POWER QUALITY ANALYSIS AND MITIGATION

UDECHUKWU CHUKWUEMEKA CHARLES

A project report submitted in partial
fulfillment of the requirement for the award of the
Degree of Master of Electrical Engineering

Faculty of Electrical and Electronic Engineering
Universiti Tun Hussein Onn Malaysia

MAY 2011

DEDICATION

To my beloved and lovely Parents, Mr. Samuel .A. Udechukwu & Mrs. Gloria .C. Udechukwu, my beloved brothers and sisters, and all my friends and loved ones, for your prayers, love, care and encouragements. God bless you all.

ACKNOWLEDGEMENT

First and foremost I would like to thank the Almighty God (ALLAH) for blessing and guiding me through all the stages of my life, up to this point. Without this guidance I would have never reached this position where I am writing this page. Secondly, I would like to express my deep gratitude, honor, and admirations to my supervisor Dr. Goh Hui Hwang, I cannot ever say enough thank you to adequately express my appreciation to him for being a supervisor , with his knowledge, experience and dedication, he provided the right vision and direction which led to the completion of this work; always prepared to help, always having time to listen and always open to discussion.

A great appreciation is also due to Dr. Kok Boon Ching, who had repeatedly given me some of his precious time for technical discussion and advice. Also the author would like to thank his laboratory technicians, Mohd Shamsuddin Bin Muslim and Mohamad Fauzi Bin Mustafa, for providing all kinds of help and assistance to him. I would also like to express my thanks to the colleagues and friends in the department at UTHM who had contributed to this work through either individual or group discussion.

Finally, the author is grateful to Almighty God, for giving the author wisdom, strength and guidance during his toughest times.

ABSTRACT

Due to increasing complexity in the power system, voltage sags and swells are now becoming one of the most significant power quality problems. Voltage sag is a short reduction voltage from nominal voltage, occurs in a short time, voltage swell is an increase in the r.m.s voltage from its nominal voltage; they are bound to have a greater impact on the industrial customers. If the voltage sags exceed two to three cycles, then manufacturing systems making use of sensitive electronic equipments are likely to be affected leading to major problems. It ultimately leads to wastage of resources (both material and human) as well as financial losses. The increasing competition in the market and the declining profits has made it pertinent for the industries to realize the significance of high-power quality. This is possible only by ensuring that uninterrupted flow of power is maintained at proper voltage levels. Electric utilities are looking for solutions to ensure high quality power supply to their customers, a lot of solutions have been developed, but this project tends look at the solving the problems by using custom power devices such as Dynamic Voltage Restorer (DVR) and Distribution Static compensator (D-STATCOM). The Dynamic Voltage Restorer appears to be an especially good solution in the current scenario. This work describes the techniques of correcting the supply voltage sag and voltage swell in a distributed system. At present, a wide range of very flexible controllers, which capitalize on newly available power electronics components, are emerging for custom power applications. Among these, the distribution static compensator and the dynamic voltage restorer are most effective devices, both of them based on the VSC principle. A DVR injects a voltage in series with the system voltage and a D-STATCOM injects a current into the system to correct the voltage sag, swell and interruption. Comprehensive results are presented to assess the performance of each device as a potential custom power solution.

ABSTRAK

Dengan meningkatnya kesukaran pada system tenaga, voltan lendut dan voltan kembang telah menjadi satu masalah yang sangat penting dalam sistem kualiti kuasa. Voltan lendut ialah pengurangan kecil pada voltan nominal, berlaku pada kadar masa yang singkat. Voltan kembang adalah peningkatan pada voltan punca min kuasa dua (pmkd) daripada voltan nominalnya; masalah ini mengikat dan mengakibatkan satu kesan yang lebih besar kepada pelanggan-pelanggan industri. Jika voltan lendut melebihi dua hingga tiga kitaran, kemudian sistem-sistem pembuatan menggunakan peralatan-peralatan elektronik sensitive berkemungkinan akan terjejas dan membawa kepada masalah lebih besar. Kesudahannya akan membawa kepada pembaziran sumber-sumber (bahan dan manusia) serta kerugian kewangan. Peningkatan persaingan dalam pasaran dan kerugian telah membuatnya menjadi penting supaya pihak-pihak industri menyedari kepentingan kuasa kualiti yang tinggi. Ini hanya berkemungkinan dengan memastikan bahawa aliran kuasa yang tidak terganggu dipelihara pada aras-aras voltan yang sesuai. Pembekal-pembekal elektrik sedang mencari penyelesaian untuk memastikan bekalan tenaga yang berkualiti tinggi disalurkan kepada pelanggan. Terdapat beberapa cara penyelesaian telah dibangunkan, tetapi projek ini lebih cenderung kepada penyelesaian masalah dengan menggunakan alat-alat kuasa yang biasa digunakan seperti *Dynamic Voltage Restorer (DVR)* dan *Distribution Static Compensator (D-STATCOM). Dynamic Voltage Restorer* menjadi satu penyelesaian yang bagus dalam senario semasa. Projek ini melibatkan teknik-teknik membetulkan bekalan voltan lendut dan voltan kembang dalam sistem pengagihan. Pada masa ini, pelbagai alat-alat kawalan fleksibal yang mengeksploitasi komponen-komponen elektronik tenaga baru yang boleh didapati adalah timbul bagi aplikasi-aplikasi tenaga biasa. Disamping itu, pengagihan kompensator statik dan pemulih voltan dinamik ialah alat-alat yang

paling berkesan dan berdasarkan prinsip *VSC*. DVR menyalurkan voltan sesiri dengan sistem voltan dan D-STATCOM menyalurkan arus kepada sistem untuk membetulkan voltan lendut, voltan kembang dan gangguan. Hasil yang komprehensif ditunjukkan bagi menilai kecekapan setiap komponen sebagai penyelesaian kuasa biasa yang berpotensi.

CONTENTS

CHAPTER 3 METHODOLOGY

CHAPTER 4 RESULTS AND DATA ANALYSIS

CHAPTER 5 CONCLUSION AND RECOMMENDATION

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS AND ABBREVIATIONS

A	-	Ampere
AC	-	Alternating Current
D.O.L	-	Direct-On-Line
EMTDC	-	Electromagnetic Transient Programme with DC Analysis
Hp/hp	-	Horsepower
IM	-	Induction Motor
PSCAD	-	Power System Computer Aided Design
Pu	-	per unit
RMS	-	Root Mean Square
kV	-	kilovolt
V	-	Volts

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Project Background

Both electric utilities and end users of electrical power are becoming increasingly concerned about the quality of electric power. The term *power quality* has become one of the most prolific buzzword in the power industry[18] . The issue in electricity power sector delivery is not confined to only energy efficiency and environment but more importantly on quality and continuity of supply or power quality and supply quality. Electrical Power quality is the degree of any deviation from the nominal values of the voltage magnitude and frequency. Power quality may also be defined as the degree to which both the utilization and delivery of electric power affects the performance of electrical equipment[2] . From a customer perspective, a power quality problem is defined as any power problem manifested in voltage, current, or frequency deviations that result in power failure or disoperation of customer of equipment. Power quality is certainly a major concern in the present era; it becomes especially important with the introduction of sophisticated devices, whose performance is very sensitive to the quality of power supply.[4].

Modern industrial processes are based a large amount of electronic devices such as programmable logic controllers and adjustable speed drives. The electronic devices are very sensitive to disturbances and thus industrial loads become less tolerant to power quality problems such as voltage dips, voltage swells, harmonics, flickers, interruptions, and notches.

Below is a table showing some common power quality problems and their effects:

Problems	Effects
Over voltage	Overstress insulation
Under voltage	Excessive motor current
Unbalance	Motor heating
Neutral-ground voltage	Digital device malfunction
Interruption	Complete shut down
Sag	Variable speed drive & computer trip-out
Swell	Overstress insulation
Fluctuations	Light flicker

Table 1.0: Some effects of power quality problems for the voltage events.

Among them, two power quality problems have been identified to be of major concern to the customers are voltage sags and swells, but this project will be focusing on voltage sags/swells, as well as interruptions.

Voltage dips are considered one of the most severe disturbances to the industrial equipment. A paper machine can be affected by disturbances of 10% voltage drop lasting for 100ms. A voltage dip of 75% (of the nominal voltage) with duration shorter than 100ms can result in material loss in the range of thousands of US dollars for the semiconductors industry. Swells and over voltages can cause over heating tripping or even destruction of industrial
equipment such as motor drives.[7]

1.2 Objectives

The aim of this project is to study the various types of power quality problems and their effects on both the utility and customer's side of the system, with more emphasis on these two namely: voltage sag and voltage swells, and how they can be mitigated with the use of the DVR (Dynamic Voltage Restorer) and the D-STATCOM (Distribution Static Compensator),which are also called custom power devices,and its effectiveness in mitigating the named power quality problems given above.

The objectives of this project are:

i. To investigate that the mitigation techniques are suitable for voltage sags,swells and interruptions in the event of a fault in a distribution system.
ii. To observe the effect on the characteristic of voltage sag, swell and interruption for the techniques.
iii. To suggest on the suitability of the techniques used for the mitigation process.

1.3 Background of study

Power quality is certainly a major concern in the present era; it becomes especially important with the introduction of sophisticated devices, whose performance is very sensitive to the quality of power supply. Modern industrial processes are based a large amount of electronic devices such as programmable logic controllers and adjustable speed drives. The electronic devices are very sensitive to disturbances and thus industrial loads become less tolerant to power quality problems such as voltage dips, voltage swells, and harmonics. Voltage dips are considered one of the most severe disturbances to the industrial equipment. Swells and over voltages can cause over heating tripping or even destruction of industrial

equipment such as motor drives. Electronic equipments are very sensitive loads against harmonics because their control depends on either the peak value or the zero crossing of the supplied voltage, which are all influenced by the harmonic distortion. This project analyzes the key issues in the power quality problems. As one of the prominent power quality problems, the origin, consequences and mitigation techniques of voltage sag/swells and interruptions problem will be discussed in detail. The study describes the techniques of correcting the problems in a distribution system by a strong power electronics based devices called Dynamic Voltage Restorer (DVR) and the Distribution Static Compensator (D-STATCOM). Voltage from both devices is connected into the system to correct the problems.The performance of the DVR and the D-STATCOM is studied for the power quality problems to be viewed.

1.4 Problem Statements

With the increased use of sophisticated electronics, high efficiency variable speed drive, and power electronic controller, power quality has become an increasing concern to utilities and customers. Voltage sags is the most common type of power quality disturbance in the distribution system. It can be caused by fault in the electrical network or by the starting of a large induction motor. Although the electric utilities have made a substantial amount of investment to improve the reliability of the network, they cannot control the external factor that causes the fault, such as lightning or accumulation of salt at a transmission tower located near to sea.

Meanwhile during short circuits, bus voltages throughout the supply network are depressed, severities of which are dependent of the distance from each bus to point where the short circuit occurs. After clearance of the fault by the protective system the voltages return to their new steady state values. Part of the circuit that is cleared will suffer supply disruption or blackout. Thus in general a short circuit will cause voltage sags/swells throughout the system and may cause blackout to a small portion of the network.

1.5 Scope of Study

The scope of study tends to look at the following,

I. Investigate the mentioned power quality problems,

II. How they can be mitigated with the custom power device introduced.

III. More details about the mitigation device would also be given,in terms of their composition and design; and also how they will be configured in an electrical system.

CHAPTER 2

LITERATURE REVIEW

2.1 Power Quality

Power quality is simply the interaction of electrical power with electrical equipment. If electrical equipment operates correctly and reliably without being damaged or stressed, we would say that the electrical power is of good quality. On the other hand, if the electrical equipment malfunctions, is unreliable, or is damaged during normal usage, we would suspect that the power quality is poor[2]. There are two approaches to the mitigation of power quality problems. The solution to the power quality can be done from customer side or from utility side . First approach is called load conditioning, which ensures that the equipment is less sensitive to power disturbances, allowing the operation even under significant voltage distortion. The other solution is to install line conditioning systems that suppress or counteracts the power system disturbances. A flexible and versatile solution to voltage quality problems is offered by active power filters. Currently they are based on PWM converters and connect to low and medium voltage distribution system in shunt or in series. Series active power filters must operate in conjunction with shunt passive filters in order to compensate load current harmonics. Shunt active power filters operate as a controllable current source and series active power filters operates as a controllable voltage source. Both schemes are implemented preferable with voltage source PWM inverters , with a dc bus having a reactive element such as a capacitor[8].

REFERENCES

1. H. Hingorani,(1995). “Introducing custom power” IEEE spectrum, vol.32 no.6, p 41-48.

2. M. H. J. Bollen,(2000) “Understanding Power Quality Problems—Voltage Sags and Interruptions” Piscataway, New York: IEEE Press.

3. M.Madrigal, E.Acha,(2000), “Modelling of Custom Power Equipment Using Harmonic Domain Techniques”, IEEE.

4. Ewald F.F, Mohammad A.S.M, (2008), Power Quality in Power Systems and Electrical Machines, Burlington,USA, Elsevier Academic Press.

5. Ray Arnold, (2001), “Solutions to Power Quality Problems” power engineering journal 2001 pages: 65-73.

6. John Stones and Alan Collinsion, (2001), “Introduction to Power Quality” power engineering journal , pages: 58 -64.

7. E. Acha, V. G. Agelidis, O. Anaya-Lara, and T. J. E. Miller,(2001), ‘Electronic Control in Electrical Power Systems,” London, U.K., Butterworth-Heinemann.

8. Gregory F. Reed, Masatoshi Takeda, (1998), "Improved power quality solutions using advanced solid-state switching and static compensation technologies," Power Engineering Society , Winter Meeting, IEEE.

9. M. Wang and A. V Mamishev, “Classification of Power Quality Events Using

Optimal Time-Frequency representation," Part 2: Application, IEEE Transactions on Power Delivery, vol. 18, pp. 544-549, 2003.

10. Flores, R.A, "State of the Art in the Classification of Power Quality Events, An Overview". Harmonics and Quality of Power, 2002, 10th International Conference on Volume 1, issue, 6-9, pp. 17-20, Oct. 2002.

11. David Hart, David Uy, Damir Novosel, Steven Kunsman, Carl LaPlace and Marco Tellarini, "Improving Power Quality", ABB Review, 4/2000.

12. Adly Girgis, Bi Chang and Elham Makram, "A Digital Recursive Measurement for On Line Tracking of Power Systems Harmonics", IEEE transactions on Power Delivery, Vol. 6, No.3 July 1991.

13. V.K. Ramachandaramurthy, A. Arulampalam, C.Fitzer, C. Zhan, M. Barnes and N.Jenkins,(2002),"Supervisory control of dynamic voltage restorers "IEE Proc.-Gener.Transm. Distrib. Vol. 151, No. 4, pp. 509-516.

14. Chris Fitzer, Mike Barnes, Peter Green,(2004), " Voltage Sag Detection Technique for a Dynamic Voltage Restore'', IEEE Transactions on Power Delivery, Vol. 40,No. 1,pp. 203-212.

15. Il-Yop Chung, Dong-Jun Won, Sang-Young Park,Seung-Il Moon, Jong-Keun Park "The DC link energy control method in dynamic voltage restorersystem" Electrical Power and Energy Systems.

16. Pohjanheimo, P. and E. Lakervi,(2000). Steady state modeling of custom power components in power distribution networks. In: IEEE Power Engineering Society Winter Meeting, pp: 2949-2954.

17. S&C Electric Company, Descriptive Bulletin 654-30,(2002),Pure Wave DVR Dynamic Voltage Restorer: Protects Sensitive loads from Voltage Sags and swells, page 2 of 4.

18. Roger C. Dugan/Mark F. McGranaghan, etc,(2002),Electrical Power Systems Quality, McGraw-Hill,Professional Engineering.

19. Douglas S. Dorr,(1995) "Point of Utilization Power Quality Study Results", IEEE Transactions on Industry Applications, Vol. 31, No. 4.

20. Bollen, M.H.J.,(2001)" Voltage sags in three-phase systems" Power Engineering Review, IEEE, Vol. 21, Issue: pp: 8 - 11, 15.

21. M.S. Looi, H.H. Goh, and B.C. Kok, ''Comparison betweem Direct-On-Line, Star-Delta and Autotransformer Induction Motor Starting Methods in terms of Power Quality, '' in IMECS, 2009, paper ICEE_56, p.1558.

22. PSCAD Electromagnetic Transients User's Guide, The Professional's Tool for Power System Simulation.