



FAKULTI KEJURUTERAAN ELEKTRIK
UNIVERSITI TEKNIKAL MALAYSIA MELAKA

LAPORAN PROJEK
SARJANA MUDA

THREE-PHASE BALANCED VOLTAGE SAG
MITIGATION BY USING VOLTAGE COMPENSATOR

Lia Asmira binti Abdul Halim

Bachelor of Electrical Engineering
June 2013

**THREE-PHASE BALANCED VOLTAGE SAGS MITIGATION BY USING VOLTAGE
COMPENSATOR**

LIA ASMIRA BINTI ABDUL HALIM

**A report submitted in partial fulfillment of the requirements for the Degree of Electrical
Engineering (Industrial Power)**

**Faculty of Electrical Engineering
UNIVERSITI TEKNIKAL MALAYSIA MELAKA**

JUN 2013

“I hereby declare that I have read through this report entitle “*Three-Phase Balanced Voltage Sags Mitigation By Using Voltage Compensator*” and found that it has comply the partial fulfillment for awarding the degree of Bachelor of Electrical Engineering (Industrial Power)”

Signature :

Name :

Date :

I declare that this report entitle “*Three-Phase Balanced Voltage Sags Mitigation by Using Voltage Compensator*” 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 :

Date :

To my beloved mother and father

ACKNOWLEDGEMENT

In the name of Allah, first of all, I want to contribute my gratitude to God Almighty, with His willing and grace, I able to finish and complete a report entitle “Three-Phase Balanced Voltage Sags by Using Voltage Compensator” for Final Year Project 2 based on regulations and terms due to duration of time given by the department of faculty.

First thought, I would like to give a big thank you to my supervisor, Sir Ir. Dr. Rosli Omar, who has helped me and supervise me when completing this final year project. Without his guide and knowledge, I would not be able to learn more about this project and gain more knowledge through it. Plus, I want to give my gratitude to Universiti Teknikal Malaysia Melaka, Faculty of Electrical Engineering, lecturers, and fellow friends weather if they involved in my final year project implementation directly or indirectly. Without them, I would not be able to have courage to complete this final year project.

With God’s willing, I want to show my appreciation to my parents and my siblings because of their support during whole years of my studies, they are always with me, supporting me for whatever obligations happen during my studies and I feel so thankful to have them in my life.

In this precious moment, I hope all knowledge that I had learned during my studies in Universiti Teknikal Malaysia Melaka, and also during completing Final Year Project are being blessed by Allah S.W.T. So, if there any mistake or false information due to my final year project report, I want to express my apologize in advance because I am still a learner and I still need to improve my ability to more better each time. Last but not least, thank you for all the precious chances that had been given to me.

ABSTRACT

In these days, power quality is becoming an important role in electrical power system. Voltage sags is one of the most harmful power quality disturbances because it can bring negative affect mostly on the sensitive loads. Basically, the characteristic of the voltage sag is important things to understand through this project. Nowadays, there have lots of new technologies rise in order to mitigate voltage sag problem on sensitive loads. For example, Dynamic Voltage Restorer (DVR), Distribution Static Compensator (D-Statcom), Uninterruptible Power Supply (UPS), Ferroresonant Transformer, Flywheel and Motor Generator (MG), Static Var Compensator (SVC), Sag Proofing Transformer, and more. In this study, proposed custom power device (CPD) which called dynamic voltage restorer (DVR) is being implemented to the three-phase power system to mitigate voltage sags occur. Basically, it is installed between the incoming supply and the loads which called as sensitive loads or electrical loads. This type of CPD is used to inject voltage on the system during voltage sag occur. So that it can compensate any interference to affect the loads. This device was being simulated by using MATLAB/Simulink at different percentage voltage sag of nominal voltage. From the simulation result, it shows that Dynamic Voltage Restorer can mitigate voltage sags successfully in the electrical power system.

ABSTRAK

Pada hari ini, kualiti kuasa adalah menjadi peranan yang penting dalam sistem kuasa elektrik. Voltan kendur adalah salah satu yang mengganggu kualiti kuasa yang merbahaya kerana ia boleh membawa kesan negatif kebanyakannya pada beban sensitif. Pada asasnya, ciri mengendur voltan adalah perkara penting untuk difahami melalui projek ini. Pada masa kini, terdapat banyak teknologi baru meningkat untuk mengurangkan masalah pengenduran voltan pada beban sensitif. Sebagai contoh, Pemulihan Voltan Dinamik (DVR), Pengagihan Pemampas Statik (D-Statcom), Tidak-Terganggu Bekalan Kuasa (UPS), Ferroresonant Transformer, Roda tenaga dan Motor Generator (MG), Statik Var Pemampas (SVC), Sag Kalis Transformer, dan banyak lagi . Dalam kajian ini, dicadangkan peranti kuasa padat (CPD) yang dikenali sebagai pemulih voltan dinamik (DVR) telah dilaksanakan untuk sistem kuasa tiga fasa untuk mengurangkan kekenduran voltan yang berlaku. Pada asasnya, ia dipasang di antara penawaran akan datang dan beban yang dipanggil sebagai beban sensitif atau beban elektrik. Jenis CPD ini digunakan untuk menyuntik voltan pada sistem semasa pengenduran voltan berlaku. Supaya ia boleh menggantikan semula gangguan kekurangan voltan yang boleh menjejaskan beban. Peranti ini digunakan dalam simulasi dengan menggunakan MATLAB/Simulink pada peratusan yang pengenduran voltan yang berbeza daripada voltan nominal. Dari hasil simulasi, ia menunjukkan bahawa Pemulihan Voltan Dinamik berjaya mengurangkan pengenduran voltan dalam sistem kuasa elektrik.

TABLE OF CONTENTS

CHAPTER	TITLE	PAGE
	ACKNOWLEDGEMENT	ii
	ABSTRACT	iii
	ABSTRAK	iv
	TABLE OF CONTENTS	v
	LIST OF FIGURES	vii
	LIST OF TABLES	ix
	LIST OF APPENDICES	x
1	INTRODUCTION	1
	1.1 Background	1
	1.2 Problem Statement	2
	1.3 Objectives	3
	1.4 Scopes of Project	3
2	LITERATURE REVIEW	4
	2.1 Overview of Voltage Sag	4
	2.2 Causes of Voltage Sag	6
	2.2.1 How Voltage Sag Occur	6
	2.2.2 Effects of Voltage Sag	6
	2.3 Characteristic of Voltage Sag	7
	2.3.1 Magnitude of Sag	7
	2.3.2 Duration of Fault	8
	2.3.3 Three-Phase Unbalance	8
	2.3.4 Phase-Angle Jump	8
	2.4 Voltage Sag Mitigation Technology	9
	2.4.1 Dynamic Voltage Restorer (DVR)	9

	2.4.2 Compensation Technique in DVR	11
3	PROJECT METHODOLOGY	12
	3.1 Introduction	12
	3.2 Flow Chart of Methodology	12
	3.3 MATLAB/Simulink	14
	3.3.1 Project Basic Circuit Model	14
	3.4 Design of Dynamic Voltage Restorer (DVR)	15
	3.4.1 Series Transformer	16
	3.4.2 Harmonic Filter	16
	3.4.3 Voltage Source Converter (VSC)	17
	3.4.4 Controller	17
	3.4.5 DC Storage Unit	17
4	SIMULATION RESULTS	18
	4.1 Modeling of DVR Techniques	18
	4.1.1 Direct-Quadrature-Zero (Dq0) Transform Controller	18
	4.2 Simulation Parameters	20
	4.3 Project Design by using MATLAB/Simulink	20
	4.4 Simulation Result without Mitigation Method	22
	4.5 Simulation Result Voltage Sags Mitigation by using DVR	23
	4.6 Total Harmonic Distortion (THD)	27
5	ANALYSIS AND DISCUSSION	33
	5.1 Result Analysis	33
	5.1.1 Simulation Result without Mitigation Method	33
	5.1.2 Simulation Result Voltage Sag Mitigation by using DVR	34
	5.1.3 DC Voltage Storage Performance Effect in DVR	34
	5.1.4 Effect of Total Harmonic Distortion	35
6	CONCLUSION AND RECOMMENDATION	37
	6.1 Introduction	37
	6.2 Conclusion	37
	6.3 Recommendation	38
	REFERENCES	39

LIST OF FIGURES

FIGURE	TITLE	PAGE
2.1	Basic waveform of voltage sag [5]	4
2.2	Simple circuit of voltage sag in power system [7]	5
2.3	Graphical representative of voltage sag [8]	7
2.4	DVR series connected [6]	10
3.1	Flow Chart of Project Progress	13
3.2	MATLAB R2010b (Simulink)	14
3.3	Basic three-phase system with fault	15
3.4	Basic DVR Configuration [6]	16
4.1	Flowchart of DVR system operation by using Dq0	19
4.2	Three-Phase Balanced Voltage Sag Mitigation by using Voltage Compensator which is DVR	21
4.3	Graph of power system with voltage sag occur without mitigation method	22
4.4	Graph of power system without voltage sag occur	22
4.5	Waveform resulted when 10% voltage sag of nominal voltage	23
4.6	Waveform resulted when 20% voltage sag of nominal voltage	24
4.7	Waveform resulted when 30% voltage sag of nominal voltage	24
4.8	Waveform resulted when 40% voltage sag of nominal voltage	25
4.9	Waveform resulted when 50% voltage sag of nominal voltage	25
4.10	Waveform resulted when 60% voltage sag of nominal voltage	26
4.11	THD of 10% voltage sag before mitigate	27
4.12	THD of 10% voltage sag after mitigate	27
4.13	THD of 20% voltage sag before mitigate	28
4.14	THD of 20% voltage sag after mitigate	28

4.15	THD of 30% voltage sag before mitigate	29
4.16	THD of 30% voltage sag after mitigate	29
4.17	THD of 40% voltage sag before mitigate	30
4.18	THD of 40% voltage sag after mitigate	30
4.19	THD of 50% voltage sag before mitigate	31
4.20	THD of 50% voltage sag after mitigate	31
4.21	THD of 60% voltage sag before mitigate	32
4.22	THD of 60% voltage sag after mitigate	32

LIST OF TABLES

TABLE	TITLE	PAGE
4.1	Specification of Project Design	20
4.2	Different Percentage of Voltage Sag	23
5.1	DC Voltage Storage	34
5.2	THD at Source (before) and at Load Voltage (after)	35

LIST OF APPENDICES

APPENDIX	TITLE	PAGE
A	Gantt Chart	41
B	Turnitin Report	42

CHAPTER 1

INTRODUCTION

1.1 Background

Power quality is always had been concerned by any electrical power engineers because of its importance in the distribution system. Engineers take that this power quality phenomenon as a parasite that can affect the voltage, current and also frequency of the power that being supplied to the consumer [1].

Nowadays, poor in power quality in an electrical delivery system is becoming an increasingly challenging because with rapidly growing in used of electrical equipment, power electronic, micro-electronics in modern life, the systems are increasingly incompatible with power environment. Mostly, power system or power that supplied from generator comes as an alternating current, while electrical appliances that being produced nowadays comes in as a direct current.

So, these new technologies are not only influenced to power quality problem, but they are also can be the biggest challenging contributor to this power quality problem. Poor in power quality can result in mostly lost in productivity, damaged equipment and also poor power efficiency and can lead the problem of the shorten in life of sensitive equipment that can resulting in expensive downtime and lost revenue.

Basically, problems in power quality can be traced to three different kinds of origins which are supply, internal distribution, and also internal loads.

- Supply – initial source of power supply such as main transformer of a building which is where the power is coming into the facility that can be monitored.
- Internal Distribution – mostly, 80% of the power quality problems happen in company's building and also the grounding systems such as improper wiring and improper grounding.
- Internal Loads - everything from variable speed drives and high tech devices to unsophisticated loads such as heaters and lights can make the quality of electrical power in a circuit. Internal loads can result in poor power factor, harmonics and disturbances.

1.2 Problem Statement

In electrical power system, there is always something new in technologies that force us to upgrade existing system, component or else in order to catch up with new technologies. There are many types of interference that may be harmful to sensitive components in electrical power system such as voltage sags or called voltage dip.

Voltage sags usually caused by short circuits, overloads or large motor starting current that happen in a short duration reductions in rms voltage [2]. Basically, sags can travel miles affecting thousands of users or customers when it generated on transmission or distribution system but certain times sags can also be generated by nearby customers. It often occurs that caused by faults.

For example line-to-line fault, single line-to-ground fault, double line-to-ground fault and also three phase fault on the power system. It can lead to the malfunction of any electrical appliances.

1.3 Objectives

The main objective of this project is to use a mitigation technique to protect electrical load or non-linear load from voltage disturbances in electrical network. From the effect of the voltage sags to the power system or industrial, solutions need to be search and create in order to solve arising problem. The other objectives are;

- To study and analyze the characteristics of the voltage sags.
- To study and analyze possible methods on voltage compensator used in order to mitigate voltage sag
- To design and develop the three-phase balanced model for voltage sag mitigation by using MATLAB/Simulink

1.4 Scope of Project

Basically, the scope for the project is focusing on the design of a system that can be used to mitigate three-phase balanced voltage sag. In addition, this project also includes the analysis about the characteristics of voltage sags, its impact on the power system, factors that affect voltage sags type and the review of the information about voltage compensator in order to mitigate voltage sag by using MATLAB/Simulink. So based on the simulation, it will generate answer so that can be analyzed and can achieved all the objectives stated.

CHAPTER 2

LITERATURE REVIEW

2.1 Overview of Voltage Sag

Based on the IEC Electrotechnical Vocabulary, voltage sag can be described as “*sudden reduction of the voltage at a point in the electrical system, followed by voltage recovery after a short period of time, from half a cycle to a few seconds*”. Usually, voltage sag caused by large currents interacted with network impedance [5].

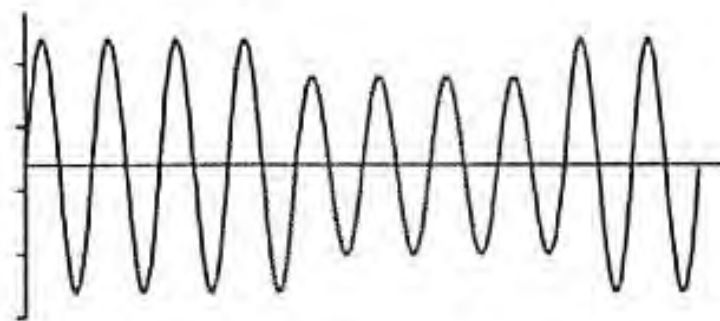


Figure 2.1: Basic waveform of voltage sag [5]

Voltage sag occur when there is a reduction of the certain amount of voltage supplied in electrical system caused by many factors and it will effect to the load side when the voltage supplied by the system is not reach the required value. According to IEEE Standard 1159-1995, “*IEEE recommended practice for monitoring electric power quality*”, voltage sag is the decrease in voltage which is RMS voltage in the electrical power system with duration from

0.5 cycles to one minute. It is also called as the remaining voltage. Based on the Figure 2.1, it show the basic waveform when voltage sag occur. Basically, voltage sag is measured by the percentage of the nominal voltage of the system. For example, voltage sag in 40% is equal to 40% of the nominal voltage which is the value of the nominal voltage, 400V, so the 40% of the nominal voltage is 160V.

Voltage sags become a main concern in power quality problem because of their negative effect to the sensitive loads or sensitive electric devices for example power electronic equipment, computers, adjustable speed drive and many more.

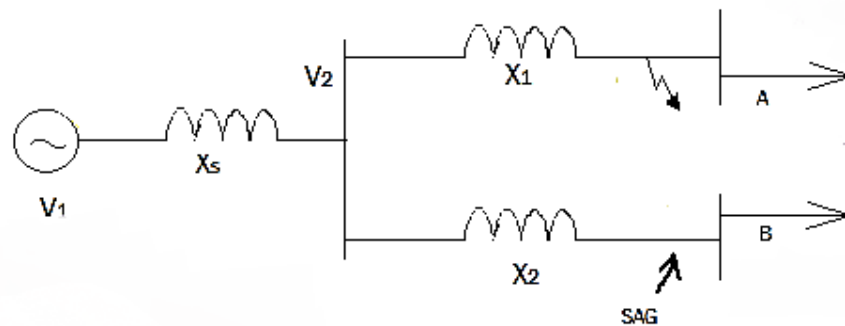


Figure 2.2: Simple circuit of voltage sag in power system [7]

From Figure 2.2 above, in normal condition, which is no fault occurring, current through A and B are equal or called balance load. When suddenly fault occurs on feeder 1, a high current or called short circuit will flow to feeder 1. Current flow in feeder 2 will be reduced based on the Kirchoff's Law and voltage will drop or called as voltage sag [7].

$$I = I_1 + I_2 \quad (\text{when no fault occurs}) \quad (2.1)$$

$$I = \frac{V_2}{x_2 + Z_{load B}} + \frac{V_2}{x_1 + Z_{load A}} \quad (2.2)$$

$$I = \frac{V_2}{x_2 + Z_{load B}} + \frac{V_2}{x_1} \quad (\text{when fault occurs}) \quad (2.3)$$

So,

$$V_2 = V_s - Ix_s \quad (2.4)$$

$\therefore V_2$ decreased from the nominal value of voltage and become voltage sag

2.2 Causes of Voltage Sag

Through this section, a literature review on voltage sag as main power quality problem is being described. It is including the definitions, effects, how to generate voltage sag and mitigation method involved.

2.2.1 How Voltage Sag Occur

Math H.J Bollen has written in his book entitle, “*Understanding Power Quality Problems*” that voltage sag normally occur or present when it caused by large of starting current or induction of motors, short circuit faults that caused by nature such as lightning and animal contact, and caused by overloads [2].

2.2.2 Effects of Voltage Sags

Basically, voltage sags is the decreasing of voltage value in the power system. When this kind of power quality disturbance occurs, it will bring major effect to the equipment that is connected to the power system. Mostly connected equipment will not operate well or usually fails to operate well. So due to this problem, it directly affect the safety of users and other connected equipment, and also production line.

2.3 Characteristic of Voltage Sag

Voltage sag is characterized by the duration which is voltage variation below the sag threshold combined with maximum reduction in rms voltage or called depth. From Figure 2.3, depth is known as retained voltage [8]. Characteristics of voltage sag can be characterized with few parameters, which are magnitude of sag, three phase unbalance, duration of fault, and also phase-angle jump [4].

2.3.1 Magnitude of Sag

Basically, sag with low magnitude called deep sag, while sag with large magnitude called as shallow sag. Mostly, sag magnitude is get from rms voltage. Magnitude of sag can be determined by various ways. Voltage and peak voltage of each cycle of half-cycle are the obvious examples, as long as the voltage is in sinusoidal waveform [4].

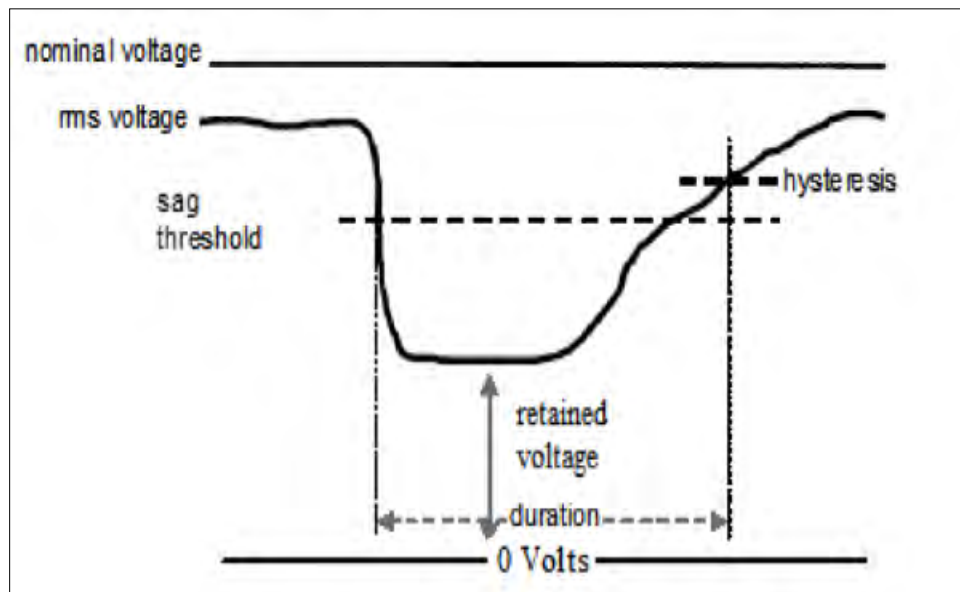


Figure 2.3: Graphical representative of voltage sag [8]

2.3.2 Duration of Fault

Basically, the duration of sag can be determined as fault-clearing time. Generally, faults in transmission system cleared faster than faults in distribution system because in transmission system, the fault-clearing time is rather small. Basically, when fault is cleared by the protection, the voltage value will return to its normal original value [4]. In transmission systems, basically fault will clear faster than in distribution systems because in transmission systems, fault-clearing time is small [4].

2.3.3 Three-Phase Unbalance

Balanced fault occur when fault of all three phase sags are equal in magnitude. If the fault is a single line-to-ground, line-to-line, or double line-to-ground depending on faulty phase, sag in all phases will be unbalanced. Mostly short circuits occur in power system is single-phase or two-phase [4].

2.3.4 Phase-Angle Jump

In power system, not only magnitude of voltage is affected, but phasor angle also affected. It so called phase-angle jump. Phase-angle jumps during three-phase faults are due to a difference in the X/R ratio between the source and the feeder. Phase-angle jumps are not of concern for most equipment but power electronic converters using phase angle information for their switching may be affected. It can cause of power electronic converters failure that use phase-angle information for their firing control [4].

2.4 Voltage Sag Mitigation Technology

Every mitigation methods have their own advantages and disadvantages. The most common methods of voltage sags mitigation are Dynamic Voltage Restorer (DVR), Distribution Static Compensator (D-Statcom), Uninterruptible Power Supply (UPS), Ferroresonant Transformer, Flywheel and Motor Generator (MG), Static Var Compensator (SVC), Sag Proofing Transformer, and more.

2.4.1 Dynamic Voltage Restorer (DVR)

For this project, proposed method to be used for mitigating the voltage sags is Dynamic Voltage Restorer (DVR). It actually works by adding extra voltage during voltage occur or called 'missing' voltage. Basically, this device injects voltage into the system in order to bring the voltage backup to the level required by the load. The main idea of this method is by injecting that missing voltage into the system whenever voltage sags are present in system supply voltage.

DVR can boost up the load-side voltage in order to avoid any interference to load. Basically, it injects voltage into the system in series [1]. Injection voltage is achieved by a switching system coupled with a transformer which is connected in series with the load.

Dynamic Voltage Restorer (DVR) able to protect a sensitive load from the distortion in the supply side during fault or overloaded in power system. Dynamic Voltage Restorer (DVR) has two types which are without energy storage and with energy storage. For DVR without energy storage, it is able to correct the voltage waveform by drawing additional current from the supply. Meanwhile, DVR with energy storage used to stored energy to correct the voltage waveform.

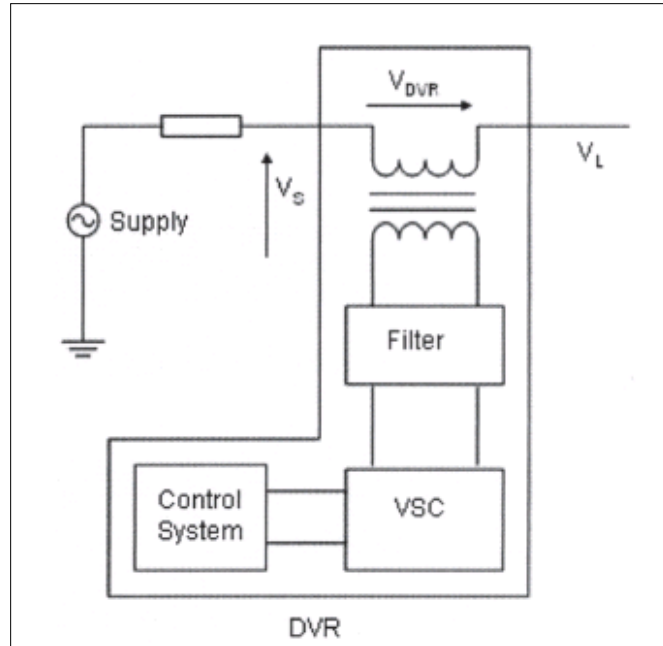


Figure 1.4: DVR series connected [6]

$$Z_{th} = R_{th} + jX_{th} \quad (2.5)$$

$$V_{DVR} + V_{th} = V_L + Z_{TH}I_L \quad (2.6)$$

When voltage drop occur at load voltage (V_L), DVR will inject a series voltage so that the desired load voltage can be maintained.

$$V_{DVR} = V_L + Z_{th}I_L - V_{th} \quad (2.7)$$

$$I_L = \left[\frac{P_L + jQ_L}{V_L} \right]^* \quad (2.8)$$

When load voltage (V_L) as reference;

$$V_{DVR} < \alpha = V_L < 0^\circ + Z_{th}I_L < (\beta - 0) - V_{th} < \delta \quad (2.9)$$

→ α, β, δ are angle of V_{DVR} , Z_{th} , and V_{th}