UNIVERSITI PUTRA MALAYSIA

DEVELOPMENT OF FLYWHEEL INVERTER SYSTEM FOR VOLTAGE SAG MITIGATION

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By

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Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia in Fulfilment of the Requirement for the Degree of Master of Science

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Specially dedicated to my lovely wife and family

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Master of Science

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July 2006

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Power quality is an issue that has been given a continuous attention by the electricity providers and also the consumers. Nowadays, the application of power electronic devices in the industrial sector has rapidly increased. Many of the equipment used in the industries are sensitive to an even small disturbance in power supply such as voltage sag. Voltage sag can cause low quality product, low production quantity and also machine restarting. The voltage sag problem can reduce the profit in long term if it is not given a proper attention.

There are many type of solutions that have been developed to mitigate the voltage sag problem. The type of solution that is usually taken by the consumers is by installing energy storage device such as battery, capacitor and motor generator (MG) to inject the power back to the AC system during the voltage sag. In this work, a flywheel is used as the energy storage device. Flywheel has few advantages such as long life cycle, low maintenance work and also cheap.

A DC machine has been used with the flywheel in this application. At normal condition, the flywheel stores kinetic energy during the rotation of the machine. The kinetic energy will be transformed to electrical energy when there is a sag in the AC system. In order to deliver the energy to the AC system, the flywheel is used with the static synchronous compensator (STATCOM) system. This system supplies reactive power to compensate the voltage loss during the sag.

This work has been divided into two parts which are the simulation and the experiment part. Two types of faults which are balanced phase fault and unbalanced phase fault have been simulated. The balanced phase fault has been created by starting of large induction motor. On the other hand, the unbalanced phase fault has been created by performing a short circuit on the AC supply system. For the experiment part, this sag mitigation system has been tested under the balanced phase fault condition.

From both the simulation and experiment results, a good agreement has been obtained. The mitigation system has shown a good ability in mitigating voltage sag problem.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia
sebagai memenuhi keperluan untuk ijazah Master Sains

MEMBANGUNKAN SISTEM PENYONGSANG RODA TENAGA UNTUK MENGATASI MASALAH VOLTAN LENDUT

Oleh

RUHAIZAD ISHAK

Julai 2006

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Kualiti kuasa adalah satu isu yang sentiasa diberikan perhatian yang berterusan oleh pembekal-pembekal elektrik dan juga pengguna-pengguna. Pada masa ini, penggunaan alat-alat elektronik kuasa di dalam sektor industri telah meningkat dengan begitu cepat. Kebanyakan peralatan kelengkapan yang digunakan dalam industri-industri adalah sensitif walaupun terhadap gangguan kecil di dalam bekalan kuasa seperti voltan lendut. Voltan lendut boleh mengakibatkan produk berkualiti rendah, pengeluaran berkuantiti rendah dan permulaan semula mesin. Masalah voltan lendut jika tidak diberikan perhatian yang sewajarnya boleh mengurangkan keuntungan dalam jangka masa panjang.

Terdapat pelbagai jenis penyelesaian yang telah dibangunkan untuk mengatasi masalah voltan lendut. Jenis penyelesaian yang biasanya diambil oleh para pengguna adalah dengan memasang alat penyimpan tenaga seperti bateri, kapasitor dan penjana motor untuk menyuntik kuasa kembali kepada sistem AC semasa voltan lendut. Di dalam kerja ini, sebuah roda tenaga digunakan sebagai alat penyimpan tenaga. Roda tenaga mempunyai beberapa kelebihan seperti tempoh hayat yang panjang, kerja penyelenggaraan yang rendah dan murah.

Sebuah mesin DC telah digunakan bersama dengan roda tenaga di dalam aplikasi ini. Pada keadaan normal, roda tenaga tersebut menyimpan tenaga kinetik semasa mesin berputar. Tenaga kinetik akan ditukar kepada tenaga elektrik apabila terdapat voltan lendut di dalam sistem AC. Bagi menyalurkan tenaga kepada sistem AC, roda tenaga tersebut digunakan bersama dengan sistem pemampas segerak statik. Sistem ini membekalkan kuasa reaktif untuk mengganti voltan yang hilang semasa voltan lendut.

Kerja ini telah dibahagikan kepada dua bahagian iaitu bahagian simulasi dan bahagian eksperimen. Dua jenis kerosakkan iaitu kerosakkan fasa seimbang dan kerosakkan fasa tidak seimbang telah disimulasikan. Untuk kerosakkan fasa seimbang, ia telah dihasilkan melalui permulaan sebuah motor aruhan yang besar. Sementara itu pula, kerosakkan fasa tidak seimbang telah dihasilkan melalui perlaksanaan litar pintas pada sistem bekalan AC tersebut. Untuk bahagian eksperimen, sistem pemulihan ini telah diuji dalam keadaan kerosakkan fasa seimbang.

Satu kesesuaian yang baik telah dicapai daripada kedua-dua keputusan simulasi dan eksperimen. Sistem pemulihan ini telah menunjukkan satu keupayaan yang baik di dalam mengatasi masalah voltan lendut.

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I certify that an examination committee has met on17 July 2006 to conduct the final examination of Ruhaizad Ishak on his Master of Science thesis entitled “Development of Flywheel Inverter System for Voltage Sag Mitigation” in accordance with Universiti Pertanian Malaysia (higher Degree) Act 1980 and Universiti Pertanian Malaysia (higher Degree) Regulations 1981. The Committee recommends that the candidate be awarded the relevant degree. The Committee Members for the candidate are as follows:

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This thesis submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirements for the degree of Master of Science. The members of the Supervisory Committee are as follows:

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DECLARATION

I hereby declare that the thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at UPM or other institutions.

RUHAIZAD ISHAK

Date: 28 July 2006

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CHAPTER 1

INTRODUCTION

1.1 Overview

Power quality is an important issue that has always received high attention from the electricity providers and the consumers. The definition of power quality has substantially evolved into different kind of meanings since it was first introduced. In the early years, the term of power quality was defined as a degree of reliability for the power supply system. In other words high power quality refers to high grade of electricity supply and contrarily low quality refers to low grade of electricity supply which due to interruptions that leads to power failure, equipment shutdown and system malfunctions. With new invention of technologies, power quality definition has been redefined. A general definition of power quality that commonly used is any problem related in voltage, current or frequency deviations that result in power failure or malfunction of customer equipment [Dugan et al, 1996].

Power quality problems cover variety of electricity phenomenon which is characterized by voltage and current. To facilitate researchers in studying power quality problems, the International Electrical Community (IEC) has classified the electricity phenomenon into several different types of groups such as transients, oscillatory, sags and swells. Shown in Table 1.1 below is an example of the power quality phenomenon and descriptions of their characteristic.

Table 1.1: Category of power disturbances

Categories	Typical duration	Typical voltage magnitude
Oscillatory	0.3 – 50 ms	0 – 4 pu
Instantaneous sag	0.5 – 30 cycles	0.1 – 0.9 pu
Instantaneous swell	0.5 – 30 cycles	1.1 – 1.8 pu
Temporary interruption	3 s – 1 min	0.1 pu
Under voltage	> 1 min	0.8 – 0.9 pu
Over voltage	> 1 min	1.1 – 1.2 pu
Harmonics	Steady state	0.5 – 0.2 %

Note: pu is per unit value

The operations of modern power electronic systems are greatly influenced by short disruption of voltage sag. The increasing sensitivity of the equipment to voltage variations has accelerated the interest of the researchers in promoting power quality solutions.

The demand for power quality solutions has increased due to the increasing awareness among the users. There are many options can be used to mitigate the voltage sag. Nevertheless the choice of the end user is always for the cheap and reliable solution. Different types of device are currently available in the market however the choice of the mitigation must be suitable with the user's operation system.

1.2 Problem Statement

Lately the power electronic devices can easily be found from the small electrical appliances to the large scale equipments. Especially in the industrial sector, most of the manual control operations have been replaced by the automated operations which use a lot of power electronic devices to control the process. All these equipment are highly prone to power disturbances such as voltage sags, swells and interruptions. Voltage sags has been the most reported disturbance that disrupts the operation of industrial sensitive equipment such as relays and microprocessors. The industrial sectors are the most affected users due to the voltage sag. Voltage sag with only few seconds may cause a huge problem in the manufacturing process such as misoperation of machines and the controlling system. As a result this causes damage in the manufacturing products and losses in the production quantity. Therefore if this problem is not given proper attention by the manufacturers, it may affect the company profit in the long term.

Basically the purpose of this research is to investigate the possibility of using the readily available machines in the manufacturing companies to overcome the voltage sag problem. Besides doing their specified tasks, in this study the function of the machines are expanded to be used as an energy storage device during. The energy that has been stored can be used to compensate the voltage loss when the voltage sag attacked the factories power system.

1.3 Aim and Objective

The idea of this work comes from the problem faced by the industrial sector in battling against the voltage sag problem. Therefore the objective of this research is to perform a voltage sag mitigation based on the mechanical energy storage system (MESS). The MESS system in this work is formed by a machine and a flywheel to generate kinetic energy.

The aim of this project is to build a complete mitigation model that can be used to overcome the voltage sag problem encountered in the industrial field. The model built in this work is firstly simulated by using power system simulation. A software program called MATLAB simulink is used to analyze the electrical function of the mitigation system. Exposure and familiarization in using the simulation program is a valuable benefit that should be collected at the end of this project. The advantage of using the simulation program is that the performance of the system can be improved prior to the implementation of the hardware work.

1.4 Scope of Work

Basically this research is to study the effect of installing voltage sag mitigation device at the end user's part especially at the industrial sector where many large machines are used. Therefore in this work, focus is given on machine components such as induction motor (as line load) and DC machine (as energy storage device) to form a situation at a factory site.

Generally this work is divided into two parts which are the simulation part and the experiment part. For the simulation part, the work is divided into two which are simulation on the power system with balanced fault (motor starting) and the other part is with unbalanced fault (short circuit). Through the simulation process, few measurement results have been collected. Normally the simulation results are more reliable l when it is supported by experiment results to prove that the system works theoretically and physically. Therefore in the final part of this work, the hardware of the system was built. However due to limitation in the lab facilities in performing the short circuit fault therefore only motor starting fault is to be experimented for the hardware part.

1.5 Thesis Layout

Generally this thesis is divided into five chapters whereby Chapter 1 gives an overview of the issues concerning with power quality. Some problems related to power quality were briefly touched in this chapter. Besides that the problem statement, aim and objective of this work is also mentioned here. The scope of work that is planned to be performed in this research is stated in this section and finally this is followed by the thesis layout.

Chapter 2 presents the details of the power quality situations. This issue is deliberately elaborated from as early as histories to present achievements. Issues on voltage sag studies covering this chapter from the start to the end. A lengthy description on characteristics, causes and effects of voltage sag were carefully delivered in this chapter. Other than