IMPROVEMENT OF VOLTAGE SAGS, HARMONIC DISTORTION AND LOW POWER FACTOR AT DISTRIBUTION SYSTEM BY USING VOLTAGE SOURCE CONVERTER (VSC) AND ACTIVE FILTER

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To my lovely wife and sons, beloved parents and siblings,
lecturers and colleagues

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ABSTRACT

For many years, power quality were not give a big issue to the power system, because it cause no effect on most of the loads connected to the distribution system. It happen because only motor and generator based system only operates at that time. When an induction motor is subjected to voltage sag, the motor still operates but with a lower output until the sag ends. It not harm the motor but only effect the performance of the motor. With the increasing use of sophisticated electronics based system, high efficiency variable speed drive, and power electronic controller, power quality has become an important agenda and it will cause increasing concern to utilities and customers.

Nowadays, voltage sags is the most common type of power quality disturbance in the distribution system. Even though it happens only in the microseconds, but it can be caused huge impact on the electronic based system. Sometimes, when fault occurs in the electrical network the nearest network connected to the fault network will sense the voltage sags event. Although the electricity utilities and semiconductor or electronic based system companies have invested some substantial amount of investment to improve the reliability of the network but they still cannot control the external and internal factor that can causes the fault, such as lightning strike, third party digging, illegally excavation activity, wrongly operated during maintenance activity or protection relay malfunction and etc. Therefore, the important thing is to come out with the solution to prevent or mitigate the network during fault event that can cause voltage sags happen. There are many researchers have come out with many method to mitigate this power quality issues such as DVR, STATCOM, SVC and many more. However, this project presents the mitigation technique to improvement power quality problem which were voltage sags, harmonic distortion and low power factor by using Voltage Source Converter (VSC) in distribution system. The VSC injects a current into the system to mitigate the voltage sags. LCL Passive Filter was then added to VSC to improve harmonic distortion and low power factor. The simulations were performed using MATLAB SIMULINK version R2010b.

ABSTRAK

Selama beberapa dekad, kualiti tenaga tidak menimbulkan sebarang masalah, kerana ia tidak mempunyai kesan pada kebanyakan beban yang dihubungkan dengan sistem pembahagian elektrik. Apabila motor induksi tertakluk kepada voltan lendud, motor masih beroperasi tetapi dengan keluaran yang lebih rendah sehingga selang berakhir. Dengan peningkatan penggunaan elektronik yang canggih, pemacu kelajuan pemboleh ubah kecekapan yang tinggi, dan kuasa pengawal elektronik, kualiti tenaga menjadi kebimbangan yang semakin meningkat kepada utiliti dan pelanggan.

Voltan lendud adalah jenis gangguan kuasa yang paling biasa dalam sistem pembahagian. Ia boleh disebabkan oleh kerosakan dalam rangkaian elektrik atau dengan permulaan motor induksi yang besar. Walaupun syarikat utiliti elektrik telah membuat sejumlah besar pelaburan untuk meningkatkan kebolehharapan rangkaian grid, mereka tidak dapat mengawal faktor luaran yang menyebabkan terpelantikan elektrik berlaku, seperti kilat atau pengumpulan garam di menara transmisi yang terletak di laut. Projek ini membuktikan peningkatan tahap kerosakan dan pembaikan masalah kualiti kuasa yang merupakan voltan lendud, gangguan harmonik dan faktor kadaran kuasa yang rendah dengan menggunakan "*Voltage Source Converter (VSC)"* dalam sistem pembahagian. VSC menyuntik arus ke dalam sistem untuk mengurangkan voltan lendud. *"LCL Passive Filter"* kemudiannya ditambah kepada VSC untuk membaikkan gangguan harmonik dan factor kadaran kuasa yang rendah. Simulasi dilakukan menggunakan MATLAB SIMULINK versi R2010b.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

IGBT	Insulated Gate Bipolar Transition
GTO	Gate Turn Off Thyristor
MOSFET	Metal Oxide Semiconductor Field Effect Transistor
VSC	Voltage Source Converter
LCL P.F	LCL Passive Filter
THD	Total Harmonic Distortion
PF	Power Factor
A.C	Alternating Current
D.C	Direct Current
IGBT	Insulated Gate Bipolar Transistor
PWM	Pulse Width Modulation
FFT	Fast Fourier Transform

CHAPTER 1

INTRODUCTION

1.1 Background Of Study

Nowadays, Power Quality (PQ) becomes a great concern to the large sensitive electricity users and electric utilities companies. With the growing technology of digitals and gadget, it will cause the semiconductors sectors become an important entity to produce the above devices. In the semiconductors factories contains a lots of sensitive and susceptive electronic and computing equipment (e.g. personal computers, desktop, electronic conveyor, computer-aided design workstations, programmable logic control (PLC) application, robotic machines, uninterruptible power supplies, fax machines, printers, etc) and other nonlinear loads (e.g. fluorescent lighting, adjustable speed drives, heating and lighting control, industrial rectifiers, arc welders, etc).

The Electric Power Research Institute (EPRI) state that on year 2012, 15 to 45% of the total electricity load was nonlinear and this figure were increasing year by years and it can be forecast to reach percentage 50% to 90% until the year 2017.

The focus on power quality problem is become an important things since the nonlinear load were expand connected to the electric distribution and transmission network. All electric networks are design interconnected and integrated each other's. Thus, any system disturbance can cause serious economic impact especially for large industrial type users due to breakdown and the process to normalize the system back will take some period of times. By knowing more on electricity connection and potential risk impact that can happen to networks and users business, users are now much more aware and beware of the PQ problems issues. Most of the users were referring back to the local electricity company to come out with solution to their PQ problem at their local network.

The term “Power Quality” generally bringing the concept and is associated with electrical distribution network and transmission network systems that experience any voltage, current or frequency deviation from normal operation condition. For normal condition, the rated power supplied (kWh) must have a sinusoidal current and voltage waveforms, the output are mostly efficient without any distortion. But in the reality is that the electricity utilities companies only can controls the magnitude and phase of the voltage levels but they are unable to control quality of the output current and output voltage unless it comes from the bus voltage and current. [1].

Thus, the electricity companies should maintain the bus voltage quality at all times. This simple consideration makes power quality (PQ) equal to voltage quality as shown in Figure 1.1.Defining precisely the Power Quality is a tremendous task; one of the common definitions is:

Definition 1: “Power quality is a summarizing concept, including different criteria to Judge the technical quality of an electric power delivery

Definition 2: “Power Quality is the degree to which both the utilization and delivery of electric power affects the performance of electric equipment”.

Definition 3: “Power quality problem is any power problem manifested in voltage, current, or frequency deviation that results in failure or disoperation of customer equipment”.

Power quality can be simply defined as shown in the interaction diagram Figure 1.1

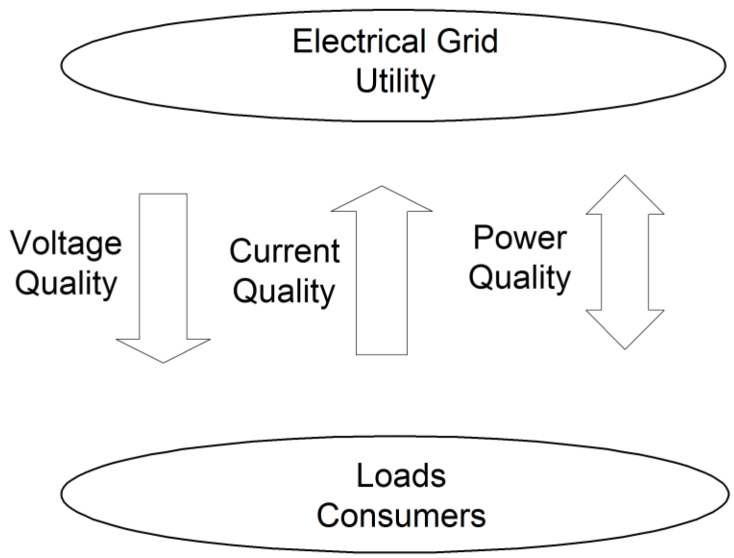

Figure 1.1: The Power Quality Diagram

Currently, delivering and maintain a certain level of voltage and current stability and sinusoidal quality should be the main focus for the planner and designer of the utility electrical companies. When electrical distribution and transmission network system is interconnected and integrated with a huge nonlinear loads their profile, grid design, and utility operation including the electric load degree of nonlinearity, all together affect and lead to the power quality problems.

Power Quality issues can be roughly broken into a number of sub-categories:

- Harmonics Distortion (integral, sub, super and inter harmonics)
- Voltage sags, swell, fluctuations, flicker and Transients
- Voltage magnitude and frequency, voltage imbalance
- Hot grounding loops and ground potential rise (GPR)
- Lower Power Factor
- Monitoring and measurement of quasi-dynamic, quasi-static and transient type phenomena.

Among them, three power quality problems have been identified to be of major concern to the customers which are voltage sags, harmonics distortion and lower power factor, this project will be focusing all above PQ problems [3].

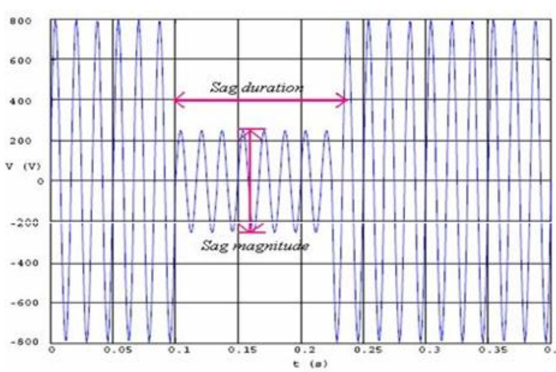

Figure 1.2: Sinusoidal waveform of the voltage sag

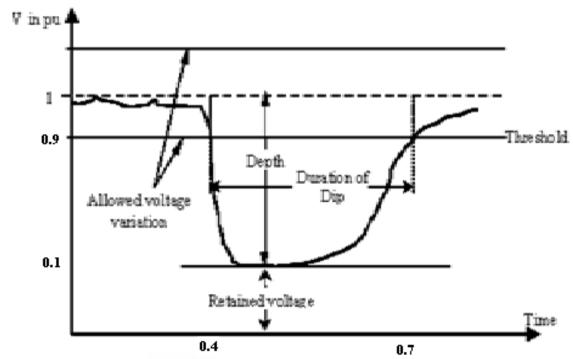

Figure 1.3: Magnitude waveform of the voltage sag

The voltage sags as defined by IEEE Standard 1159, IEEE Recommended Practice for Monitoring Electric Power Quality, is "a decrease in RMS voltage or current at the power frequency for durations from 0.5 cycles to 1 minute, reported as the remaining voltage". Typical values are between 0.1 p.u. and 0.9 p.u., and typical fault clearing times range from three to thirty cycles depending on the fault current magnitude and the type of over current detection and interruption.

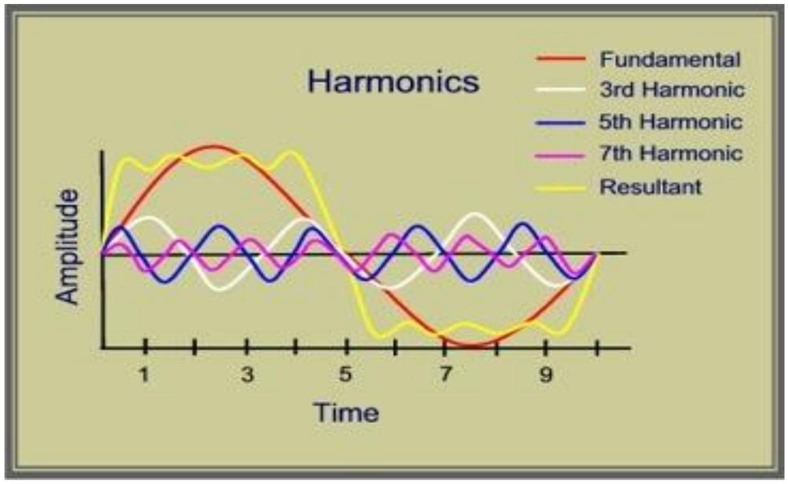

Figure 1.4: Harmonic Distortion waveform amplitude VS time

Definition for a harmonic is “a sinusoidal component of a periodic wave or quantity having a frequency that is an integral multiple of the fundamental frequency. Some references refer to “clean” or “pure” power as those without any harmonics. But such clean waveforms typically only exist in a laboratory. Harmonics have been around for a long time and will continue to do so.

The frequencies of the harmonics are different, depending on the fundamental frequency. For example, the 2nd harmonic on a 60 Hz system is 2*60 or 120 Hz. At 50Hz, the second harmonic is 2* 50 or 100Hz. 300Hz is the 5th harmonic in a 60 Hz system or the 6th harmonic in a 50 Hz system.

1.2 PROBLEM STATEMENT

In Malaysia, statistics of raining weather with lighting are higher compare to summer weather. It can be prove by knowing “tengkujuh” seasons. By present of raining with lightning, it can cause a fault that can affect to our electrical grid system. Additionally, fault also were also can cause by poor workmanship, wrong operation, load overloading and third party dig up.

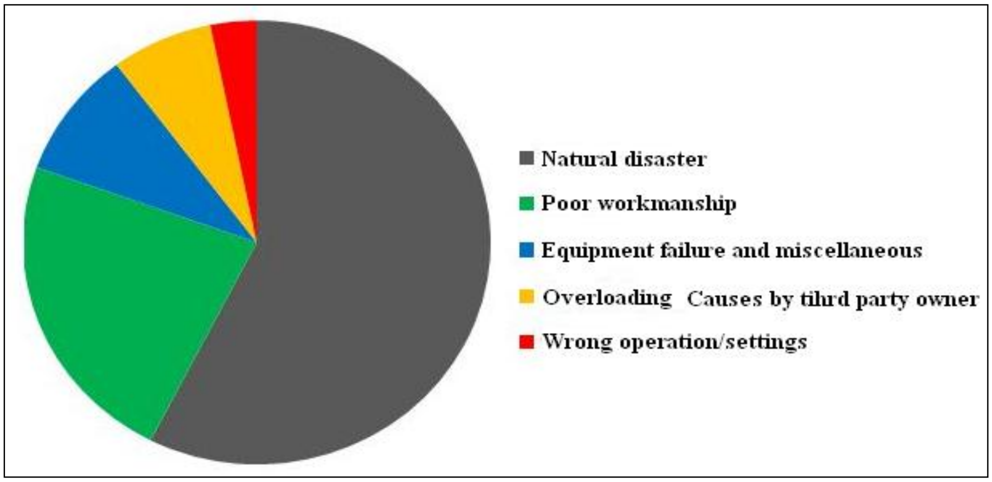

Figure 1.5: Statistics causes of fault by pai chart

When the fault occurs at distribution system it will cause the interruption to the system. If this condition prolong, it will trip the breaker and cause load loss. Additionally, load that nearest grid connected to the interruptions will sense Power Quality issues such as voltage sags, Harmonic and low power factor. For the industrial with sensitive equipment, they will easily sense the impact cause by this interruption. It will drive to malfunction and damaged to electrical and sensitive equipment [11]

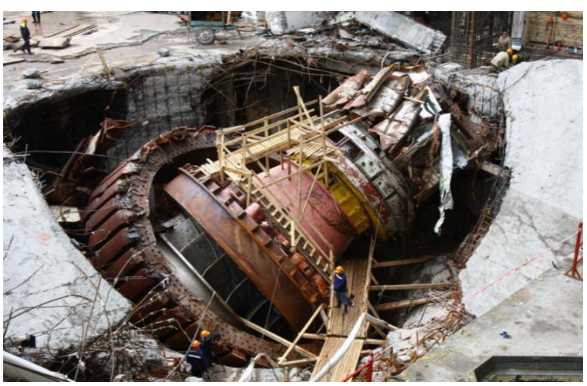

Figure 1.6: Turbine damaged

Figure 1.7: Combustion chamber explode

A details analysis and investigation on the cost of losses due to power quality problem has not been carried out yet. However, it has been reported that on year 2011 a petrochemical , oil and gas , semiconductor and arc furnace based industries customer in the Tenaga Nasional Berhad (TNB) system can lose up to

RM2,164,000.000 related to power quality problem due to voltage sag. Another semiconductor-based industry in the Klang Valley has estimated the loss of RM500, 000.00 per incident for the year 2013. Other types of industries such as cement and garment industries in Malaysia have also reported huge losses due to power quality problems. One cement plant has reported an average loss of RM300, 000.00 per incident on year 2014.

Cause of Interruption	**No. of Interruptions**	
Natural Disasters (wind, storm, flood, land slides etc.)	38.9%	37.6%
Caused by third parties	7.1%	8.3%
Poor Workmanship	14.4%	12.8%
Over Loading	11.6%	10.5%
Wrong Operation/Settings	0.3%	0.2%
Equipment failure	13.9%	17.7%
Miscellaneous	13.8%	12.9%
Total	37,761	48,566

Table 1.1: Cause of TNB network disruption

In general, voltage sags can causes speed of rotating motor out from their synchronize speed. If the event prolong until certain period, it can cause the motor to stop. Additionally, voltage sags also can cause digital devices to reset to its default setting that causing losing of data, equipment damage and/or failure, materials spoilage, lost production due to downtime. Thus, the impact are additional costs, more product reworks, poor end product quality, reworks, impacts on customer relations such as late delivery and loss of reputation upon customers trust, loss of potential sales and lastly incurred a lots of cost to investigations the root cause and solve the problem [5].

Therefore, this project intends to investigate mitigation technique that is suitable for voltage sags with different type of fault. This fault will be controlled by varying values of fault resistance.

1.2 Objectives

To eliminate the noise of error signal sense by PI controller, improve the voltage sags more than 0.9 p.u, reduce THD less 8 %, and increase a lower power factor of VSC close to unity.

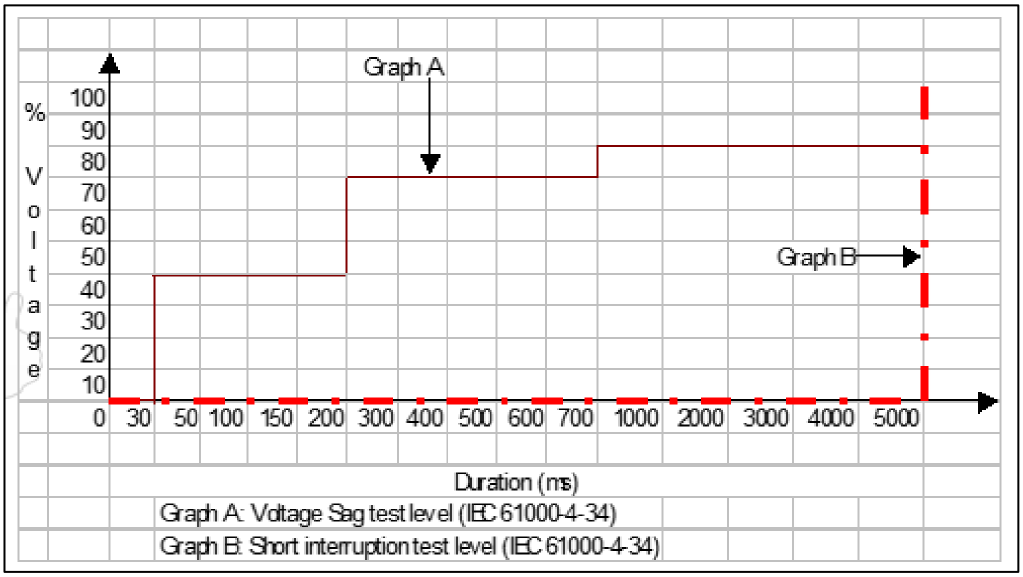

Figure 1.8: MINIMUM IMMUNITY IEC 61000-4-34

Bus voltage V at PCC	Individual harmonic (%)	Total harmonic distortion THD (%)
$V \leq 1.0$ kV	5.0	8.0
1 kV $< V \leq$ 69 kV	3.0	5.0
69 kV $< V \leq$ 161 kV	1.5	2.5
161 kV $< V$	1.0	1.5[a]

Table 1.2: IEEE 519-2014 edition harmonic allowable limit

1.4 Scope of Work

This project presents the effectiveness using VSC with LCL Passive Filter to improve fault level and mitigate voltage sags, harmonics distortion and low power factor that occurs in an industrial distribution system and also to evaluation the total of harmonic distortion (THD) by using FFT analysis on MATLAB/SIMULINK. THD in this project was varied at output (load), where the current harmonic data were collected.

The distribution system was design by using MATLAB/SIMULINK. VSC with LCL passive filter was injected at the center of load point through coupling transformer in order to mitigate missing voltage caused by fault. Four different types of fault was injected into distribution system to analyze the effect of voltage sags at four different types of fault.

The data was observed and comparison was made in order to recognize which types of fault gives the worst effect of voltage sags to distribution system. Therefore, a suggestion can be made in future research VSC with LCL Passive Filter can be located refer to this type of fault only.

1.5 PROJECT ORGANIZATION

Chapter 1 Focus on project report present introduction, objective, and scope of work and organization of the project report.

Chapter 2 Focus on a literature review on the previous researchers on the other switching devices use in voltage source converter (VSC) to mitigate the voltage sags, harmonic distortion and lower power factor.

Chapter 3 In this chapter includes explanation about theory of VSC with LCL Passive Filter.

Chapter 4 Presents the overall methodology to complete this project.

Chapter 5 Focus on the result of the simulation process using MATLAB SIMULINK. The waveform and results of voltage sags and current harmonic distortion were discussed.

Chapter 6 Presents the conclusion and future development of the project.

Lastly, the simulation results show that the voltage sags can be mitigate by inserting VSC to the distribution system. By adding LCL Passive filter to VSC, the THD reduced within the IEEE STD 1992-2004. The power factors also increase close to unity. Thus, it can be concluded that by adding VSC with LCL filter the power quality is improved.

6.2 Future Development

For the future development Hybrid system Voltage Source Converter (HDSTATCOM) with Magnetically Controllable Reactor (MCR) can be used. MCR is a simple system and configuration, less harmonics, less response time and large regulating response.

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