value.

d. Objects of the Invention/Project :

Object of this project is to reduce major power quality problem occur in transmission line like voltage sag and swell and provide the Excellent Voltage Regulation.

e. Drawing(s) :

f. Description of the Invention

The modeling and simulation of a DVR using MATLAB/SIMULINK has been presented. A control system based on dq0 technique which is detect error between source side of the DVR and its reference for Voltage Sag and Swell correction. The simulation shows that the DVR performance is satisfactory in mitigating Voltage Sag and Swell for R-L load as well as motor load.

From simulation results also show that the DVR compensates the Voltage Sag and Swell quickly and provides excellent voltage regulation. The DVR handles balanced situation without any difficulties and injects as well as restores the appropriate voltage component to correct quickly any deviation in the supply voltage to keep the load voltage balanced and constant at the nominal value.

g. Examples

h. Unique Features of the Project

This Project gives fast to the power quality problems like Voltage Sag and Swell so Reliability of supply is maintain.

5. Date & Signature :

Date : 19 - May - 2015

Sign and Date Vishvkumar Sanjaybhai Shah	Sign and Date Hiren Arjanbhai Munjani
Sign and Date Sagar Parsotambhai Galani	Sign and Date Miteshkumar Parbhubhai Patel

6. Abstract of the project / invention :

Power quality problem is an occurrence manifested as a nonstandard voltage, current or frequency that can cause failure or a miss-operation of equipment. With power quality problem utility distribution networks, industrial loads, sensitive loads etc. are suffered. Power quality problem dealt here is Voltage Sag /Swell. To overcome the problem related to power quality, custom power devices are introduced. A number of power quality solutions are provided by custom power devices. At present a wide range of very flexible controllers, which capitalize on newly available power electronics components, are introduce for custom power applications.

Power system capability can be increased by the use of Flexible AC Transmission System devices (FACTS) in transmission systems experiencing high power flows. The Dynamic Voltage Restorer (DVR) is the key series compensation devices that open up new opportunities to control the power on transmission systems in order to enhance their utilization, increase power transfer capability and to improve voltage profile. The fast response of this device makes it the efficient solution for improving powerPower quality problem is an occurrence manifested as a nonstandard voltage, current or frequency that can cause failure or a miss-operation of equipment. With power quality problem utility distribution networks, industrial loads, sensitive loads etc. are suffered. Power quality problem dealt here is Voltage Sag /Swell. To overcome the problem related to power quality, custom power devices are introduced. A number of power quality solutions are provided by custom power devices. At present a wide range of very flexible controllers, which capitalize on newly available power electronics components, are introduce for custom power applications.

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Drawing Attachments :

FORM 3
THE PATENTS ACT, 1970
(39 OF 1970)
&
THE PATENTS RULES, 2003
STATEMENT AND UNDERTAKING UNDER SECTION 8

1. Declaration :

I/We, Vishvkumar Sanjaybhai Shah ,
Hiren Arjanbhai Munjani ,
Sagar Parsotambhai Galani ,
Miteshkumar Parbhubhai Patel ,

2. Name, Address and Nationality of the joint Applicant :

Vishvkumar Sanjaybhai Shah (Indian)
Address : Electrical Engineering , Shri Swami Atmanand Saraswati Of Technology, Surat , Gujarat Technologycal University.

Hiren Arjanbhai Munjani (Indian)
Address : Electrical Engineering , Shri Swami Atmanand Saraswati Of Technology, Surat , Gujarat Technologycal University.

Sagar Parsotambhai Galani (Indian)
Address : Electrical Engineering , Shri Swami Atmanand Saraswati Of Technology, Surat , Gujarat Technologycal University.

Miteshkumar Parbhubhai Patel (Indian)
Address : Electrical Engineering , Shri Swami Atmanand Saraswati Of Technology, Surat , Gujarat Technologycal University.

Here by declare:

(i) that I/We have not made any application for the same/substantially the same invention outside India.
(ii) that the right in the application(s) has/have been assigned to,

Name of the Country	*Date of Application*	*Application Number*	*Status of the Application*	*Date of Publication*	*Date of Grant*
N/A	*N/A*	*N/A*	*N/A*	*N/A*	*N/A*

(iii) that I/We undertake that up to the date of grant of patent by the Controller , I/We would keep him inform in writing the details regarding corresponding application(s) for patents filed outside India within 3 months from the date of filing of such application.

Dated this **19** day of **May** , **2015**.

3. Signature of Applicants :

Note : This is just a mock Patent Drafting Exercise (PDE) for semester 8, BE students of GTU. These documents are not to be submitted with any patent office.

Sign and Date
Vishvkumar Sanjaybhai Shah

Sign and Date
Hiren Arjanbhai Munjani

Sign and Date
Sagar Parsotambhai Galani

Sign and Date
Miteshkumar Parbhubhai Patel

To
The Controller of Patent
The Patent Office, at **Mumbai**.

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Removal of Voltage Sag using Dynamic Voltage Restorer (DVR)

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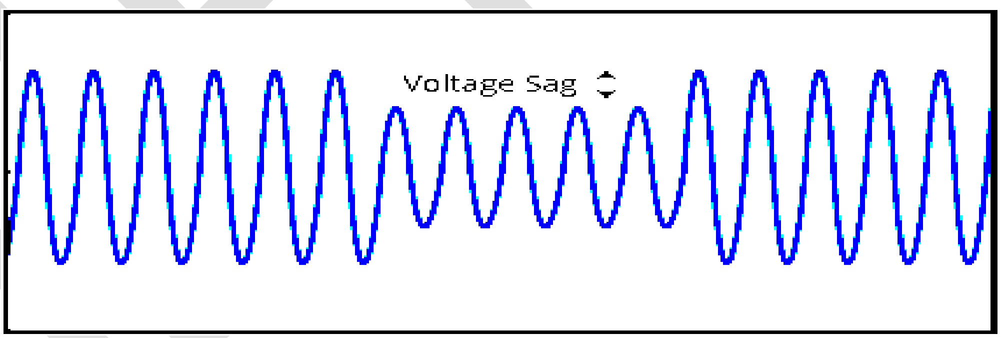
Abstract - Power quality problem is an occurrence manifested as a nonstandard voltage, current or frequency that can cause failure or a miss-operation of equipment. With power quality problem utility distribution networks, industrial loads, sensitive loads etc. are suffered. Power quality problem dealt here is Voltage Sag. To overcome the problem related to power quality, custom power devices are introduced. A number of power quality solutions are provided by custom power devices. At present a wide range of very flexible controllers, which capitalize on newly available power electronics components, are introduce for custom power applications. Power system capability can be increased by the use of Flexible AC Transmission System devices (FACTS) in transmission systems experiencing high power flows. The Dynamic Voltage Restorer (DVR) is the key series compensation devices that open up new opportunities to control the power on transmission systems in order to enhance their utilization, increase power transfer capability and to improve voltage profile. The fast response of this device makes it the efficient solution for improving power quality in distribution systems.

Keywords – Voltage Sag, Power Quality, FACTS device, DVR, Voltage Profile, Series Compensation, IEEE

INTRODUCTION

Power Quality determines the fitness of electrical power to consumer devices. Synchronization of the voltage frequency and phase allows electrical systems to function in their intended manner without significant loss of performance or life expectancy. IEEE Standard (IEEE1100) defines Power Quality as “the concept of powering and grounding sensitive electronic equipment in a manner suitable for the equipment”. If the Power Quality of the network is good, then any loads connected to it will run satisfactory and efficiently. Power quality problems include a wide range of disturbance such as Voltage Sag, Voltage Swell, Frequency Disturbances, Harmonic Distortion, Impulse Transients, Electro Magnetic Interference and Electro Static Discharge. One of the most common power frequency disturbances is Voltage Sag. Voltage Sag is defined as a short reduction in voltage magnitude for duration of time, and it is the most important and commonly occurring Power Quality issue. The definition to characterize Voltage Sag in terms of duration and magnitude vary according to the authority. IEEE standard (IEEE1159, 1995) defines Voltage Sag as a decrease of RMS voltage from 0.1 to 0.9 per unit (p.u.), for duration of 0.5 cycles to 1 minute. Voltage Sags are mostly caused by system fault and last for duration ranging from 3 cycles to 30 cycles depending on the fault clearing time. Voltage Sag is caused by Short Circuit fault on the system, Transformer energizing, heavy load switching, motor starting, customer load addition, large load addition in utility service area etc



Principle of DVR (Dynamic Voltage Restorer)

DVR (Dynamic Voltage Restorer) is a static VAR device. It has wide applications in a variety of transmission and distribution systems. It is a series Compensation device, which protects sensitive electric load from Power Quality problems such as Voltage Sags, Voltage Swells, Voltage and Frequency unbalances and Harmonics distortion with the help of power electronic devices which are used in Voltage Source Converters (VSC). The first DVR was installed on 12.47 KV system located in Anderson, South Carolina, North America in 1996. DVR is small in size and it is a better power effective device as compared to other FACTs devices like DSTATCOM, SSSC and UPFC. DVR is the most effective and efficient custom power device because it has certain advantages like lower cost, smaller size and its fast response towards the disturbances. The capability of injection voltage by DVR system is 50% of nominal voltage. This allows DVRs to successfully provide protection against sags to 50% for durations of up to 0.1 seconds. Furthermore, most Voltage Sags rarely reach less than 50%.The Dynamic Voltage Restorer is also used to mitigate the damaging effects of Voltage Swells, voltage unbalance and other waveform distortions. DVR Works to mitigate any supply voltage disturbance, especially Voltage

Sag, by inserting a voltage with the required magnitude and phase shift in order to restore the load voltage to its rated value.

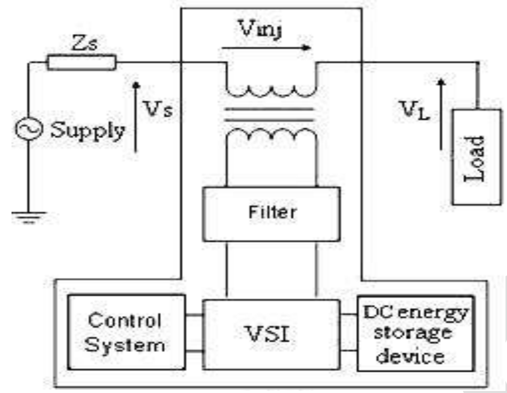


FIGURE 2 Basic component of Dynamic Voltage restorer

DVR consist of following components:

A. Voltage Source converter (VSC):

It is a power electronic system, which consists of switching devices and storage unit to generate sinusoidal voltage at any required frequency, magnitude, and phase angle. This could be a 3 phase–3 wire VSC or 3 phase–4 wire VSC. The latter permits the injection of zero–sequence voltages.

B. An Injection/Booster transformer:

In most DVR applications the DVR is equipped with injection transformers to ensure galvanic isolation and to simplify the converter topology and protection equipment. Three single phase transformers are connected in series with the distribution feeder to couple the VSC to the higher distribution voltage level.

C. Harmonic filter:

The filter is inserted to reduce the switching harmonics generated by the PWM VSC. The filters can be placed either on the high voltage side or the converter side of the boosting transformer. The advantages of the converter side filters are (a) the components are rated at lower voltage and (b) higher order harmonic currents do not flow through the transformer windings.

D. Storage Devices:

This is required to provide active power to the load during deep voltage sags. Lead–acid batteries, flywheel or Super Conducting Magnetic Energy Source (SMES) can be used as energy storage.

Simulation of Voltage Sag for RL Load

A Voltage Sag is defined as a momentary decrease in the root mean square (RMS) of Voltage ranging from 0.1-0.9 p.u., and a duration lasting for half a cycle to one minute. As shown in Figure 3.1, complete modal of DVR for removal of voltage sag is simulated and satisfactory results are achieved. In below simulation modal, Voltage Sag is generated with the help of three phase programmable voltage source which is shown in Figure 3.2. As explain, for removal of Voltage Sag basically following arrangement is required which are as follows:

1. Control strategy of DVR
2. Voltage source converter
3. Generation of gate pulse for VSC

In DVR modal, filter circuit is also used because when the DVR is suddenly inject the voltage to the transmission line of distribution system with the help of injecting transformer then some disturbances are occur which lead to spike in a load voltage. To reduce that spikes L-C filter circuit is used. Control strategy basically abc to dq0 transformation i.e., Clarke Park transformation and dq0 to abc transformation i.e., inverse Clarke Park transformation is used, which is shown in below Figure 3.3.

Simulation modal rating of DVR:

1. Supply Voltage = 3-Ø 1p.u. 50Hz
2. Voltage at Sag = 3-Ø 0.6p.u. 50Hz
3. Injected Voltage = 3-Ø 0.4p.u. 50Hz
4. R-L load:
   I. P = 1KW
   II. Q_L = 1000VAR

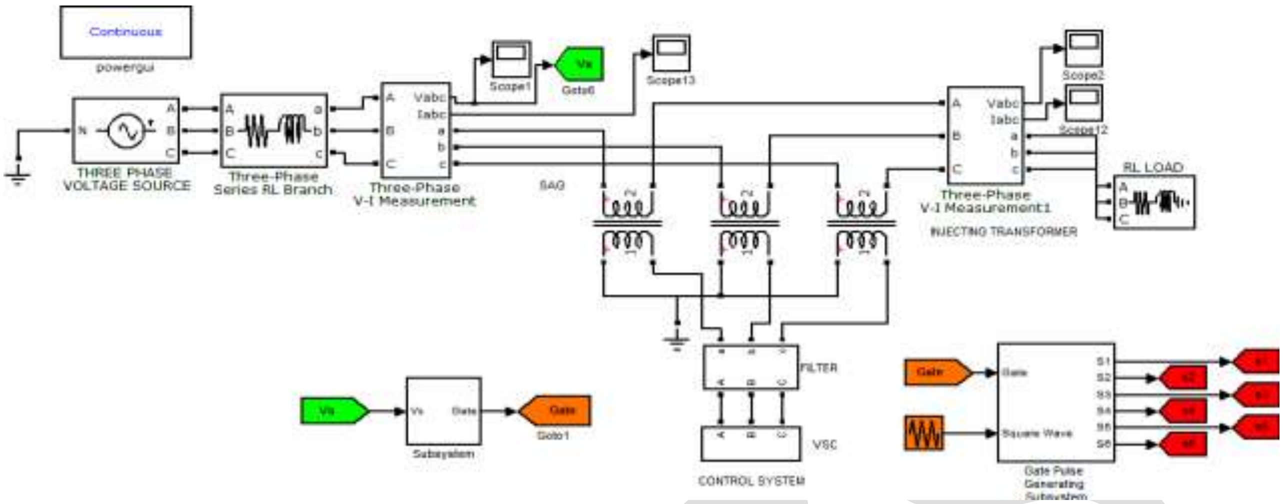


FIGURE 3.1 Simulation modal of DVR for removal of Voltage Sag

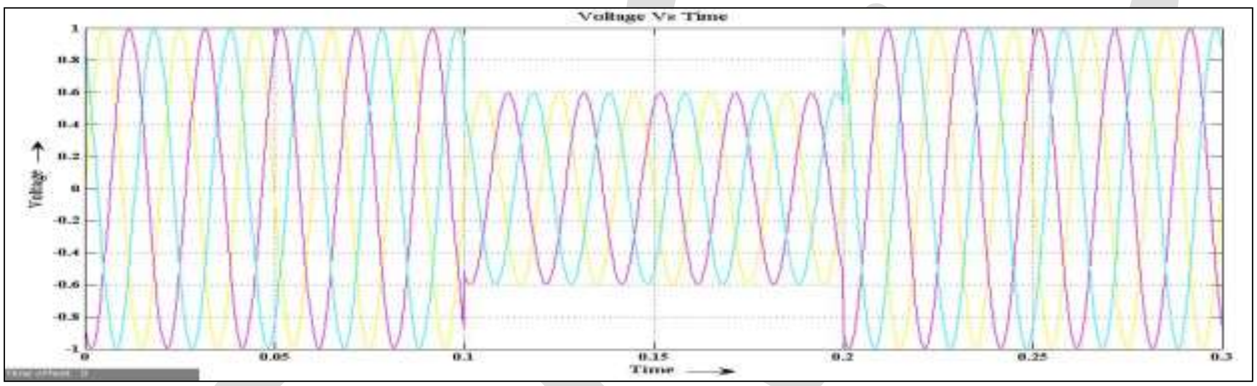


FIGURE 3.2 Wave form of Voltage Sag

As shown in above figure voltage sag is generated by the using of programmable voltage source. As shown, voltage sag is taking place in between 0.1sec to 0.2sec. At the time of voltage sag period, the voltage is reducing to 0.6 p.u.

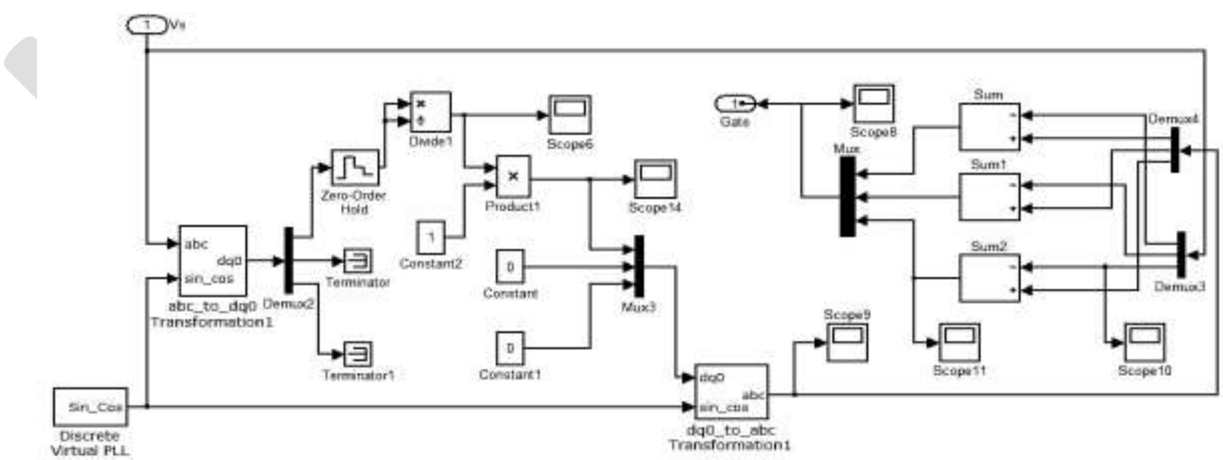


Figure 3.3 Control strategy of DVR

As discussed, firstly supply voltage (including voltage sag) is convert from abc to dq0 with the help abc to dq0 transformation. Here reference sine wave, which is vectorized inputs in terms sine wave is provided for abc to dq0 transformation. After this transformation zero order hold is used to hold at Voltage Sag in the waveform of one axis either it is direct axis or quadrature axis. After the zero order hold reference, voltage signal will multiply and divided by itself due to that 1p.u. signal will be generated in direct axis or quadrature axis. That 1p.u. signal will compare with the constant 1 with the help of product block to generate 1p.u. signal in

either direct or quadrature axis. To generate 1p.u. in AC system dq0 to abc transformation is performed. In this transformation two inputs are taken from zero i.e. terminator signal and remaining one input is taken from above generated 1p.u.
Here dq0 to abc transformation is done with the help of dq0 to abc transformation in which stationary frame is converted into rotatory frame. Due to that sine wave with the magnitude 1p.u. is generated is three phase system. This 1p.u. reference sine wave is compared with the supply voltage due to that error is generated, which is required to be injected in the system. Magnitude of error in p.u. will be injected to the system with the help of injecting transformer.

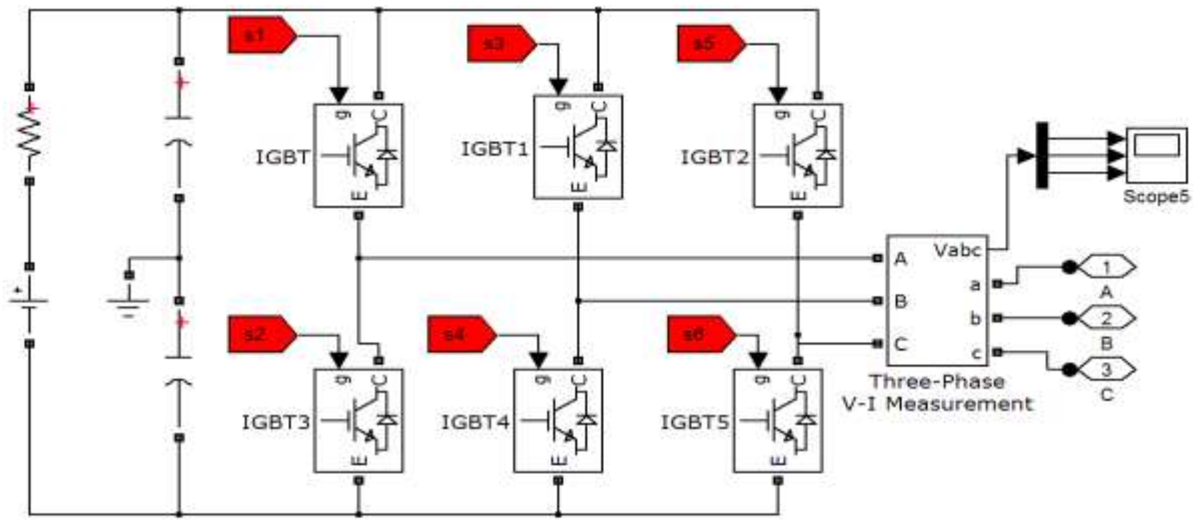


Figure 3.4 Voltage Source Converter Subsystem

Voltage source converter is made up of combination of six IGBTs. Here separate gate signal is provided for generation of voltage in p.u. which is required to be injected. Three arm of voltage source converter consisting of two IGBTs each. Each IGBT is operated for 60° of conduction period. Two IGBTs in one arm cannot be operated simultaneously. Here gate signal is provided by comparison of two signals one is error signal which is generated in the control strategy of DVR and other one triangular or carrier signal. Here comparison is performed with the help of Boolean expression. According to this comparison gate pulse is generated in square wave which is given to the irrespective IGBTs. Comparison is made in between carrier signal which is in triangular form and modulating signals (error signal) which in sinusoidal form. Hence this voltage source converter is also known as sinusoidal pulse width inverter (SPWM).

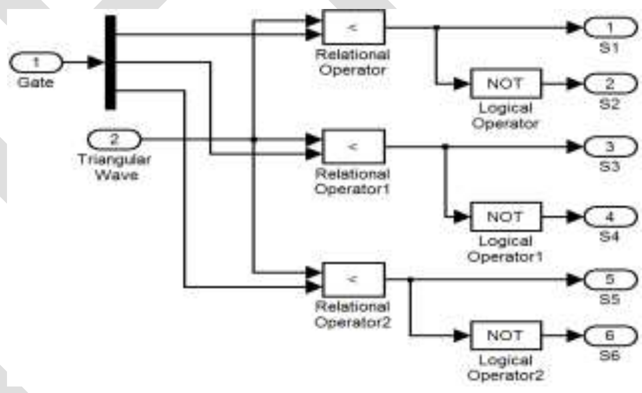


FIGURE 3.5 Gate pulse Controller

Gate pulse controlling mechanism is shown in above Figure 3.5. This gate pulse is fed to the irrespective IGBTs of voltage source converter. Due to that voltage source converter will generate error voltage in p.u. System, which is required to be injected in the system with the help of injecting transformer. After injection operation Voltage Sag will be mitigated.

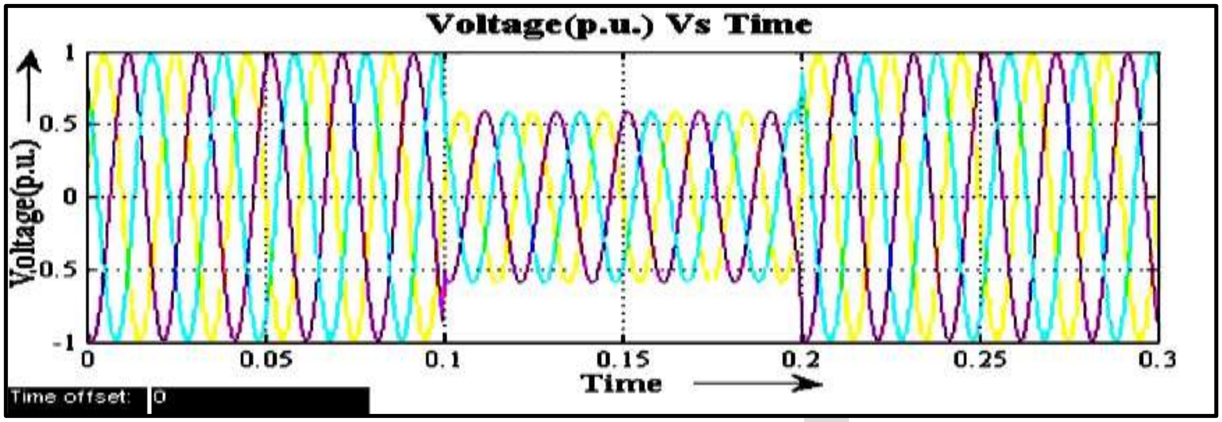


FIGURE 3.6 Voltage Sag for 0.1 sec to 0.2 sec

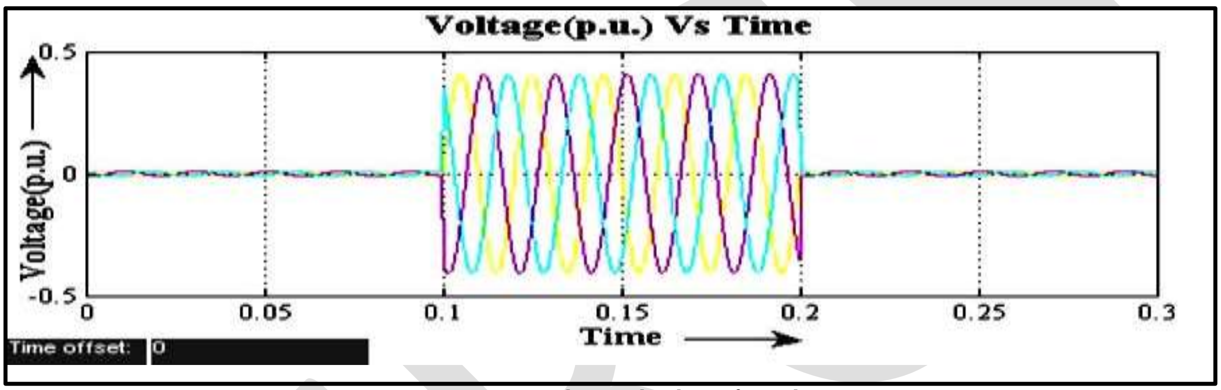


FIGURE 3.7 Required Injected Voltage after Voltage Sag

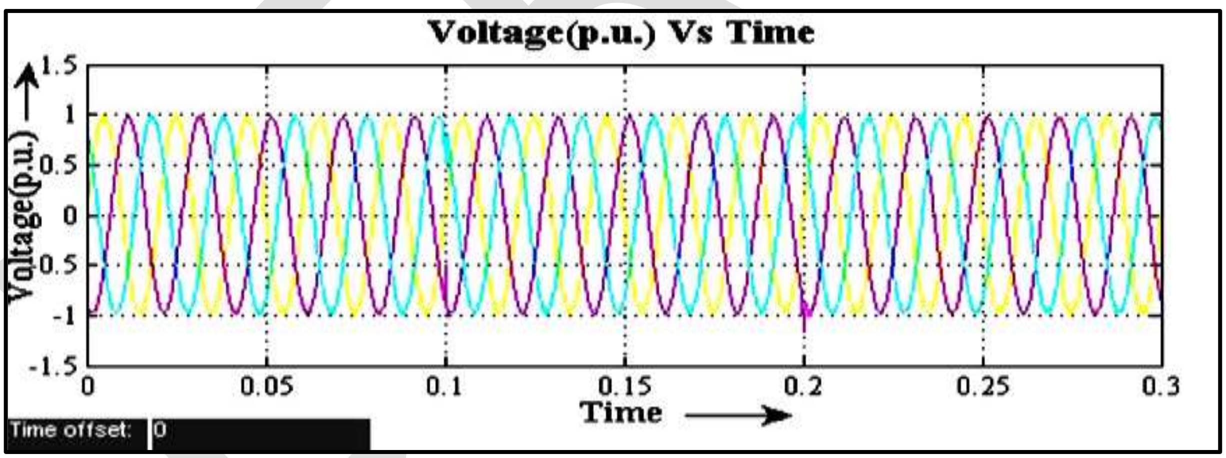


FIGURE 3.8 Voltages after Removal of Voltage Sag

When Voltage Sag is taking place, supply voltage is affected as shown in above Figure 3.6 and magnitude of Voltage Sag is about 0.6p.u. for time period of about 0.1 to 0.2sec. In accordance with error signal and reference signal the require voltage which is to be injected in the system is taken from voltage source converter through injection transformer shown in above Figure 3.7 and Figure 3.8 shows voltage result after removal of voltage sag. This result is achieved by the above mention control strategy of DVR which shows smooth voltage profile of system.

ACKNOWLEDGMENT

The authors sincerely thank to Electrical Engineering Department, Shree Swami Atmanand Saraswati Institute of Technology, Surat for providing facility to carryout this work.

CONCLUSION

The modeling and simulation of a DVR using MATLAB/SIMULINK has been presented. A control system based on dq0 technique which is detect error between source side of the DVR and its reference for Voltage Sags correction. The simulation result shows that the DVR performance is satisfactory for removal of voltage sags. From simulation results also show that the DVR compensates the voltage sags quickly and provides excellent voltage regulation. The DVR handles both balanced and unbalanced situations without any difficulties and injects the appropriate voltage component to correct quickly any deviation in the supply voltage to keep the load voltage balanced and constant at the nominal value.

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