“ I hereby declare that I have read through this report entitle “Voltage Dip Mitigation by Controlling Voltage and Current DQ Components” and found that it has comply the partial fulfillment for awarding the degree of Bachelor of Electrical Engineering (Control, Instrumentation and Automation)”

Signature : ....

Supervisor’s Name : MOHAMED AZMI BIN SAID

Date : 18TH JUNE 2014

VOLTAGE DIP MITIGATION BY CONTROLLING VOLTAGE AND CURRENT DQ COMPONENTS

SYARIFAH SYAKILA BINTI SYED WAHAB

A report submitted in partial fulfillment of the requirement for the degree of Bachelor of Electrical Engineering (Control, Instrumentation and Automation)

Faculty of Electrical Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2014

I declare that this report entitle "*Voltage Dip Mitigation by Controlling Voltage and Current DQ Components*" is the result of my own research except as cited in the references. The report has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature : ....

Name : SYARIFAH SYAKILA BINTI SYED WAHAB

Date : 18^{TH} JUNE 2014

Specially dedicated:

To my beloved mother Muziah binti Ahmad,

My beloved sisters,

My supervisor and all my lecturers

And all my friends

For their encouragement, support and motivation

Through my journey of education.

ACKNOWLEDGEMENT

Alhamdulillah, I am greatly indebted to Allah SWT on His mercy and blessing for making this project successful.

I would like to take this opportunity to express my profound gratitude and deep regards to my honorable supervisor, Encik Mohamed Azmi bin Said for his exemplary guidance, monitoring and constant encouragement throughout my study. The blessing, help and guidance given by him time to time shall carry me a long way in the journey of life on which I am about to embark.

A special thanks goes to my family, my team mates: Ayu Amira Zahari and all my friends for always give support and accompany me to finish this final year project report.

ABSTRACT

Power quality problems, especially voltage dip contribute a major negative impact on industrial productivity. There is much available method to compensate voltage dip. This report briefly examines the method voltage dip mitigation by controlling voltage and current DQ components, and compares performance attributes of uncompensated system and compensated system. Important comparison points include performance of time response and efficiency of controller. The method of mitigation voltage is simulated by using PSCAD software.

ABSTRAK

Masalah kualiti kuasa, terutama voltan susut menyumbang kesan negatif yang besar kepada produktiviti industri. Terdapat banyak kaedah yang ada untuk memperbaiki voltan susut. Laporan ini secara ringkas mengkaji mitigasi voltan susut dengan kaedah mengawal voltan dan komponen DQ, dan membandingkan sifat-sifat persembahan sistem sebelum pembaikan dan selepas pembaikan. Antara perkara perbandingan yang penting ialah persembahan tindak balas masa dan kecekapan pengawal. Kaedah voltan mitigasi ini disimulasikan dengan menggunakan perisian PSCAD.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLE

CHAPTER 1

INTRODUCTION

1.1 MOTIVATION

Consumer of large electrical power such as industrial is concern about power quality problem. The common power quality problem happen is voltage dip, voltage swell and interruptions. Among of this power quality problem, voltage dip is the most common disturbance occurred. Generally, voltage dip is the decreasing of voltage in short period.

Nowadays, the high technology industry will likely use sensitive equipments in their industry in order to apply energy saving concept. However, the sensitive equipment cannot withstand the sudden fluctuation of voltage like voltage dip. As the voltage dip is happen, this sensitive equipment will be malfunction. The breakdown of sensitive electronic equipment can cause significant financial losses. This is because in many production processes, loss of some equipment can cause to a full shut down of production. From [1], the losses in industry in the United States, due to voltage dips are over $20 annually. Instead of repair or buy the new equipment, the money can used to produce more products. Therefore, it is important to mitigate voltage dip to increase the productivity of operational, economical and quality of services of industrial area.

1.2 PROBLEM STATEMENT

In power system, the voltage dip usually happens in transmission line and distribution system. Voltage dips is caused by different event that can occur in the power system such as transformer energizing, high starting current and sudden high current that lead to ground fault (current leakage to the earth). One of the situations that caused voltage dip to be produced is, as in industrial application, starting large motor yields a very high current. Based on Ohm's law, high current is affected on the decreasing of voltage. The decreasing of voltage in this situation is called as voltage dip.

Ideally, power distribution system should provide their customers with an uninterrupted flow of energy at smooth sinusoidal voltage at the contracted magnitude level and frequency. However, in real life, power systems have numerous non linear signals, which significantly affect the quality of power supplies [2]. Therefore, the source of voltage dips problems is unavoidable. So it is important to find a way to overcome voltage dips. Power system analysis is needed to gain some knowledge about how to maintain the level of voltage even there is fault occur.

1.3 OBJECTIVES

There are three main objectives of this project which are:

1. To design a method of mitigating power line voltage dip by using current and voltage DQ components through transforming three phase reference frames to rotating reference frame.
2. To simulate voltage dip mitigation system by using PSCAD software.
3. To analyze the performance of the uncompensated and compensated system by using simulation software (PSCAD, MATLAB, etc).

1.4 SCOPE OF RESEARCH

The power quality problem can be categorized into nine which is voltage dips, voltage swells, harmonics, frequency deviations, transients, unbalance, flicker, interruptions and waveform distortion. Amongst of all this power quality problem, the voltage dips is the only power quality problem that will be focused on.

There are two types of three phase system which is balanced system and unbalanced system. The balanced three phase system is chosen to be the type of system to be tested by voltage dips.

To analyze and simplify the three phase system, there are several method can be used. The method that will be used in this project is DQ transformation.

To mitigate voltage dips, one of the solutions is by injecting reactive power into transmission line. There are several methods to inject reactive power into transmission line. The proposed method is by controlling shunt current DQ component. To controlling shunt current DQ component, the custom power devices used is current source. Current source can be injected in two ways which is series connection and shunt connection. This study will focus on mitigate voltage dips by injecting shunt current source.

As the definition of voltage dips is power voltage drops to a level below 90% of standard voltage for no longer than a minute, this project is about to design the controller to mitigate voltage dips for situation of 10% voltage dips [3].

This project will cover simulation part only.

CHAPTER 2

LITERATURE REVIEW

2.1 BACKGROUND OF PROJECT

2.1.1 Voltage Dip Definition

Voltage dip is the decreasing between 0.1 to 0.9 pu in the RMS voltage at the power frequency with duration from 0.5 cycles to 1 minute [4]. For more understanding, voltage dip is visualized as Figure 2.1.

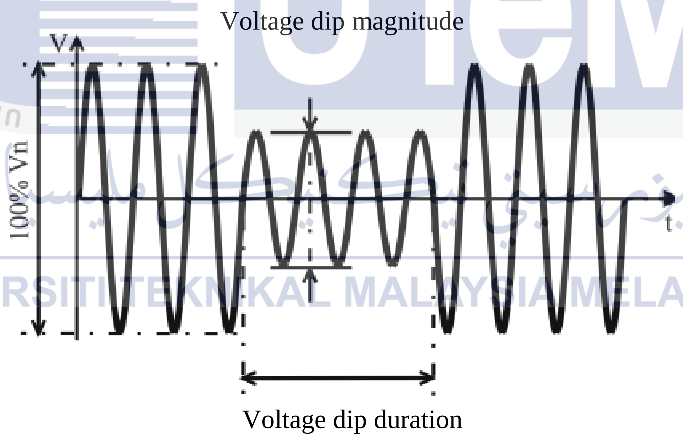

Figure 2.1: Waveform of voltage dip

2.1.2 Transformation Of Three Phase Reference Frames To Rotating Reference Frame

Three phase reference frame signal can be transformed into rotating reference frame signal [5]. One of the method signal transformation can be used is Clarke's and Park's transformation. Clarke's and Park's transformation is mathematical transformation that rotates the reference frame of three-phase systems in order to simplify the analysis of three-phase circuits. Clarke's and Park's transformation transform signal by cascade as

Figure 2.2. In other word, to transform three phase reference frame signal into rotating reference signal, the Clarke's and Park's transformation is work in separate way.

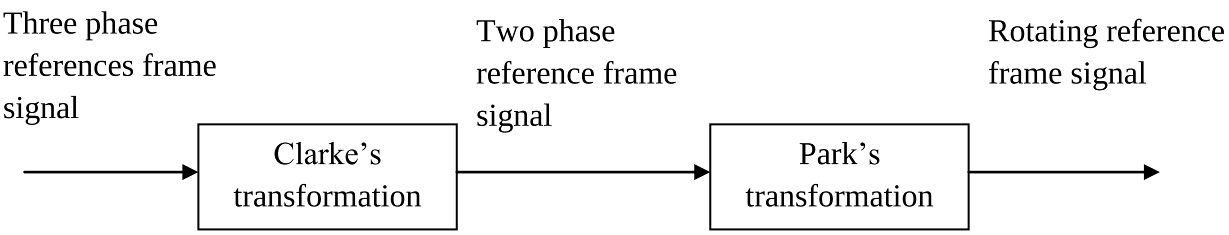

Figure 2.2: Block diagram of Clarke's and Park's transform

Clarke's transform is transformation three phase stationary parameter from a-b-c system into two phase stationary reference frame as Figure 2.3. The variable of two phase stationary reference frame is called as α and β.

Figure 2.3: Clarke's transformation

The three phase stationary parameter from a-b-c system is transform into two phase stationary reference frame based on the equation below:

$$F = T_{\alpha\beta o} \, . \, [\, F_{abc} \,] \qquad (2.1)$$

Where;

F : Parameter such as voltage, current, line leakage.

F_{abc} : Parameter such as voltage, current, line leakage in abc form.

$T_{\alpha\,\beta\,o}$ from equation (2.1) is obtained as below:

$$T_{\alpha\,\beta\,o} = \frac{2}{3}\begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix} \tag{2.2}$$

After simplify the equation (2.1), the equation of two phase stationary reference frame is as below:

$$V_{\alpha} = \frac{2}{3}V_{a} - \frac{1}{3}(V_{b} - V_{c}) \tag{2.3}$$

$$V_{\beta} = \frac{2\,V_{b} - V_{c}}{\sqrt{3}} \tag{2.4}$$

$$V_{0} = \frac{1\,(V_{a}+V_{b}+V_{c})}{3} \tag{2.5}$$

The equation of inverse Clark's transformation is as below:

$$V_{a} = V_{\alpha} \tag{2.6}$$

$$V_{b} = \frac{-\,V_{\alpha} + \sqrt{3}\,V_{\beta_{c}}}{2} \tag{2.7}$$

$$V_{c} = \frac{-\,V_{\alpha} - \sqrt{3}\,V_{\beta_{c}}}{2} \tag{2.8}$$

Park's transform is transformation of three phase stationary parameters into two phase orthogonal rotary reference frame as Figure 2.4. The variable of two phase orthogonal rotary reference frame is called as d and q (DQ components).

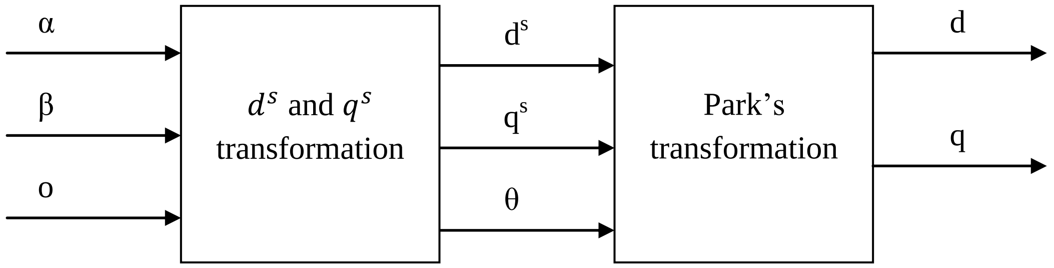

Figure 2.4: Park's transformation

The three phase stationary parameters is transform into two phase orthogonal stationary reference frame based on the equation below:

$$V_{d\,q\,o}\,(\theta) = T_{d\,q\,o}\,(\theta)\ \cdot [\, V_{\alpha\,\beta\,o}\,] \tag{2.9}$$

V : Parameter such as voltage, current, line leakage.

$T_{d\,q\,o}$ from equation (2.9) is obtained as below:

$$T_{d\,q\,o} = \begin{bmatrix} \cos\theta & \sin\theta & 0 \\ -\sin\theta & \cos\theta & 0 \\ 0 & 0 & 1 \end{bmatrix} \tag{2.10}$$

To transform three phase stationary parameters into two phase orthogonal rotary reference frame, the equations involve are:

$$V_d = V_\alpha \cos\theta + V_\beta \sin\theta \tag{2.11}$$

$$V_q = -V_\alpha \sin\theta + V_\beta \cos\theta \tag{2.12}$$

The equation of inverse Park's transformation are as below:

$$V_\alpha = V_d \cos\theta - V_q \sin\theta \tag{2.13}$$

$$V_\beta = V_d \sin\theta + V_q \cos\theta \tag{2.14}$$

The difference between three phase reference, two phase reference and rotating reference frame that produced from Clarke's and Parks transform is demonstrated in Figure 2.5.

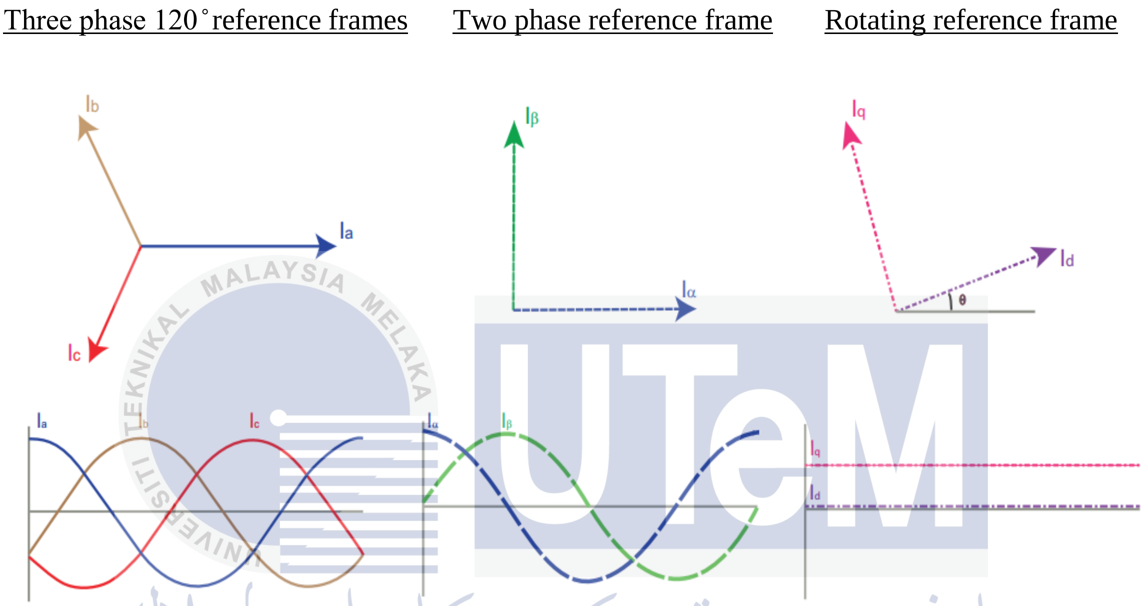

Figure 2.5: Graph and polar form of three phase reference frames signal, two phase reference signal and rotating reference frame signal

2.1.3 Control System

To gain better understanding on the project, the control system of power system should be studied. Figure 2.6 show the basic closed loop control system. In this project, the block plant represents the power system. The power system is consists of generator, transmission line or distribution system. The disturbance represents the fault (voltage dip). The block controller is a feedback controller, such as P controller, PI controller, PD controller or PID controller.

The process in closed loop control system is as follows. When the plant is experience fault, the sensor will sense the amount of output signal is not equal to the desired output signal. Then the output signal will be compared to the reference signal by controller. The controller will process the signal and compensate the signal.

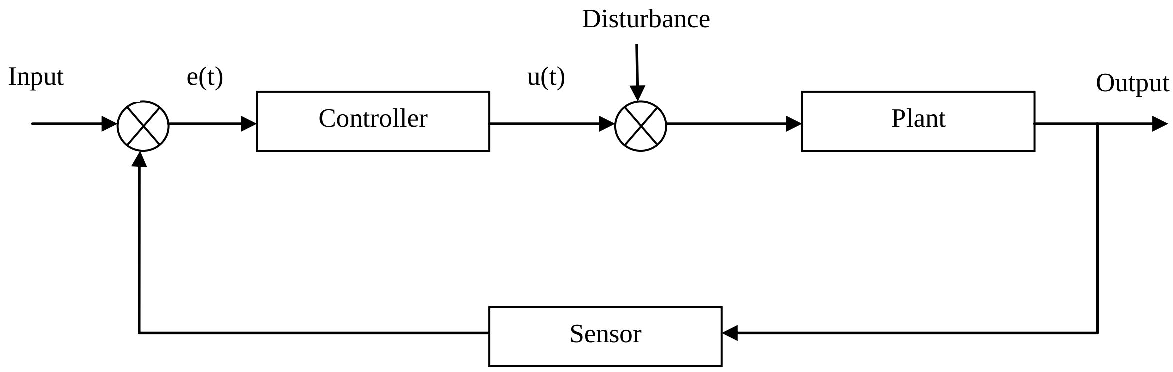

Figure 2.6: Basic closed loop control system

2.1.4 PI Controller

The combination of proportional gain and integral gain is called as PI-controller. The PI-controller is expressed in the equation that contains proportional gain and integral gain as Equation 2.15:

$$u(t) = Kp\ e(t) + Ki \int e(t)\ dt \tag{2.15}$$

Kp: Proportional gain

Ki: Integral gain

From the Equation 2.15, Kp and Ki are the tuning knobs. To obtain the desired output, this tuning knob is adjusted. The function of Kp is to increase the speed of response. The function of Ki is to eliminate the steady state error.

2.1.5 Advantage Of PSCAD Software

PSCAD software can be used to simulate the circuit of power system. PSCAD software is chosen to simulate the circuit of power system because PSCAD software is software that makes use of intelligent techniques to computerize the power quality evaluations for improved accuracy and efficiency since manual analysis takes considerable time and would require special knowledge [6]. Another advantage of PSCAD is ability to interface with MATLAB/SIMULINK software.

2.2 RELATED PREVIOUS WORKS

2.2.1 Solutions To Voltage Dip

To improve voltage dip in industrial plant, first action is find which process in the plant is sensitive to voltage dip [7]. Then understand the product manufacturing process and operation of the equipment. Next step is identifying which equipment is critical to the other machine operation and will be adversely affected by voltage dip. The example of equipment is Adjustable Speed Drive (ADS) and control and logic circuit. The methods to repair the voltage dip on ADS are reprogramming the response of ADS and restart the motor after a user-defined time delay. While the methods to improve voltage dip on control and logic circuit are use Semi F47 compliant power source, change the trip setting of control circuit and install a coil hold-in device.

Phase of power is categorized into two, which is single phase power and three phase power. To mitigate voltage dip that happens in single phase power and three phase power, consumer should use power conditioning devices. The example of single phase power conditioning devices that available in market is Uninterruptible Power Supply (UPS), Constant Voltage Transformer (CVT), Dip Proofing Inverter, Voltage Dip Compensator (VDC), Dynamic Compensator (Dynacom) and Dynamic Sag Corrector (DySC). The example of three phase power conditioning devices that available in market is Active Voltage Conditioner (AVC), Datawave, Flywheel, Dynamic Voltage Restorer (DVR), three phases Dynamic Compensator (Dynacom), Dynamic Sag Corrector (ProDysc) and Dynamic Sag Corrector (MegaDysc).

2.2.2 Shunt-Connected Voltage Source Converter (VSC)

One of the methods to mitigate voltage dip is by set shunt-connected VSC [8]. The control system of shunt connected VSC is consists of two controllers which is vector current controller and vector voltage controller. The vector current controller generates a reference signal proportional to the VSC output voltage in order to track the reference VSC output current. While voltage controller generate a reference signal proportional to the output voltage VSC current. The purpose is to maintain the voltage above the capacitor constant to the desired value.

The three phase system can be expressed by two-phase system by obtain the DQ components. The block diagram of the transformation is as Figure 2.7. The purpose of transformation of three phase system into two-phase system is because to facilitate the PI controller to sense the amount of fault in the line voltage. To get the DQ components, voltage and current will be converted to fixed coordinate α β and then to DQ components. To calculate DQ components, it is important to carry out the calculation of transformation angle θ(t). The transformation angle θ(t) will be calculated by Phase-Locked Loop (PLL).

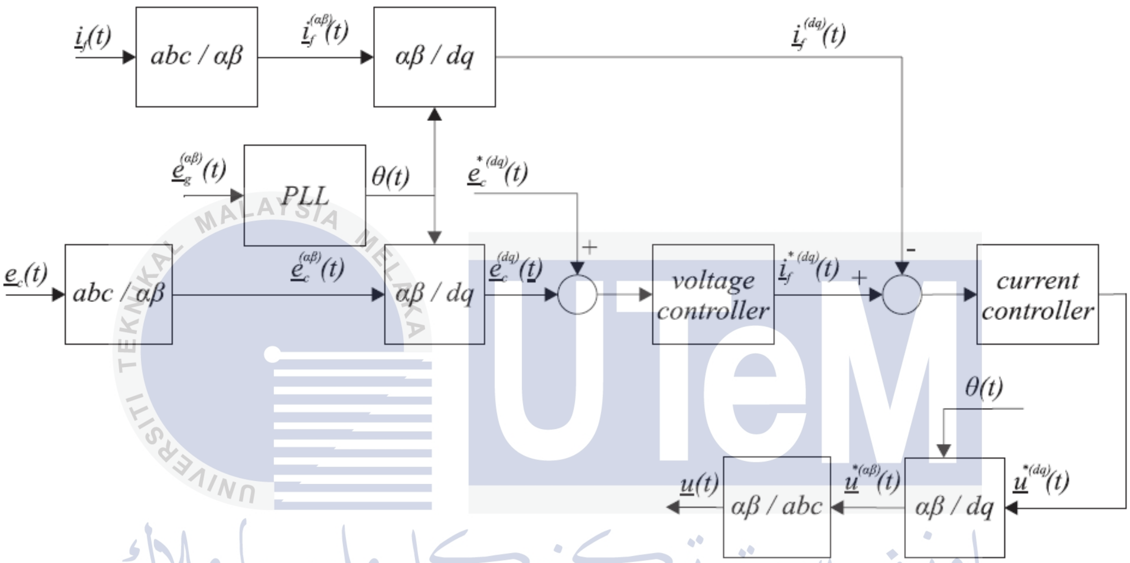

Figure 2.7: Block diagram of the implemented control system

2.2.3 Phase-Locked Loop

Phase-Locked Loop (PLL) is one of the controllers that used to sense the difference (error) between phase of reference signal and phase of line voltage with fault [9]. PLL is consisting of variable frequency oscillator and phase detector. The function of oscillator is to generate a periodic signal. The function of phase detector is to compares the phase of output signal with the phase of the input signal and adjust the oscillator to keep the phases matched. The output signal is bring back toward the input signal for comparison is called a feedback loop since the output is ‘feed back’ toward the input forming a loop.

2.2.4 Mathematical Model And Control Strategy On DQ Frame

The shunt active power filter (SAPF) functions as the tool to solve the harmonic problem because compare to passive power filter, this filter produce higher efficiency and more flexible [10]. The process of using SAPF is categorized into three main parts. First part is harmonic detection technique to calculate the reference currents of the SAPF. The example of technique of calculating reference current is instantaneous power theory (PQ), the synchronous reference frame (SRF), the a-b-c reference frame, the synchronous detection (SD) and the DQ axis with Fourier (DQF) [11]. The second part is design structure of SAPF. The structure of SAPF is consisting of the voltage source inverter (VSI) with six IGBTs. The last part is the control method and control strategy to control the compensating currents. To generate the switching signals, the pulse modulation technique is used.

2.2.5 DSTATCOM

Voltage dip contributes more than 80% power quality problem [12]. The STATCOM is one of the methods to mitigate voltage dip and correct the power factor. Generally, DSTATCOM is used to produce or absorb reactive power. The static compensator (STATCOM) is called as Distribution STATCOM (DSTATCOM) only when it is used in low voltage distribution system. The DSTATCOM is a three phases and shunt connected power electronic based device, connected at distribution system. The voltage source converter (VSC) and DC link capacitor is used as a DSTATCOM. Modified Power Balance Theory (PBT) based control algorithm is used for controlling the DSTATCOM [13]. Power balance control algorithm functions as extracting reference source currents for voltage regulation at Point of Common Coupling (PCC). Figure 2.8 shows the simplified system diagram of a DSTATCOM which is consist of IGBT based VSC, coupling inductor, control strategy and DC link capacitor.

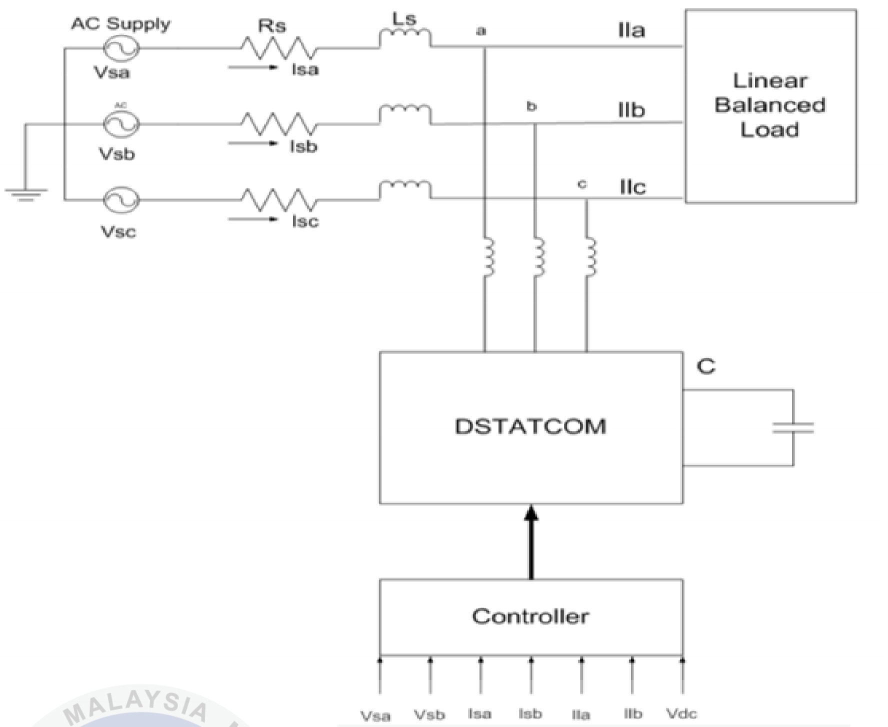

Figure 2.8: Simplified system diagram of a DSTATCOM

2.2.6 Dynamic Voltage Restorer (DVR)

One of the methods to compensate the power quality problem such as voltage sag/swell and harmonics is by using the DVR [14]. Among of the algorithm method, the DQO algorithm is used as method applied in DVR system. To regulate the load side voltage, the DVR is proposing the series connected solid state device that injects voltage into the system. Usually, the DVR is installed between the supply and the critical load feeder at the Point of Common Coupling (PCC). The main components of the DVR consists of an injection transformer, harmonic filter, series VSI (VSC) energy storage and control system as shown in Figure 2.9.

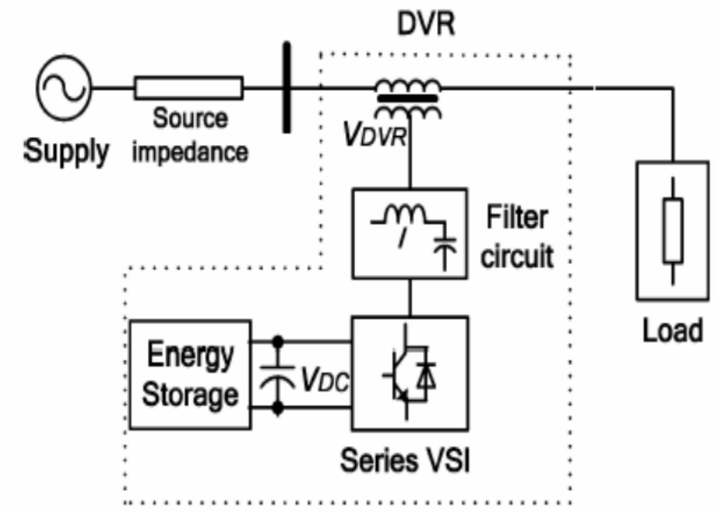

Figure 2.9: Circuit diagram of DVR

The function of DVR is to inject the dynamically control voltage V_{DVR} generated by a force commutated converter in series to the bus voltage. When the fault occurs, with the aid of DQO transformation, the inverter output can be control in phase with the incoming ac source. Two basic control methods that carried out by DVR is detection of fault and compensate the fault system. A Figure 2.10 show a flow chart of the feed forward DQO transformation for voltage sags/ swells detection. The modulation signal that allows generating a commutation pattern for the power switches (IGBT's) constituting the voltage source converter is considered as the error signal. The commutation pattern is generated by the Sinusoidal Pulse Width Modulation technique (SPWM) [15]. To generate a unit sinusoidal wave in phase, the Phase-Locked Loop (PLL) circuit is used.

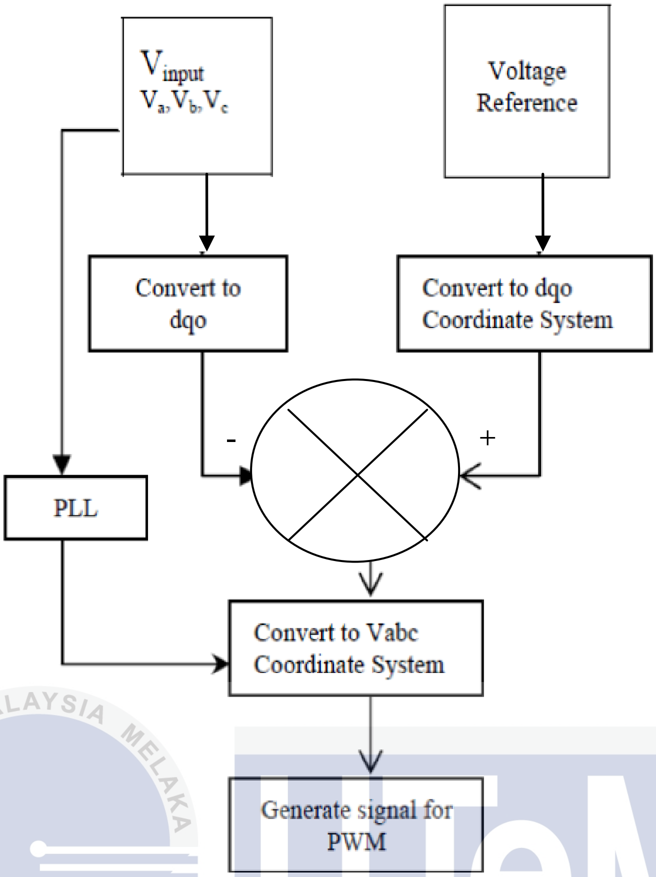

Figure 2.10: Flow chart of feed forward control technique for DVR based on DQO Transformation

2.3 SUMMARY

2.3.1 Summary Of Background Of Project

The definition of voltage dip, the transformation of three phase reference frames to rotating reference frame, the control system of power system, advantage of PSCAD software and the uses of MATLAB software has been presented.

2.3.2 Summary Of Related Previous Works

From the section 2.2.1, the custom power device used for mitigate voltage dip can be categorized into three which is in for sensitive equipment, for single phase power system and for three phase power system. From the section 2.2.2, the block diagram of implemented control system can be used as idea to simulate control design circuit. Based on the section 2.2.3, the PLL controller circuit can be created to determine the angle three phase signals. From the section 2.2.4, the mathematical and control strategy on DQ frame can be referred to carry out the transformation of three phase reference frames to rotating reference frame (as objective). From the section 2.2.5, the DSTATCOM will be test for produce and absorb reactive power, since the custom power device in this project will be used to inject reactive current. From the section 2.2.6, the DQO algorithm method will be used to design control system in this project. The flow chart of feed forward control technique for DVR based on DQO transformation is very useful in order to planning the designation of control system.

CHAPTER 3

METHODOLOGY

3.1 RESEARCH

3.1.1 Voltage Dip Mitigation

The process of the voltage dip mitigation will be explained clearly in the flowchart as in Figure 3.1. From the flowchart; firstly the three phase signal that obtained from transmission line will be transformed into DQ signal by DQ controller. Then the DQ signal will be compared with reference signal to get the amount of signal, named as error signal. The error signal will be send into PI controller. The function of PI controller is as controller that improves the performance of error signals. Then inverse DQ controller will transform the DQ error signal into three phase signal. The three phase signal will be the source of shunt external current source. Shunt external current source will inject reactive current into transmission line to compensate line voltage. The amount of reactive current injected is based on the amount of error signal. Lastly, the three phase signal is ready to deliver into distribution system.

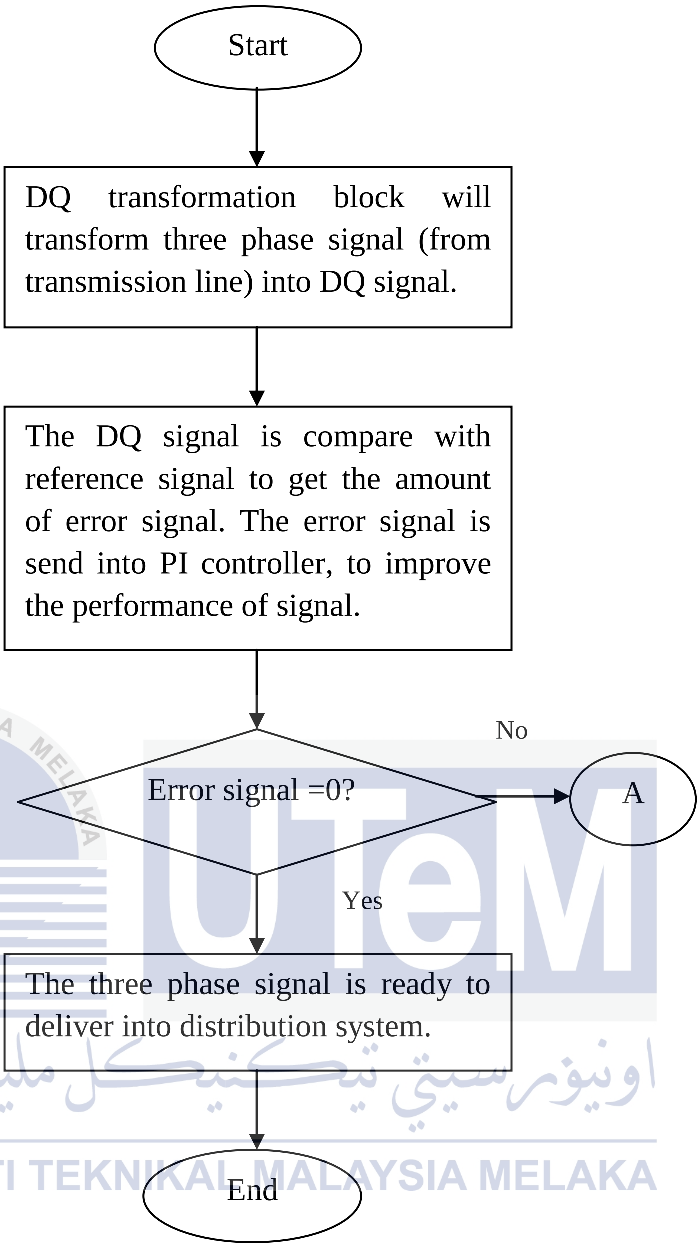

Figure 3.1: Flowchart of mitigating voltage dips process

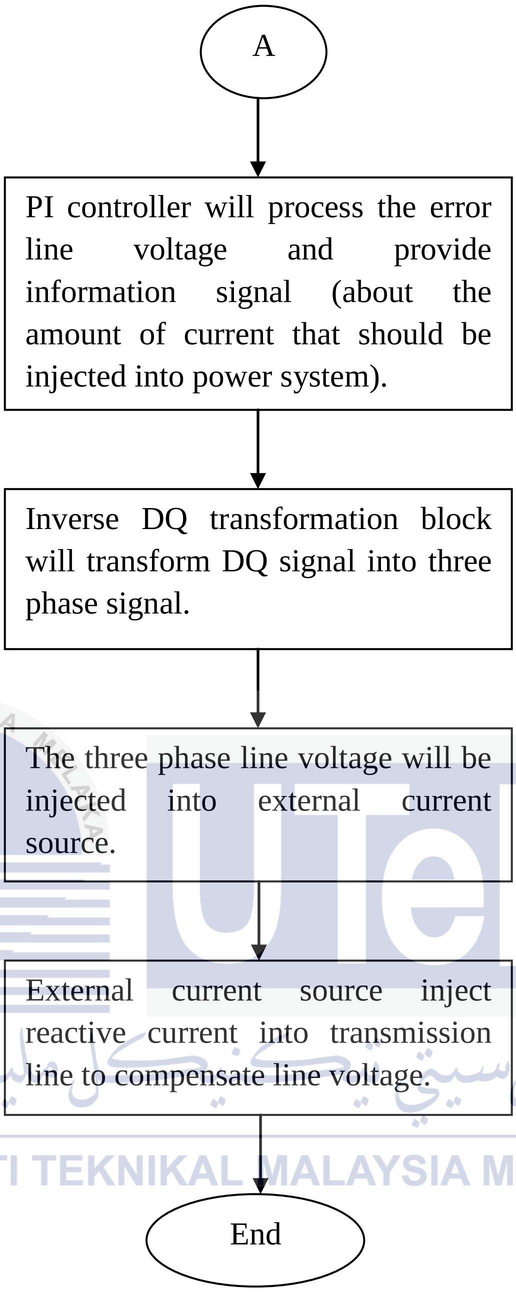

Figure 3.1: Flowchart of mitigating voltage dips process (continue)

3.1.2 Method Of Mitigating Power Line Voltage Dip By Using Current And Voltage DQ component

To mitigate voltage dip, one of the methods is by injecting shunt reactive current to the power system. Power system produces periodic three phase signal which is in sinusoidal form as shown in Figure 3.2. One of the most common types of reference signal is step input. Step input is in step form. To compensate output signal, the reference signal (step form) and output signal (sinusoidal form) should be compared so the difference between two signals can be compensated. However, it is quite complicated to compare signal when it is in different form. Therefore, one of the signals should be transformed into another form so both of the signals are in the same form. To simplify the analysis, the sinusoidal graph of three phase reference frame will be transform into rotating reference frame signal by Park's and Clarke's transformation. The shape of graph of voltage and current rotating reference frame signal is as Figure 3.3. The graph in linear form (rotating reference frame signal) is easiest to analyze compared to sinusoidal graph form (three phase reference frames signal).

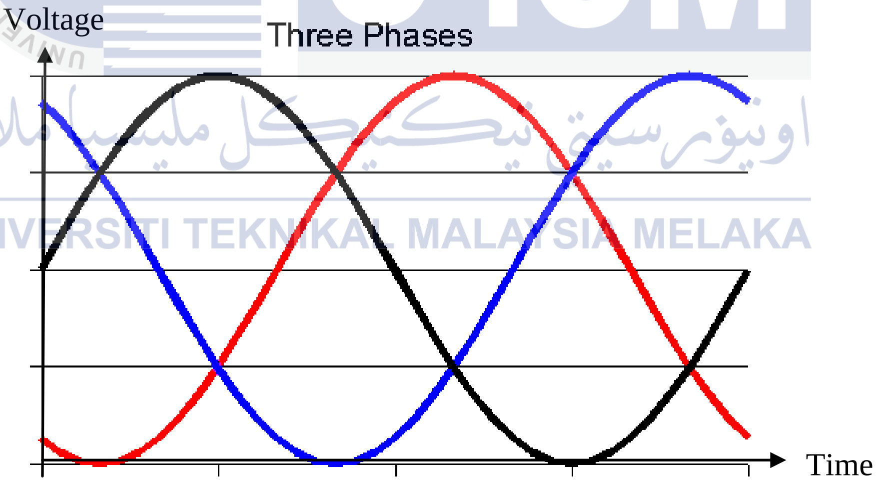

Figure 3.2: The three phase reference frames signal graph

Figure 3.3: The rotating reference (Vd, Vq) frame signal graph

3.1.3 Simulation Of Voltage Dip Mitigation

The simulation is tested by using PSCAD software. The simulation can be divided into two part which are simulation without voltage dip and simulation with voltage dip.

a) Simulation Without Voltage Dip

The simulation without voltage dip will be designed as Figure 3.4. The system without voltage dip is consists of power supply with source impedance, Zs (represents load generator), line impedance, Z_L (represents load transmission system) and load impedance, Z_{Load} (represents load distribution system).

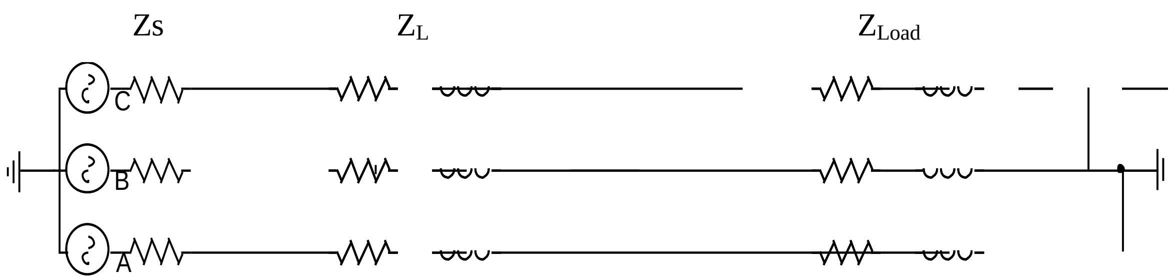

Figure 3.4: System without voltage dip

Next is the design of the DQ transformation block. The function of DQ transformation block is to transform the three phase signal into DQ signal. The DQ transformation is placed on the distribution system. The line voltage which is in three phase state that are produced from transmission system will be transformed into DQ signal by using DQ transformation. The DQ transformation block is designed based on Clark's and Park's transformation.

Clark's transformation block is designed in PSCAD based on the Equation 2.3, 2.4 and 2.5. The use of Clark's transformation is to transform signal Va, Vb and Vc into signal Vo, Vα and V_{β}. The block to obtained Vo is as Figure 3.5. The block to obtained Vα is as Figure 3.6. The block to obtained V_{β} is as Figure 3.7.

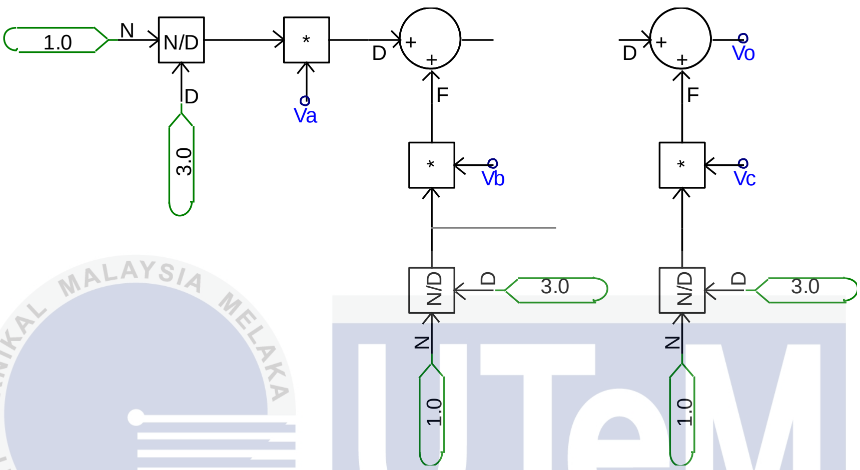

Figure 3.5: Vo block

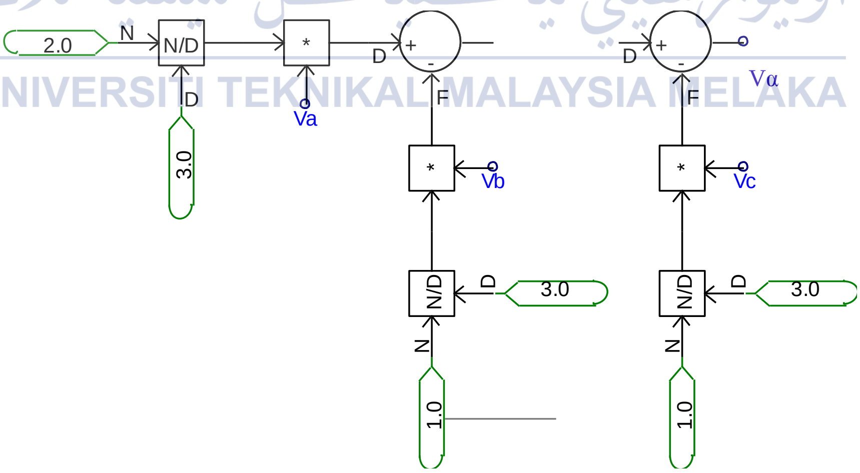

Figure 3.6: Vα block

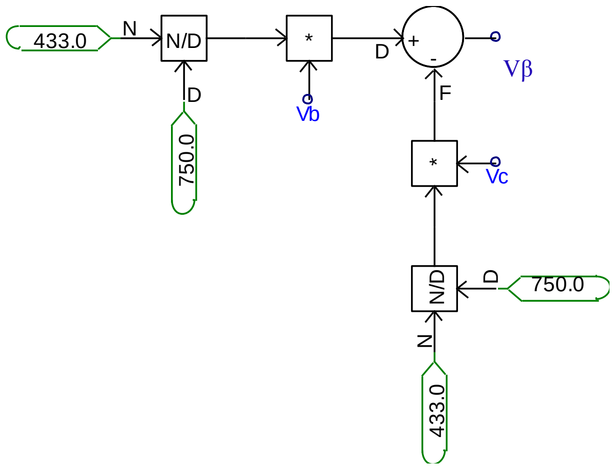

Figure 3.7: V_β block

Park's transformation block is designed in PSCAD based on the Equation 2.11 and 2.12. The use of Park's transformation is to transform signal Vα and V_β into signal Vd and Vq. The circuit to obtained Vd is as Figure 3.8. The circuit to obtained Vq is as Figure 3.9.

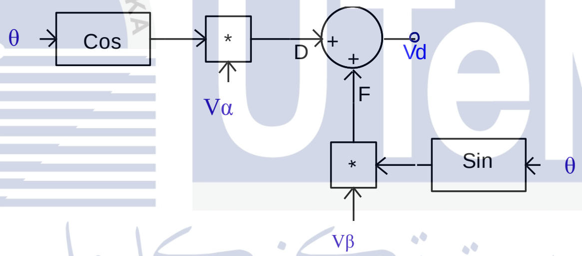

Figure 3.8: Vd block

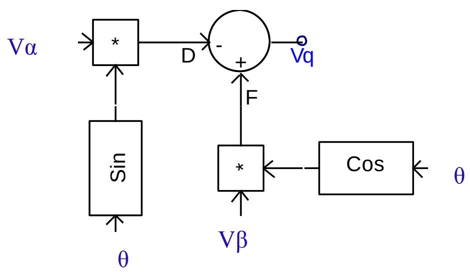

Figure 3.9: Vq block

Park's transformation block require angle between Va, Vb and Vc. To get the angle θ between Va, Vb and Vc, the PLL block is designed as Figure 3.10.

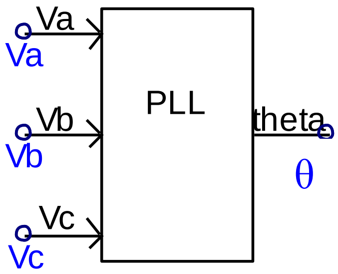

Figure 3.10: PLL block

The line voltage DQ component will be compared with reference voltage. If there is difference between these two signals, therefore the system is experience fault. The amount of difference between these two signals is called as error line voltage.

The error line voltage will tell the amount of voltage that should be mitigating in line voltage. The error line voltage will be transformed into reactive current by using external current source. However, the error line voltage should be constant, which mean no transient response. The reason is to minimize the distortion of reactive current. The distortion from reactive current will create distortion in the system during process of mitigating line voltage. Therefore, the controller is needed to make error line voltage to be constant. The controller chosen for this simulation is PI controller. The function of PI controller is to increase the speed of the response and also to eliminate the steady state error. The error line voltage produced will be processed in PI controller as Figure 3.11.

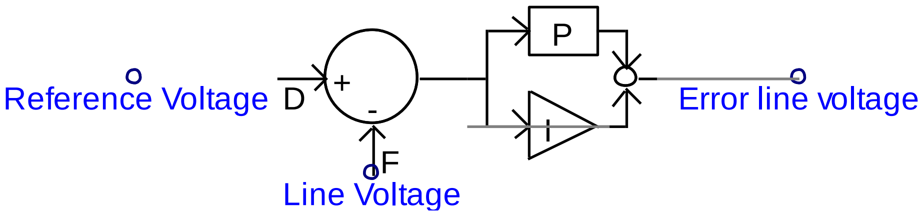

Figure 3.11: PI controller

The error line voltage produced from PI controller is in DQ component form. However, the voltage and reactive current that needed in process of mitigating voltage dip is require in three phase form signal. Therefore, the error line voltage produced from PI controller which is in DQ form signal will be transformed into three phase signal, by using inverse DQ controller. The inverse DQ controller is designed based on inverse Park's transform and inverse Clark's transform.

Inverse Park's transformation block is designed in PSCAD based on the Equation 2.6, 2.7 and 2.8. The inverse Park's transformation has transform transforms Vd and Vq into Vα and V_β. The block to obtained Vα is as Figure 3.12. The block to obtained V_β is as Figure 3.13.

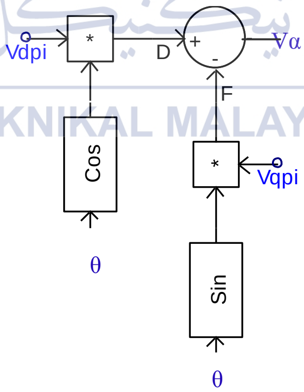

Figure 3.12: Vα block

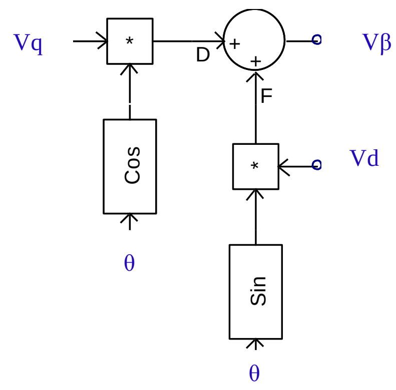

Figure 3.13: V_β block

Inverse Clark's transformation block is designed in PSCAD based on the Equation 2.13 and 2.14. The inverse Clark's transformation has transform Vα and V_β signal into Va, Vb and Vc. The block to obtained Va is as Figure 3.14. The block to obtained Vb is as Figure 3.15. The block to obtained Vc is as Figure 3.16.

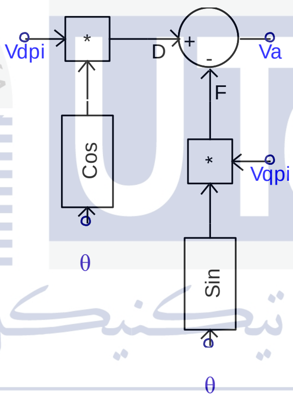

Figure 3.14: Va block

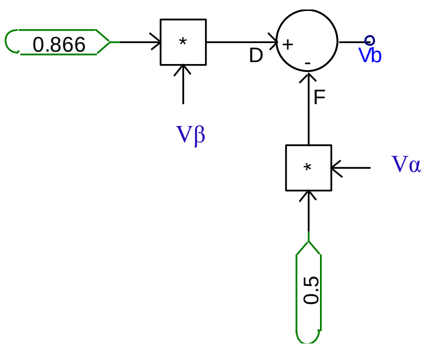

Figure 3.15: Vb block

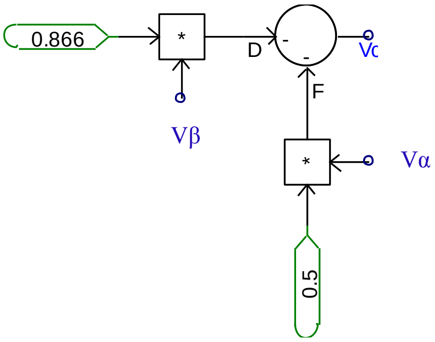

Figure 3.16: Vc block

b) Simulation With Voltage Dip

The simulation with voltage dip will be designed as Figure 3.17. This simulation is same with simulation without voltage dip. The difference is, in simulation with voltage dip, the fault is installed. The fault is installed to create voltage dip. Fault could result from three places which is generator, transmission system and distribution system. Voltage dip is more likely to happen on distribution system. Fault can be categorized into three types which is ground-to-ground fault, single line to ground fault and line-to-line fault. The majority type of fault happen is single line to ground fault. Therefore, in simulation, fault will be placed on distribution system as single line to ground fault. The fault impedance will be adjusted until the amount of voltage dip in line voltage is 10% from line voltage.

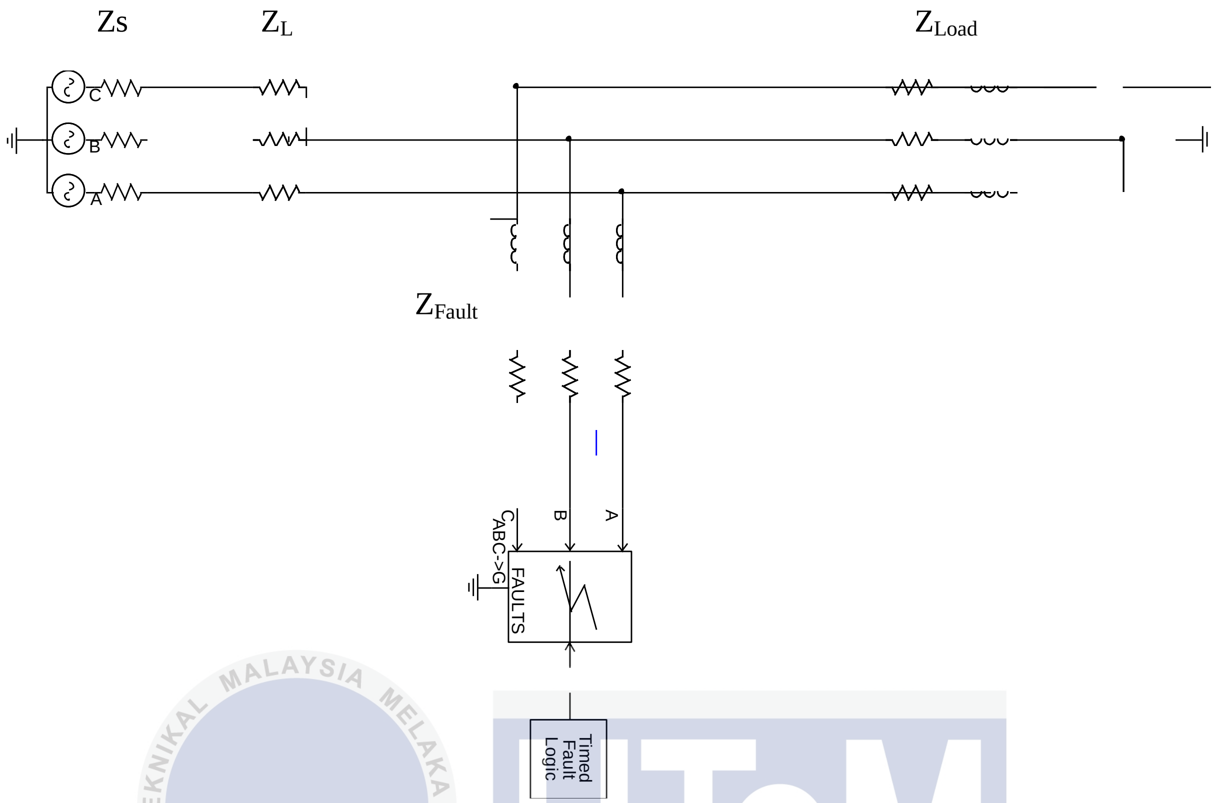

Figure 3.17: Simulation with voltage dip

To mitigate the voltage dip, the reactive current will be injected into the system as Figure 3.18. The error line voltage will be injected into external current source to produce reactive current. The reactive current will be injected into distribution system to mitigate line voltage until the line voltage is same level as the line voltage before voltage dip happen. As error line voltage only exist when voltage dip is happen, the reactive current is injected only when the voltage dip is happen in the power system.

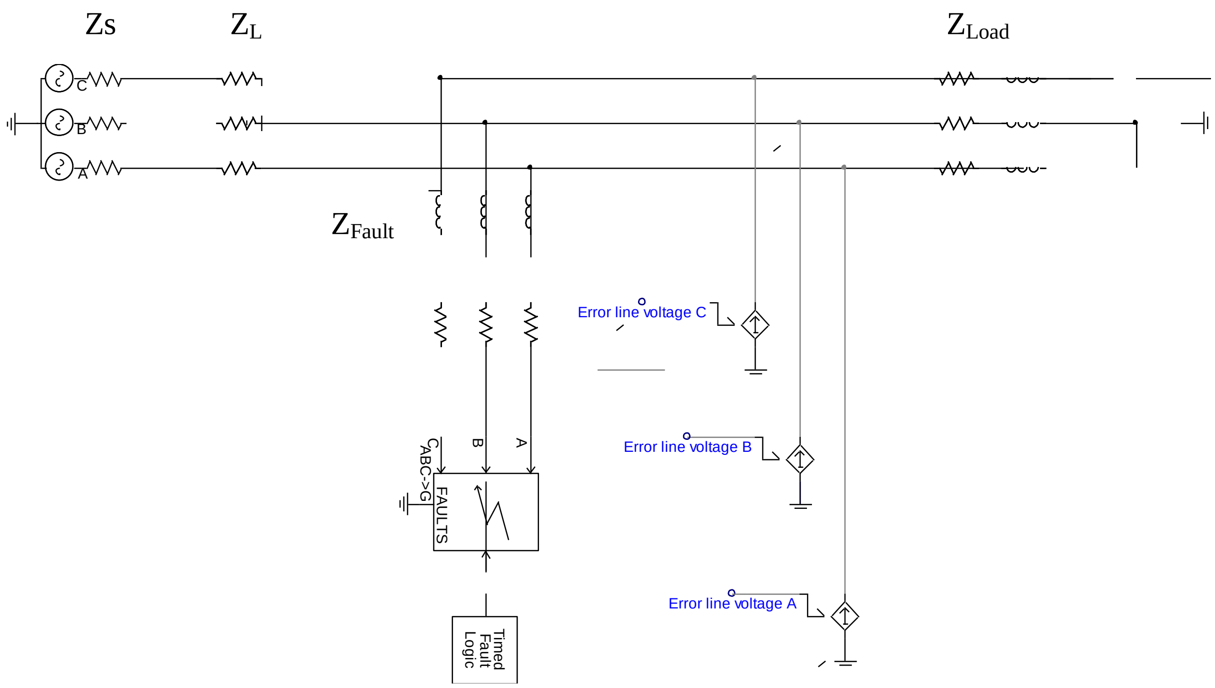

Figure 3.18: Reactive current injected

The system parameters used in the simulation are presented in Table 3.1.

Table 3.1 System parameters used in the simulation model

Va = Vb = Vc = 240V	Z_{Fault} = 17 + j0.3
Zs = 1Ω	f = 50 Hz
Z_L = 1Ω	Kp = 0.001
Z_{Load} = 1Ω	Ki = 20

CHAPTER 4

RESULTS AND DISCUSSION

This chapter discuss the results obtained from the PSCAD software. Since the objective of the project is to mitigate voltage dip, the results will show the voltage mitigation.

4.1 SIMULATION RESULTS

The simulation test is planned to represent the capability of the reactive power compensation in order to mitigate voltage dip. The base quantities, the impedance of source, transmission line and load, the DQ component conversion parameters as well as their controller of the test system are showed in the Chapter 3.

4.1.1 PROCESS TIMELINE

The result will be produced based on the process timeline diagram in Figure 4.1:

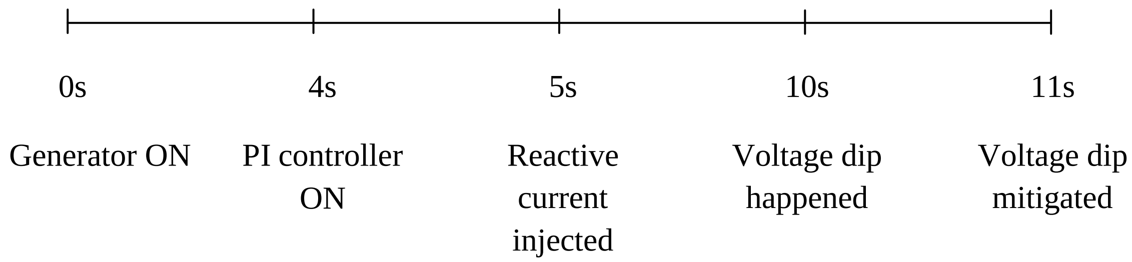

Figure 4.1: Process timeline diagram

a) Generator ON

The generator will be ON at 0s.At this point; the test system has not experience voltage dip yet. The simulation result on line voltage of three phase component is as Figure 4.1 and line voltage of DQ component is as Figure 4.2. The settling time of line voltage for three phase component and DQ component is recorded in Table 4.1. Based on the Table 4.1, the settling time for line voltage of DQ component is longer compare to line voltage for three phase component. This is because of the conversion from three phase component into DQ component is takes time. Therefore the time for line voltage of DQ component to be stable will be affected.

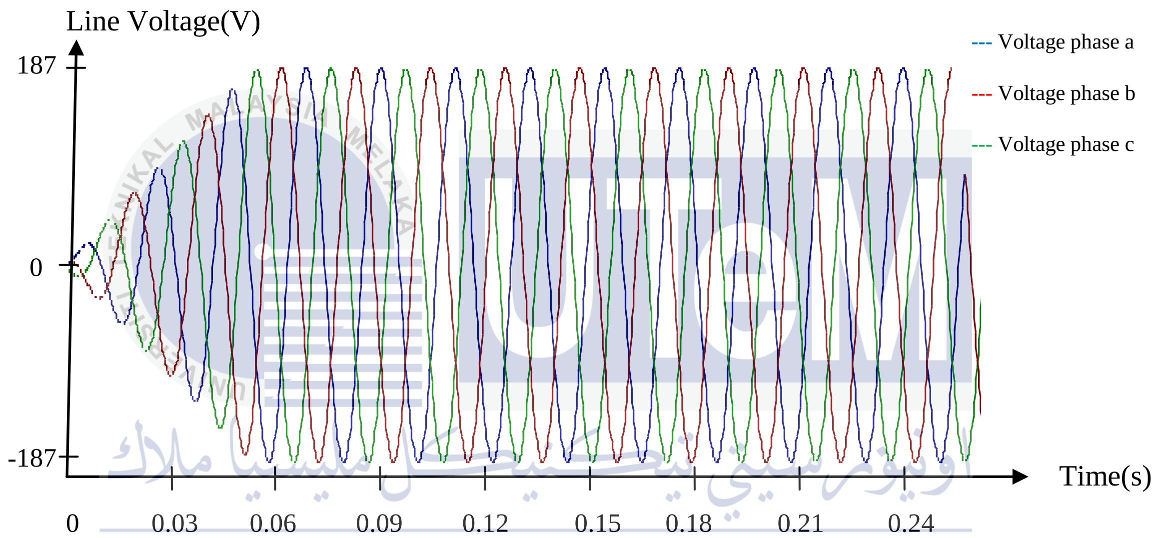

Figure 4.1: Line voltage of three phase component

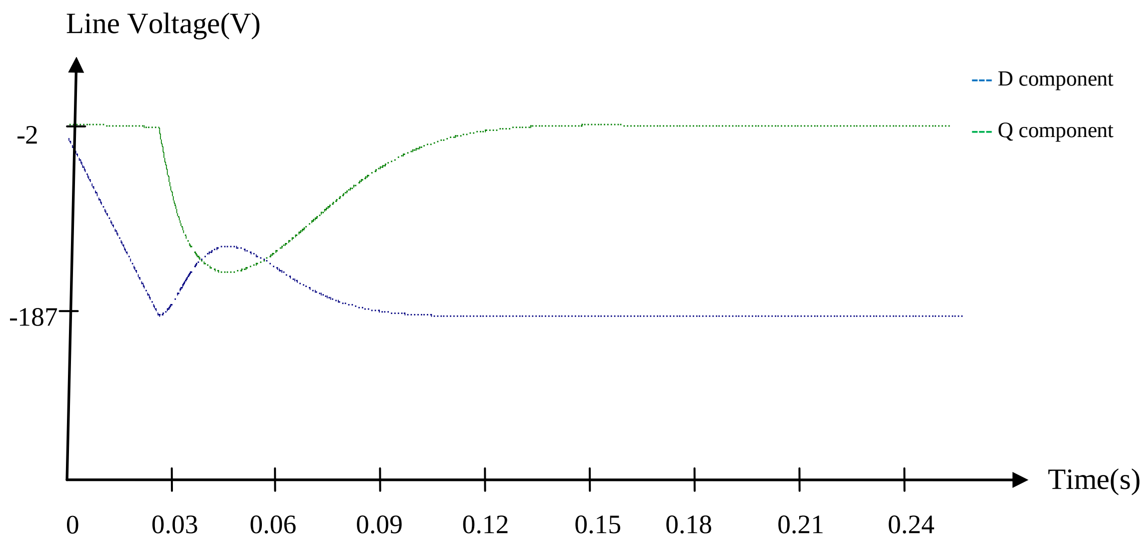

Figure 4.2: Line voltage of DQ component

Table 4.1: Settling time of line voltage

	Settling time(s)
Line voltage for three phase component	0.06
Line voltage for DQ component	0.37

b) PI Controller ON

To ensure the power system produce signal with good performance, the PI controller is activated in simulation. The PI controller is activated at error line voltage. Figure 4.3 shows the transient response of error voltage without and with PI controller. Figure 4.4 shows the steady state response of error voltage without and with PI controller. From Figure 4.3 and Figure 4.4, there is significant difference between error line voltage without PI controller and with PI controller. The difference is recorded in Table 4.2. From Table 4.2, it can be concluded that PI controller can remove overshoot, reduce settling time and remove steady state error.

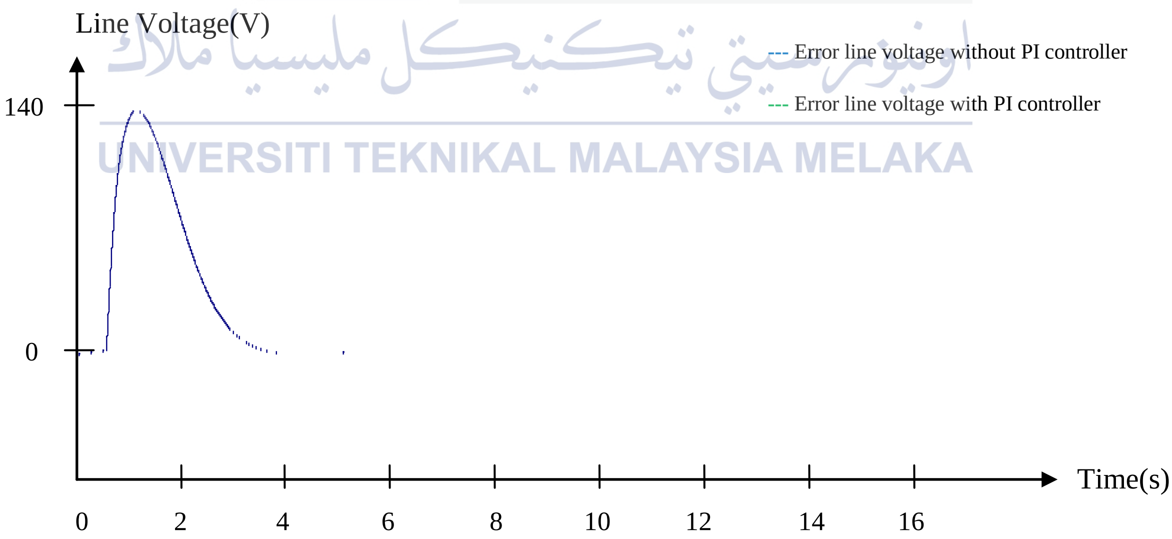

Figure 4.3: Error voltage without and with PI controller

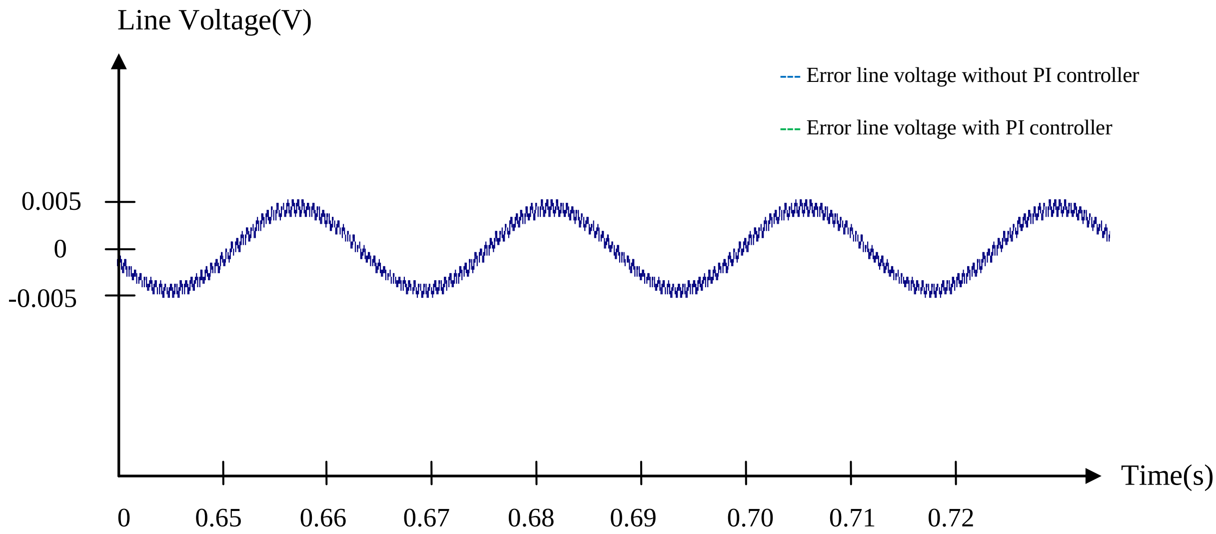

Figure 4.4: Steady state response

Table 4.2: Difference between error voltage without and with PI controller

	Overshoot(%)	Settling time(s)	Steady state error(V)
Error voltage without PI controller	5 723	0.40	0.01
Error voltage with PI controller	0	0.00	0.00

To activated PI controller, the signal should in stable state. The reason is if the PI controller is activated before the signal is stable, the error of signal will be enlarged. This has been proved as shown in Figure 4.5 and Figure 4.6. The signal is stable at 0.06s as shown in Figure 4.7. The percentage of error of line voltage is recorded in Table 4.3. Based on the Table 4.3, the error of line voltage when PI controller is activated before signal is stable is larger compare to error of line voltage when PI controller is activated after signal is stable.

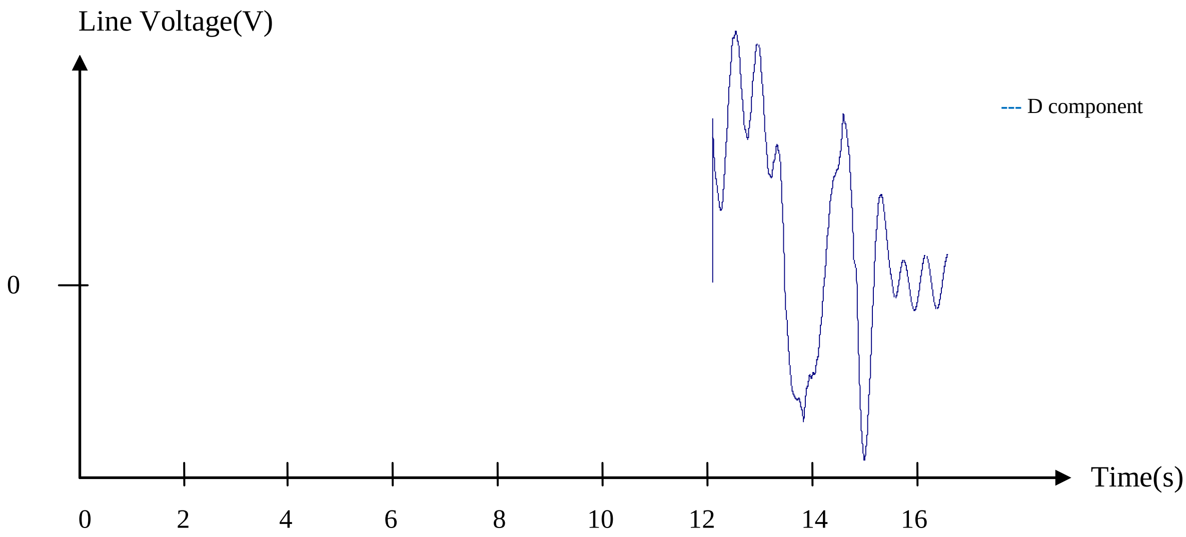

Figure 4.5: Line voltage when PI controller is activated before signal is stable

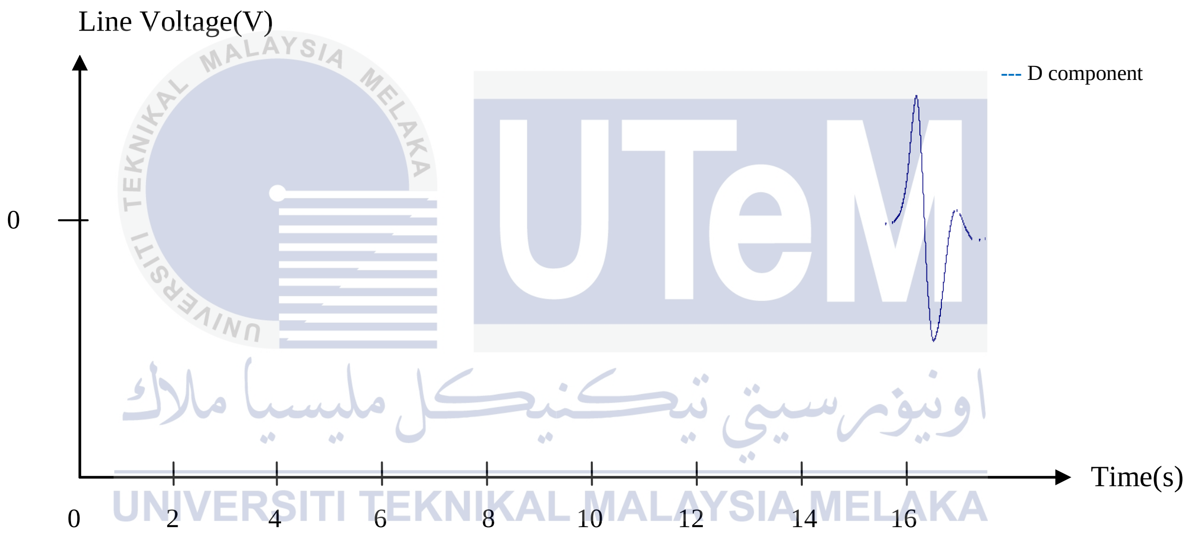

Figure 4.6: Line voltage when PI controller is activated after signal is stable

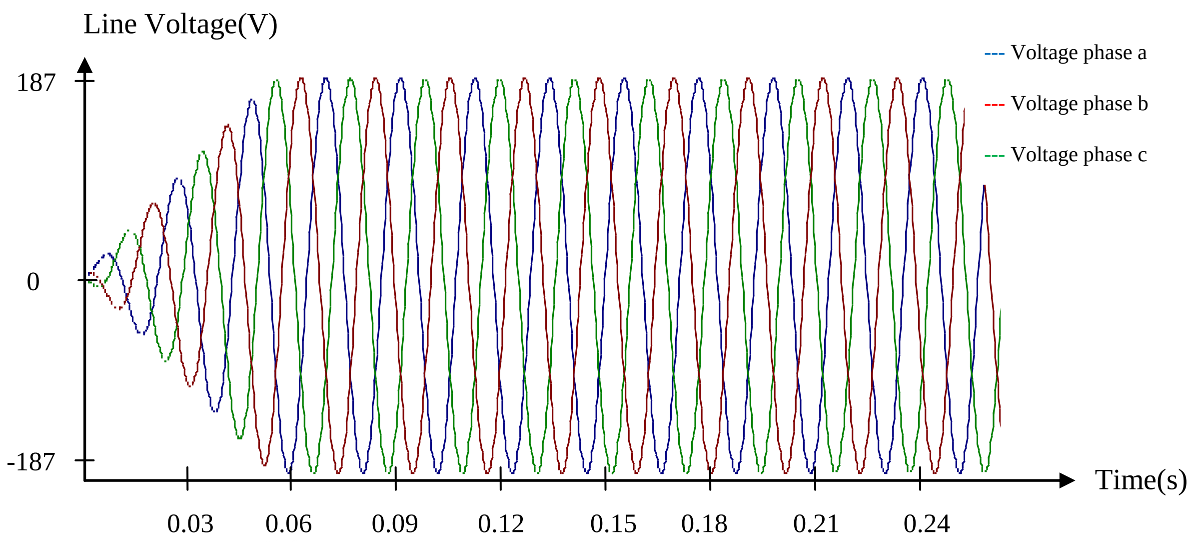

Figure 4.7: The signal is start to stable at 4s

Table 4.3: Percentage of error of line voltage

	Percentage of error line voltage (%)
Line voltage when PI controller is activated before signal is stable	77
Line voltage when PI controller is activated after signal is stable	33

c) Reactive Current Injected

Now the error line voltage is clean from overshoot. So the amount of error line voltage is suitable to be injected into external current source. The external current source will transform error line voltage into reactive current. From Figure 4.8, at 0s to 10s, the no reactive current is injected into the system because at this point, no voltage dip is happen. At 10s to 10.05s, the reactive current is injected into the system because at this point, voltage dip is happen. Reactive current will mitigate the voltage dip.

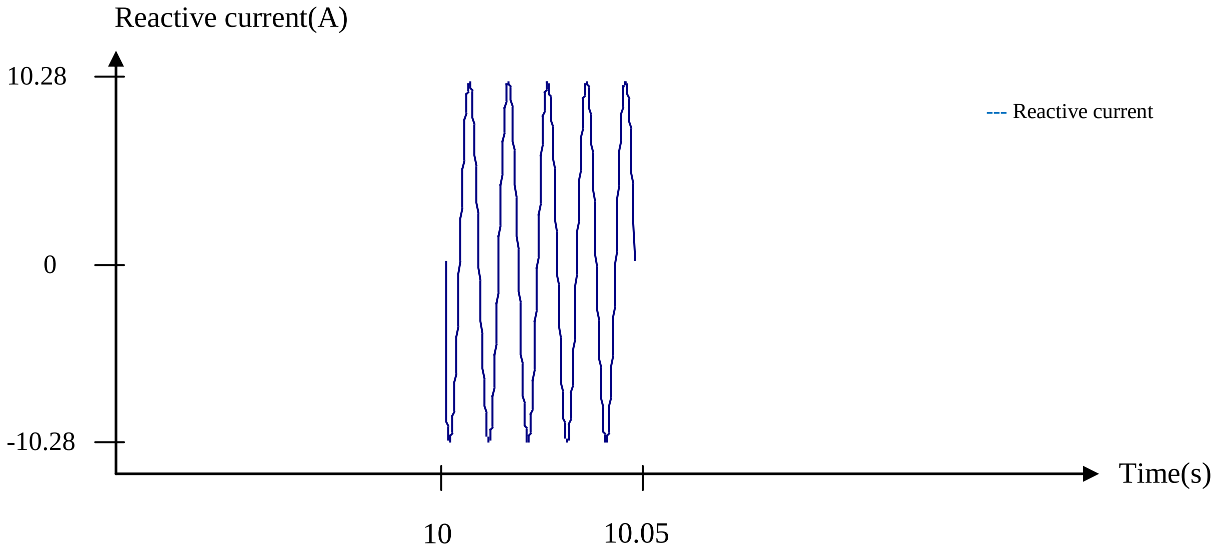

Figure 4.8: Reactive current injected into the system

d) Voltage Dip Happened

The fault is introduced at 10s until 10.05s. As shown in Figure 4.9 and Figure 4.10, there is decreasing of voltage at 10s until 10.05s. The decreasing of voltage is voltage dip.

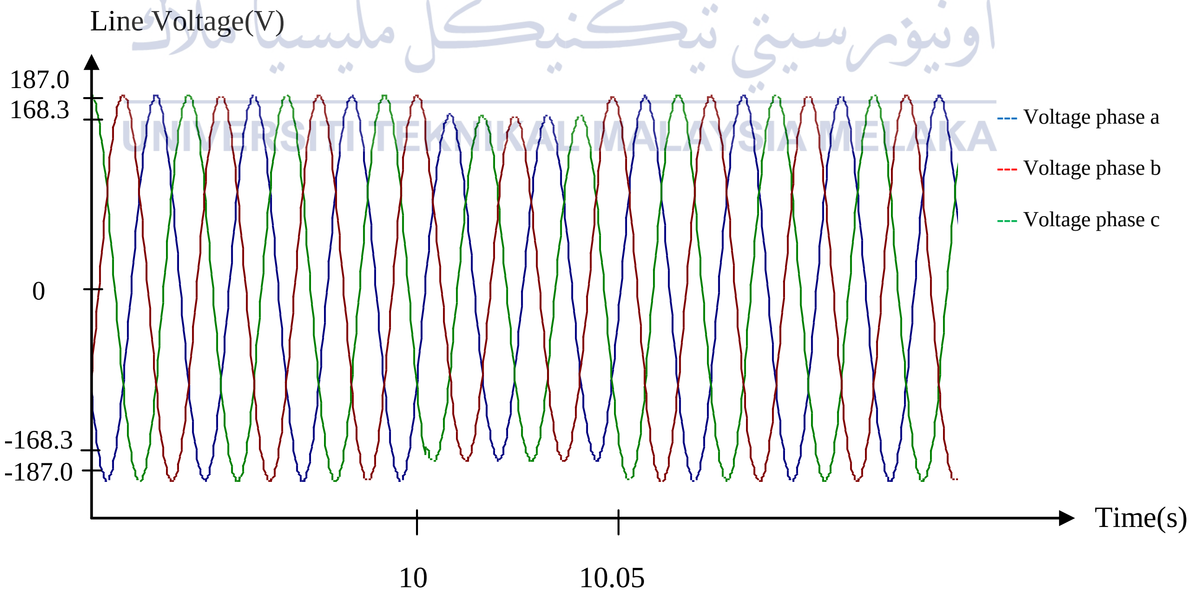

Figure 4.9: Line voltage in three phase component with voltage dip

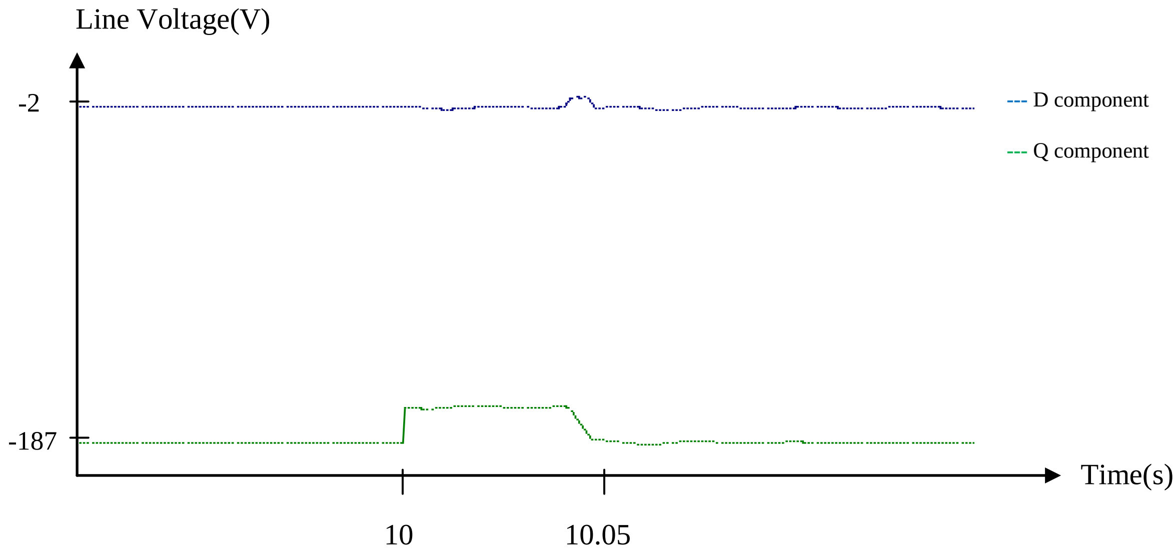

Figure 4.10: Line voltage in DQ component with voltage dip

e) Voltage Dip Mitigated

As voltage dip is happen at 10s, the error voltage produced between line voltage and reference voltage will be processed to produce reactive current. The reactive current is injected at 10s into the system to compensate the voltage dip. From Figure 4.11, Figure 4.12 and Figure 4.13, there is distortion at the point of increasing voltage and decreasing of voltage before the line voltage is stable. This is happen because of two reasons. First is because during the system is receiving reactive current, the line voltage needs time to stable when increasing and decreasing. Secondly is because the accumulation of significant figure between line voltage and reference voltage.

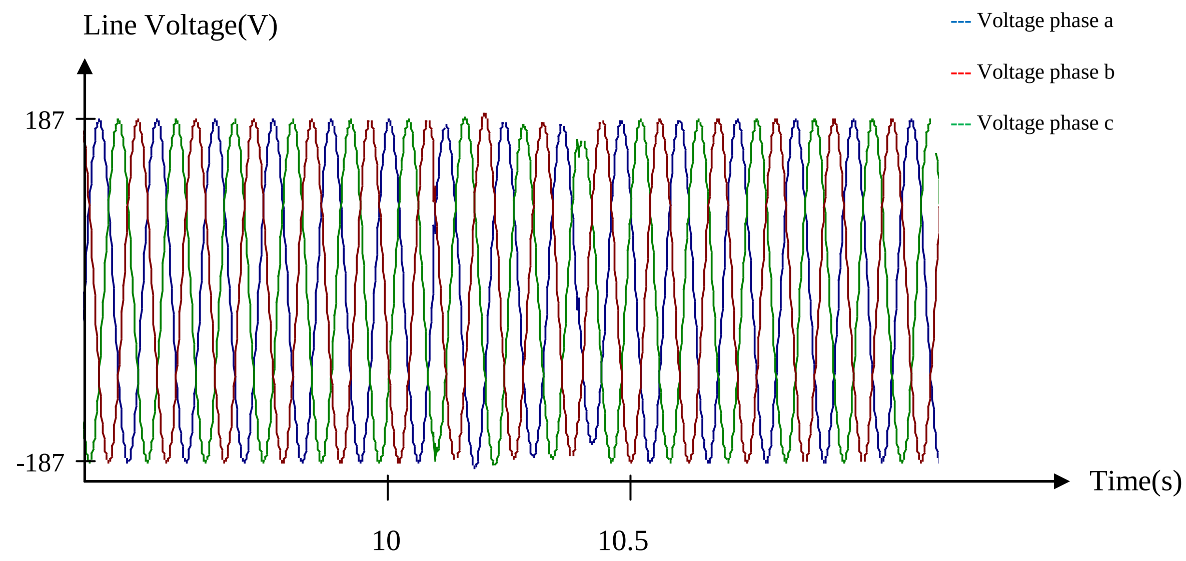

Figure 4.11: Line voltage in three phase form after compensation

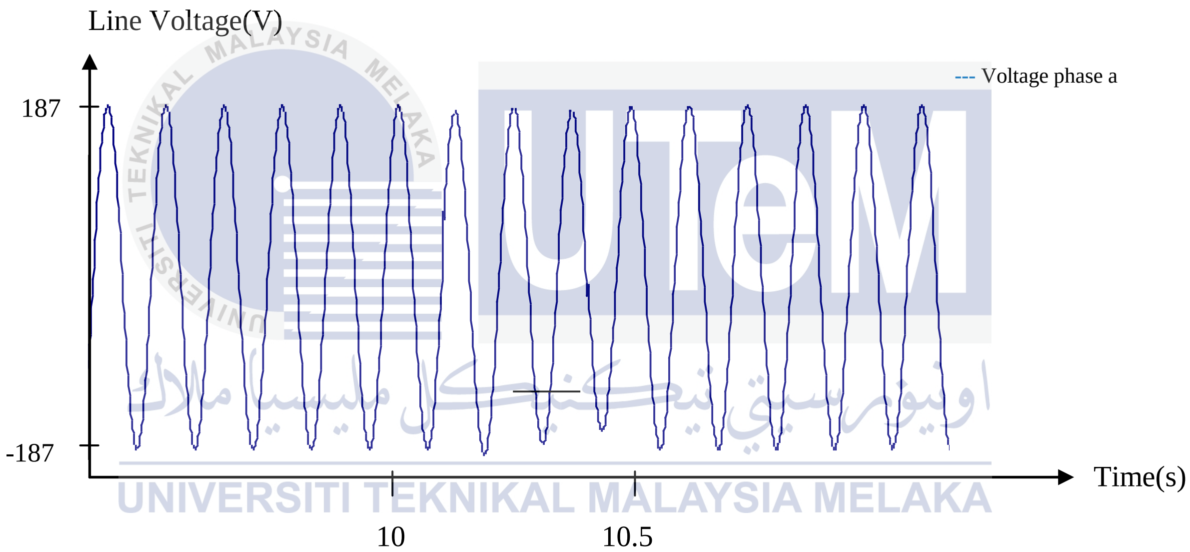

Figure 4.12: Line voltage phase a after compensation

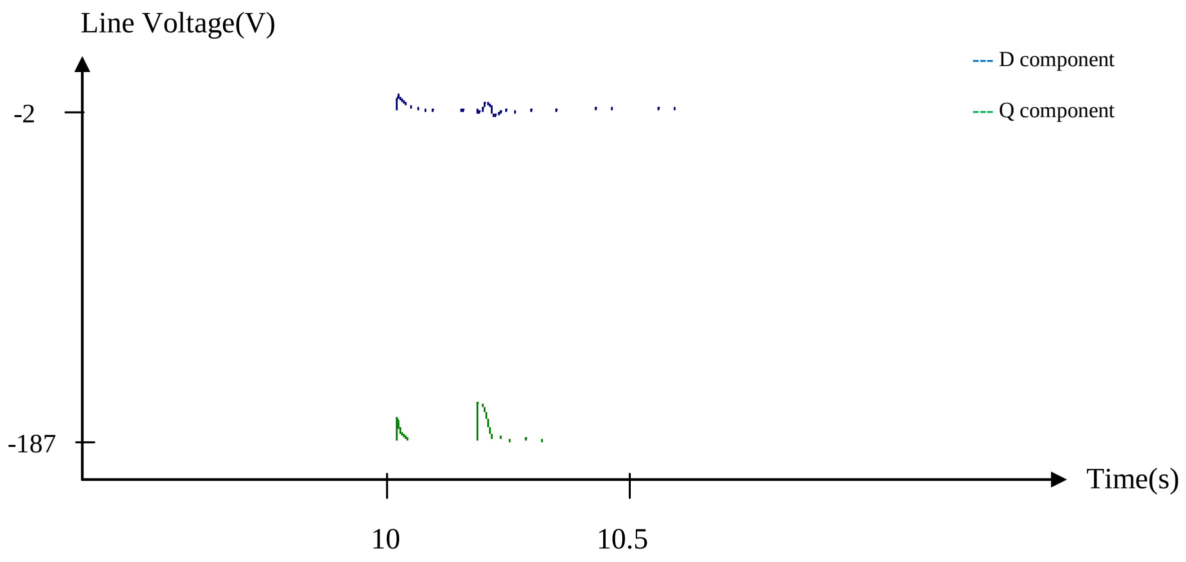

Figure 4.13: Line voltage in DQ form after compensation

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

One of the objectives of this project is to design a method of mitigating power line voltage dip by using current and voltage DQ component through transforming three phase reference frames to rotating reference frame. The current and voltage is transforming into DQ component by using DQ transformation block. The DQ transformation block is designed based on the theory of Clarke's and Park's transform.

The DQ components are processed through PI controller. The PI controller will process error line voltage and injected it into shunt external current source to produce reactive current. However, the error line voltage cannot be injected into shunt external current source in DQ form, because the line voltage in the system is in three phase form. Therefore, the DQ components will be transforming back into three phase signal. Now the three phase error line voltage can be injected into shunt external current source. The shunt external current source will transform the error line voltage into reactive current. The reactive current is injected into simulation test to mitigate the voltage dip. All of this process will be simulated in PSCAD software.

In order to analyze the performance of voltage and current during voltage dip duration, two stage of analysis model will be built which is simulation without voltage dip and simulation with voltage dip. The analysis process has been processed in PSCAD software. The characteristic of error signal is studied based on the data analyzed.

5.2 RECOMMENDATION

There are several suggestions for future work of this project. One of it is to get the best solution for mitigating voltage dip; the method of the mitigating voltage dip from this project can be compared to another method.

Besides that, people can further this project by study on how to minimize or remove the distortion at the line voltage after compensation.

Last but not least, the proposed method from this project should be better evaluated by connecting it into more realistic network which the voltage dip can be simulate more accurately.

REFERENCES

[1] B.H. Chowdhury, "Power Quality", *EEQPRC Endeavour Energy Power Quality & Reliability Centre*, 2001.

[2] E. Grebe Thomas, "Application of Distribution System Capacitor Banks And Their Impact On Power Quality", *IEEE Transactions on Industry Application*, Vol. 3, pp. 714-719, 1996.

[3] Derek Maule, "Voltage Dips Mitigation", *Claude Lyons Ltd*, 2001.

[4] Massimo Bongiorno, "Control Of Voltage Source Converters For Voltage Dip Mitigation In Shunt And Series Configurations", *Chalmers Bibliotek*, 2004.

[5] Sun Dan, "Clarke's And Park's Transformations", *College of Electrical Engineering, Zhejiang University*, 2008.

[6] E. Acha, "Modelling And Analysis Of Custom Power Systems By PSCAD/EMTDC", *IEEE Transactions on Power Delivery*, Vol. 17, pp. 266 - 272 2002.

[7] Mohamed Fuad Faisal, "Voltage Sag Solutions For Industrial Customer", *Tenaga Nasional Berhad*, 2007.

[8] Paolo Cilona, "Modelling And Analysis Of Shunt-Connected Voltage Source Converter For Voltage Dip Mitigation", *Chalmers University of Technology, Sweden*, 2010.

[9] Guan-Chyun Hsieh, "Phase-Locked Loop Techniques. A survey", *IEEE Transactions on Industrial Electronics*, Vol. 43, pp. 609-615, 1996.

[10] P. Santiprapan, K-L. Areerak and K-N. Areerak, "Mathematical Model And Control Strategy On DQ Frame For Shunt Active Power Filters", World Academy of Science, Engineering and Technology, 2011.

[11] Sujitjorn, S., Areerak, K.-L. and Kulworawanichpong, T., "The DQ Axis With Fourier (DQF) Method For Harmonic Identification", *IEEE Transactions on Power Delivery*, Vol. 22, pp. 737 - 739, 2007.

[12] A.Mahyavanshi, M. A. Mulla, R. Chudamani, "Reactive Power Compensation By Controlling The DSTATCOM", *International Journal of Emerging Technology and Advanced Engineering*, Vol. 2, pp. 212-218, 2012.

[13] B. Singh, S. Kumar, "Modified Power Balance Theory For Control Of DSTATCOM", International Conference on Power Electronic Drives and Energy

Systems for Industrial Growth - PEDES , 2010.

[14] V. Krishnan, “An Enhancement Method For The Compensation Voltage Sag/Swell And Harmonics By Dynamic Voltage Restorer”, *International Journal of Modern Engineering Research (IJMER)*, Vol. 2, pp. 475-478, 2012.

[15] A. Ramasamy, K. I. Rengan,V. K. Ramachandaramurthy, “Dynamic Voltage Restorer For Voltage Sag Compensation”, *International Conference on Power Electronic Drives and Energy Systems - PEDES* , Vol. 2, pp. 1289 - 1294, 2005.