“ I hereby declare that I have read through this report entitle “Simulation And Experiment Development For 3-Phase Voltage Dip Mitigation Using D-Q Controller” 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 : ....

Date : ....

SIMULATION AND EXPERIMENT DEVELOPMENT FOR 3-PHASE VOLTAGE DIP MITIGATION USING D-Q CONTROLLER

AHMAD ARIF BIN AHMAD FAUZI

This Report is Submitted in Partial Fulfillment of Requirements for the Degree of Bachelor in Electrical Engineering (Control, Instrumentation and Automation)

Faculty of Electrical Engineering
UNIVERSITI TEKNIKAL MALAYSIA MELAKA

June 2015

I declare that this report entitle "Simulation And Experiment Development For 3-Phase Voltage Dip Mitigation Using D-Q Controller" 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 : 'Arif

Name : Ahmad 'Arif Bin Ahmad Fauzi

Date : 23 June 2015

To my beloved mother and father

ACKNOWLEDGEMENT

I would like to express my deepest appreciation to all those who provided me the possibility to complete this report. A special gratitude to my supervisor Encik Mohamed Azmi bin Said, whose contribution in stimulating suggestions and encouragement, helped me to coordinate my project.

Furthermore, I would like to acknowledge to the FKE's staff who gave the permission to use all required components to complete the project "Simulation and Experiment Development for 3-Phase Voltage Dip Mitigation using D-Q Controller".

Last but not least, many thanks go to the head of the final year project whose have invested his full effort in guiding the team in achieving the goal. I have to appreciate the guidance given by other supervisors as well as panels especially in our project presentation that has improved our presentation skills and also big thanks on their comments and advices.

ABSTRACT

There are few problems in power quality system that need to be considered in order to ensure a good power supply system. One of the major power quality problem that is commonly occur is voltage dip as well known as short reduction of voltage in a period of time. The concern about the damage of the highly sensitive equipment led to the improvement to mitigate the voltage dip since not all equipment can stand sudden fluctuation of voltage flow. The objectives of this research are to develope a control system, simulate and experiment the designed circuit via PSCAD software to perform voltage dip mitigation process using D-Q controller. This research is implemented one of the method to mitigate the voltage which is by using mitigation devices. The simulation of the voltage dip mitigation are conducted for three phase line voltage which is then transformed into DQ signal. The system is set to 10% fault which represented the maximum value of the error that can be fixed. Then the reactive current is injected into the system to compensate the voltage dip. Based on the result obtained, the reactive current injected can mitigate the voltage dip. From simulation, voltage dip is set to occurred at time of 2s to 3s as the PI controller is switched on. The voltage supply is decresed from 0.7071 kV to 0.6364 kV. After that, the reactive current is injected and resulted to a phase shift of 0.1% and remain the line voltage back to 0.7071 kV. Besides, the transient analysis showed that D component exhibited higher overshoot value and longer settling time in comparison to the Q component after compensation. However, both D and Q component indicated the same value of steady state error. In conclusion, the overall performance of the designed control system in this study shows an improvement of the voltage dip mitigation.

ABSTRAK

Terdapat beberapa masalah dalam sistem kualiti kuasa yang perlu diambil berat untuk memastikan sistem bekalan kuasa berjalan dengan baik. Salah satu masalah besar yang biasa berlaku dalam sistem kualiti kuasa ialah penurunan voltan atau juga dikenali sebagai pengurangan singkat dalam satu masa. Keprihatinan terhadap kerosakan peralatan yang sangat sensitif membawa kepada penambahbaikan dalam mengatasi masalah penurunan voltan kerana tidak semua peralatan dapat menerima turun naik voltan yang mendadak. Kajian ini bertujuan untuk membina satu sistem kawalan, simulasi, dan uji kaji terhadap litar yang direka menggunakan perisian PSCAD untuk mengatasi masalah penurunan voltan menggunakan pengawal D-Q. Kajian ini menggunakan salah satu kaedah untuk mengatasi masalah penurunan voltan iaitu dengan menggunakan peralatan. Simulasi ini telah dijalankan terhadap voltan tiga fasa dimana kemudiannya ditukar kepada signal D-Q. Di dalam sistem ini, kecacatan sebanyak 10% telah ditetapkan selaku nilai maksimum yang boleh ditangani. Kemudian, *reactive current* telah disuntik ke dalam sistem untuk menyeimbangkan masalah penurunan voltan. Berdasarkan keputusan yang diperolehi, *reactive current* yang disuntik dapat mengatasi masalah penurunan voltan. Daripada simulasi, masalah penurunan voltan berlaku pada masa 2 saat ke 3 saat sebaik sahaja PI controller dihidupkan. Bekalan voltan telah menurun daripada 0.7071 kV kepada 0.6364 kV. Selepas itu, *reactive current* telah disuntik dan mengakibatkan perubahan fasa sebanyak 0.1% seterusnya voltan kembali kepada 0.7071 kV seperti asal. Selain itu, analisa *transient* menunjukkan bahawa komponen D menghasilkan nilai *overshoot* yang lebih tinggi dan *settling time* yang lebih panjang berbanding komponen Q setelah peyeimbangan berlaku. Bagaimanapun, nilai bagi *steady state error* adalah sama untu kedua-dua komponen. Sebagai konklusi, prestasi keseluruhan sistem kawalan yang telah direka dalam kajian ini menunjukkan penambahbaikan dalam mengatasi masalah penurunan voltan.

TABLE OF CONTENTS

LIST OF FIGURE

LIST OF TABLES

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Motivation

Large consumption of electrical power such as in industries are concern about the power quality problems. Generally, the common power quality problems that occurs are voltage swell, interruptions, and voltage dip. The most frequent disturbance that occured is voltage dip and it is considered as the most serious problem compared to other power quality problems. Voltage dip or also known as voltage dip is a short reduction of voltage in a period of time. In order to overcome the problem, most of the high technology industries prefer to implement advanced technology system including the sensitive equipments to apply energy saving concept. However, not all of the sensitive equipments can withstand sudden fluctuation such as voltage dip phenomenon. Thus, the equipments will be malfunction as the voltage dip occurred and resulted to a significant financial losses. The implications of damage to equipments can cause the production process had to terminated. As the example, USA experienced losses over $20 annually due to voltage dip problem. Therefore, it is important to find the solution to mitigate voltage dip problem to increase the productivity, economy and quality in industrial sector.

1.2 Problem Statement

The voltage dip usually occurred in distribution system and transmission line. The trigger that cause voltage dip to happen is the different event that take place in the power system such as transformer energizing, high starting current and sudden high current that led to the ground fault (current leakage to the earth). As the example, one of the condition that led to the voltage dip to occur in industrial application is a very high current yielded from starting a large motor. Furthermore, Ohm's law have stated that high current is resulted from the reduction of voltage. In this situation, the reduction of voltage is classified as voltage dip.

An ideal power distribution system should ensure that the customers were provided with uninterrupted flow of energy at smooth sinusoidal voltage at the fluctuation of magnitude and frequency. On the other hand, various linear signals which affect the quality of power supply in power system are significant in real life. Therefore, there are quite impossible to avoid the trigger of the voltage dip and it is important to overcome the problem. Thus, power system analysis is required in order to maintain the voltage level.

1.3 Objectives

The objectives of the project is to:

1. Design a method of mitigating power line voltage dip using current and voltage DQ components by tranforming three phase reference frames to rotating reference frames.
2. Simulate the voltage dip mitigation system by using PSCAD software.
3. Analyze the performance of the uncompensated and compensated system by using simulation software (PSCAD, MATLAB, etc).

1.4 Scope of Research

Power quality problems can be defined as the deviation of current or voltage from the ideal waveform. There are many type of problems such as voltage swells, harmonics, flickers, voltage dips, interruptions, transients, waveform distortions, unbalance and frequency deviations. This research conducted are only focusing on voltage dip problem.

Three phase system consist of two type which are balanced and unbalanced system. The research is conducted using balanced three phase system to test the voltage dip problem.

In this research, DQ transformation method was selected among other method to analyze and simplify three phase system.

One of the solution to mitigate voltage dip is by injecting reactive power into transmission line. Among other several methods to inject reactive power into transmission line, controlling shunt current DQ component is proposed. To control shunt current DQ component, current source is used as the custom power devices. This research is conducted to mitigate voltage dip by injecting shunt current source.

Furthermore, this researh also applying SVPWM and inverter in the control system which perhaps could give a better result in comparison with the other method used.

The research included the experiment using simulation to design a controller to mitigate voltage dip of maximum 10%.

CHAPTER 2

LITERATURE REVIEW

2.1 Voltage Dip

High power quality system with 100% reliability is the ability of the electrical system to deliver a clean signal without interruptions [1]. Control system consist of generator, transmission line and distribution line as ilustrated in Figure 2.1. In closed loop control system, the sensor can detect the amount of output signal which is not equal to the desired output signal when the plant experience fault. Then the comparison between the output signal and the reference signal is made using the controller. Next, the controller processed the signal and compensate the signals.

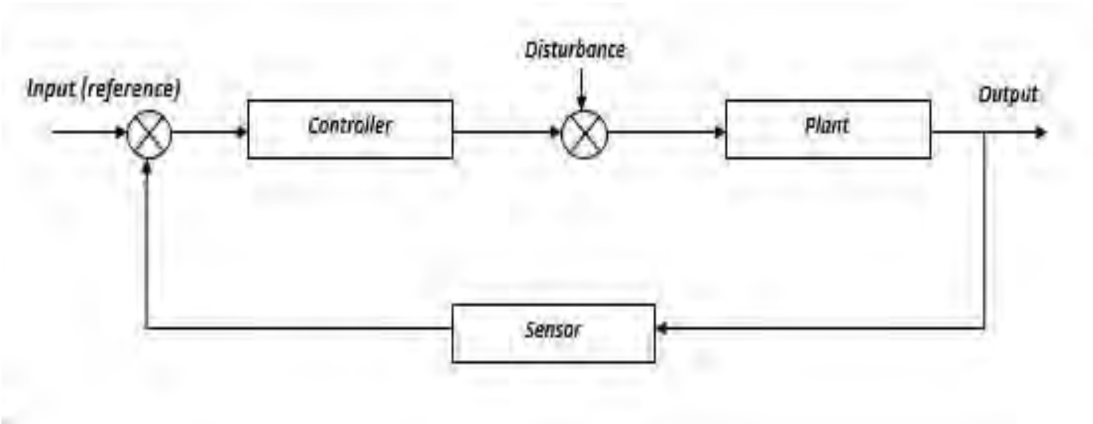

Figure 2.1 : Basic closed loop control system

However, a poor power quality in electrical equipments may resulted in degradation or impairment [2]. Ideally, power distribution system should ensure that the customers were provided with uninterrupted flow of energy at smooth sinusoidal voltage at the contracted magnitude level and frequency. In contrast, numerous linear signals which affect the quality of power supply in power system are significant in real life [3].

One of the most severe problem that always occur in the distribution system is a reduction of voltage called voltage dip [4]. Therefore, there are quite impossible to avoid the trigger of the voltage dip and it is important to overcome the problem. According to IEEE Std.1159-1995, voltage dip can be defined as the momentarily decrease in the root mean square (RMS) voltage of duration greater than half a cycle and less than one minute with magnitude in the range of 0.1 to 0.9 per unit [5].

A typical voltage dip example measured in three phase system recorded three sinusoidal waveforms correspond to three phase-to-phase instantaneous voltagesas in Figure 2.2. The voltage show a drop in magnitude and then remain to the same magnitude as at the beginning in the third channel [6].

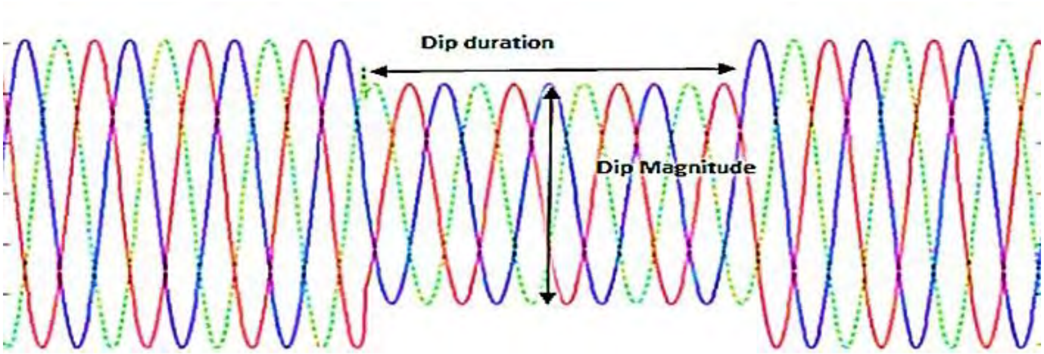

Figure 2.2 : Voltage dip waveform

2.2 Voltage Dip Mitigation

Industrial customer are concern about the short-duration power disturbances such as voltage dips, voltage swells and short interruptions. It is a major problem that may happen due to broad usage of sensitive electronic in automation process even in only few hundred of milliseconds [5]. Thus, power system analysis is required to gain some knowledge in maintaining the voltage level. Voltage dip mitigation are essential to overcome in order to save costs and minimize losses.

The first action that need to be done in order to improve voltage dip problem in industrial plant is determining which process seems to be sensitive to voltage dip and understands the manufacturing process of the product and the operation of the equipment [7]. There are few different solutions to mitigate the voltage dip problem which are by improving the power system, load immunity and the installation of the mitigation devices [5]. There are few different solutions to mitigate the voltage dip problem which are by improving the power system, load immunity and the installation of the mitigation devices [8]. concluded that among all of the method provided, the installation of the mitigation device seems to be the only methods to protect the system against voltage dip.

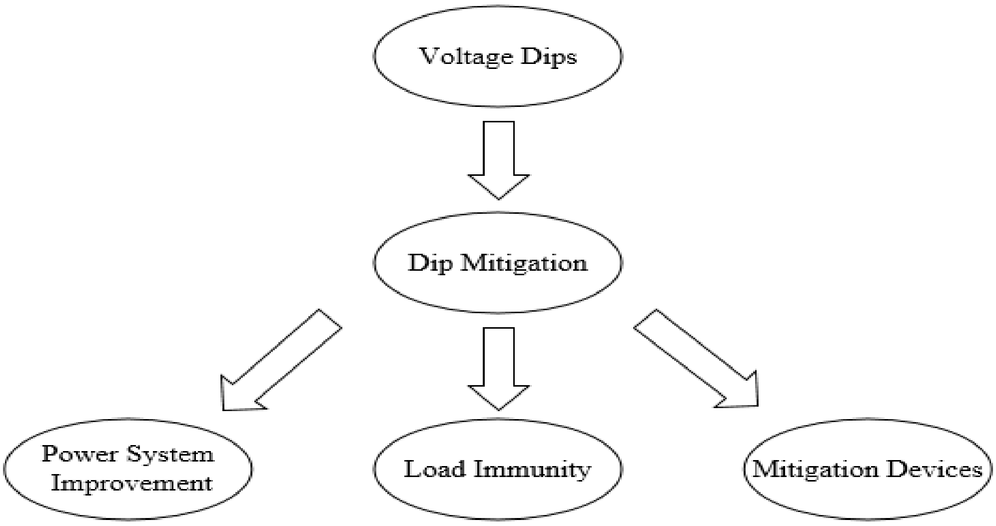

Figure 2.3 : Voltage dip mitigation method [8]**.**

The installation of mitigation device such as custom power devices or controllers at suitable location can improve the voltage profile and considerably reduce the power losses since voltage is strongly influenced by random load and fluctuations which is difficult to control [4]. Custom power devices or controllers include converters, injection transformers, static switches, master-control modules, inverters, and energy-storage modules that can perform voltage-regulation functions and current-interruption in a distribution system [9]. In this project, a controller is implemented in order to mitigate voltage dip.

There are two phase of power, which are single phase power and three phase power. To mitigate voltage dip occurred in the phase power, the use of power conditioning devices is one of the solution available. The most common single phase power conditioning devices in markets are Uninterruptible Power Supply (UPS), Dynamic Compensator (Dynacom), Constant Voltage Transformer (CVT), Dynamic Sag Corrector (DySC), Dip Proofing Inverter and Voltage Dip Compensator (VDC). Otherwise, Dynamic Sag Corrector (MegaDysc), Datawave, Flywheel, Dynamic Sag Corrector (ProDysc), Active Voltage Conditioner (AVC), Dynamic Voltage Restorer (DVR) and three phases Dynamic Compensator (Dynacom) are the power conditioning devices for three phase system

The controller system consist of few elements such as PI controller, inverse Park's and Clark's transformation, SVPWM switching technique and inverter. The working principle of the controller system is almost similar to the study from [10]. The shunt active power filter DQ frame mathematical model and control strategy used pulse width modulation (PWM) with PI controller.

2.2.1. PI Controller

Referring to the block plant, the disturbance represent the fault(voltage dip) while the block controller is a feedback controller, such as P controller, PI controller, PD controller or PID controller.

The combination of proportional gain and integral gain is called as PI-controller. The PI-controller can be expressed in the equation that contains proportional gain and integral gain that is abbreviated as Kp and Ki such as in equation (2.1).

$$u(t) = Kp\ e(t) + Ki \int e\ (t)\ dt \qquad (2.1)$$

From equation (2.1), Kp and Ki are the tuning knobs which can be adjusted to obtain the desired output. The function of Kp is to increase the speed of response and Ki is functioning to eliminate the steady state error.

2.2.2. Inverse Park's And Clark's Transformation

Three phase reference frame signal can be transformed into rotating reference frame signal by using Clarke's and Park's transformation [11]. Clarke's and Park's transformation is a mathematical transformation that transform reference frame of three-phase systems into rotating reference frames in order to simplify the analysis of three-phase circuits. However, the Clarke's and Park's transformation work in separate way to transform the signals by cascade as sillustrated in Figure 2.4.

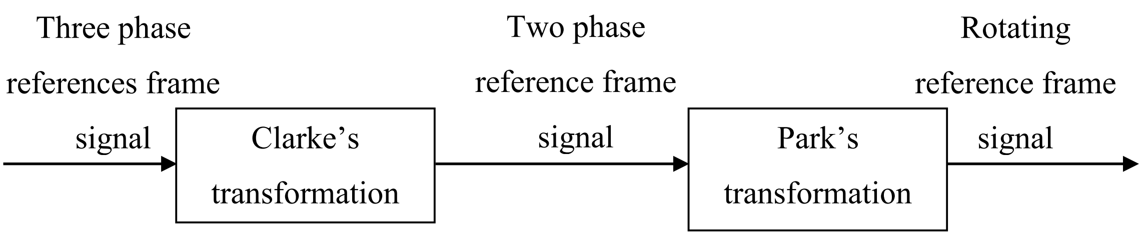

Figure 2.4 : Block diagram of Clarke's transformation and Park's transformation

Clarke's transformation is three phase stationary circuit with the parameter of a-b-c system into two phase stationary reference frame such as in Figure 2.3. The variable of two phase stationary reference frame is denoted as α and β.

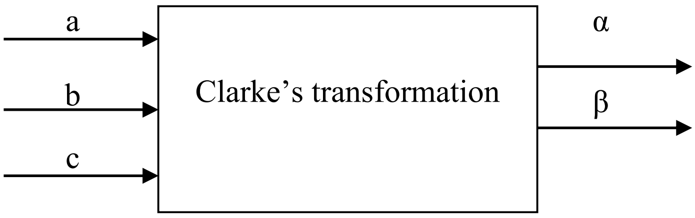

Figure 2.5: Clarke's transformation

The three phase stationary parameter from a-b-c system is transformed into two phase stationary reference frame based on the equation (2.2) where F represent the parameter such as voltage, current, line leakage and F_{abc} is the parameter such as voltage, current, line leakage in abc form.

$$F = T_{\alpha\beta o} \cdot [F_{abc}] \qquad (2.2)$$

$T_{\alpha\,\beta\,o}$ from equation (2.2) is obtained from equation (2.3).

$$T_{\alpha\,\beta\,o} = \frac{2}{3}\begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix} \tag{2.3}$$

The equation of two phase stationary reference frame is obtained such as in equation (2.4), (2.5), (2.6), after simplifying equation (2.2),

$$V_\alpha = \frac{2}{3}V_a - \frac{1}{3}(V_b - V_c) \tag{2.4}$$

$$V_\beta = \frac{2\,V_b - V_c}{\sqrt{3}} \tag{2.5}$$

$$V_0 = \frac{1\,(V_a + V_b + V_c)}{3} \tag{2.6}$$

The equation of inverse Clark's transformation is noted as in equation (2.7), (2.8), (2.9) for each part.

$$V_a = V_\alpha \tag{2.7}$$

$$V_b = \frac{-V_\alpha + \sqrt{3}\,V_{\beta_c}}{2} \tag{2.8}$$

$$V_c = \frac{-V_\alpha - \sqrt{3}\,V_{\beta_c}}{2} \tag{2.9}$$

Otherwise, Park's transformation tranform the three phase stationary parameters into two phase orthogonal rotary reference frame with two variable called d and q (DQ components) as shown in Figure 2.6.

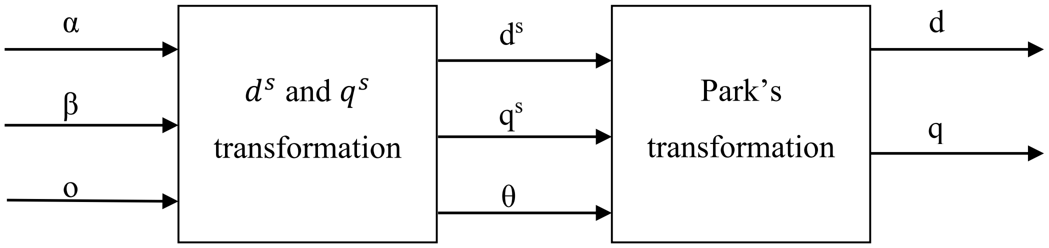

Figure 2.6 : Park's transformation

The three phase stationary parameters is transformed into two phase orthogonal stationary reference frame based on the equation (2.10) where V_d or V_q represent the parameter such as voltage, current, line leakage.

$$V_{dqo}(\theta) = T_{dqo}(\theta).\,[\,V_{\alpha\beta o}\,] \tag{2.10}$$

T_{dqo} from equation (2.10) is obtained from equation (2.11).

$$T_{dqo} = \begin{bmatrix} \cos\theta & \sin\theta & 0 \\ -\sin\theta & \cos\theta & 0 \\ 0 & 0 & 1 \end{bmatrix} \tag{2.11}$$

Equation (2.12) and (2.13) are involved to transform three phase stationary parameters into two phase orthogonal rotary reference frame.

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

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

The equation of inverse Park's transformation are obtained as in equation (2.14) and (2.15).

$$V_\alpha = V_d \cos\theta - V_q \sin\theta \tag{2.14}$$

$$V_\beta = V_d \sin\theta + V_q \cos\theta \tag{2.15}$$

Clarke's and Parks transformation resulted in different products of three phase reference after being transformed into two phase reference and rotating reference frame. The differences can be seen as demonstrated in Figure 2.7

Three phase 120 reffrence frame | Two phase reffrence frame | Rotating reffrence frame

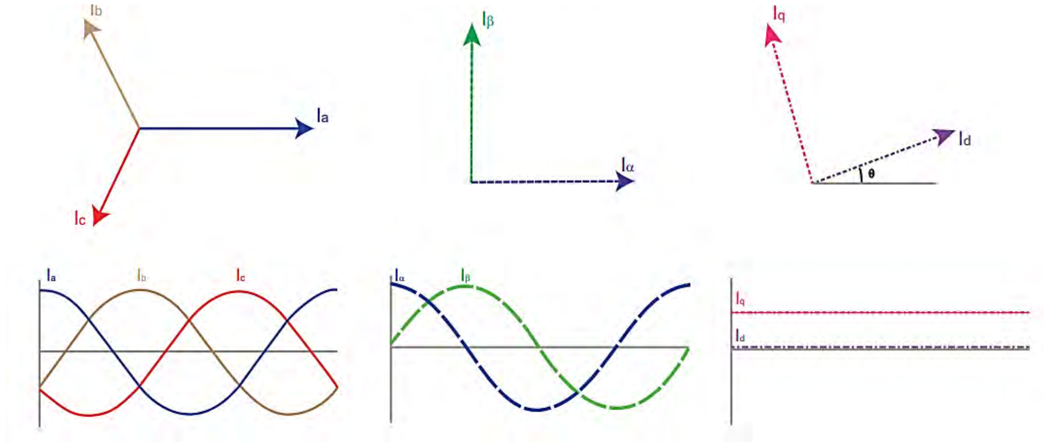

Figure 2.7 : Graph and polar form of three phase reference frames signal, two phase reference signal and rotating reference frame signal

2.2.3 Shunt-Connected Voltage Source Converter (VSC)

One of the methods to mitigate voltage dip is using shunt-connected VSC [5]. The control system of shunt connected VSC consists of two controllers which are vector current controller and vector voltage controller. The structure of the shunt active power filter is the voltage source inverter (VSI) [10]. The reference signal is generated from vector current controller which is proportional to the VSC output voltage to track the reference VSC output current. While voltage controller generated a reference signal proportional to the output voltage VSC current to maintain the voltage above the capacitor constant to the desired value. The block diagram of the transformation to obtain DQ components of two-phase obtained for three phase system is illustrated in Figure 2.8.

The transformation of three phase system into two-phase system is aimed to simplify the PI controller for sensing the amount of fault in the line voltage. Voltage and current need to be converted to $\alpha\,\beta$ then *ab* need to be converted to obtain DQ components. Morever, the calculation of transformation angle $\theta(t)$ is required to calculate DQ components. Then, the transformation angle $\theta(t)$ is calculated by Phase-Locked Loop(PLL).