UNIVERSITY OF ÇUKUROVA
INSTITUTE OF NATURAL AND APPLIED SCIENCES

MSc THESIS

Yusuf Alper KAPLAN

MODELING AND ANALYSIS OF CUSTOM POWER PARK BY PSCAD/EMTDC PROGRAM

DEPARTMENT OF ELECTRICAL AND ELECTRONICS ENGINEERING

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YÜKSEK LİSANS TEZİ

ELEKTRİK ELEKTRONİK MÜHENDİSLİĞİ ANABİLİM DALI

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ABSTRACT

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The advances in power electronics based devices to improve power quality have been increased the interest on Custom Power Park (CPP). CPP concept means the integration of multiple CP Devices within the Industrial/Commercial Park, which offers customers high quality of power at the distribution system voltage level. CPP is one of the most useful solutions to prevent voltage sags/swells and harmonics from distribution lines.

In this thesis, CPP has been modeled by using PSCAD/EMTDC program. CPP is composed of Static Transfer Switch (STS) and Dynamic Voltage Restorer (DVR). The operation principles of STS and DVR have been explained in detail and then they have been modeled with PSCAD/EMTDC program. Simulation results have been comprehensively investigated. Different types of faults are applied for STS and DVR in CPP and the response of the system for these disturbances are examined.

Keywords: Power Quality, Custom Power Park, Dynamic Voltage Restorer, Static Transfer Switch

ÖZ

YÜKSEK LİSANS TEZİ

ÖZEL AMAÇLI GÜÇ PARKININ PSCAD/EMTDC PROGRAMINDA MODELLEMESİ VE ANALİZ EDİLMESİ

Yusuf Alper KAPLAN

ELEKTRİK ELEKTRONİK MÜHENDİSLİĞİ ANABİLİM DALI
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Doç. Dr. İlyas EKER

Güç kalitesini iyileştirmek için kulanılan güç elektroniği tabanlı donanımlardaki gelişmeler, Özel Amaçlı Güç Parkına olan ilgiyi arttırmıştır. Özel Amaçlı Güç Parkı, endüstriel ve ticari park dahilinde çoklu özel amaçlı güç aygıtlarının bütünlüğü anlamına gelip, dağıtım sistemindeki gerilim seviyesinde müşterilere kaliteli güç sunar. Dağıtım hatlarında oluşan gerilim düşümü/yükselimi ve harmonikleri önlemek gerekmektedir ve bunun için Özel Amaçlı Güç Parkı uygulamaları en uygun çözümlerden biridir.

Bu tezde Özel Amaçlı Güç Parkı PSCAD/EMTDC programı kullanılarak modellenmiştir. Özel Amaçlı Güç Parkı, Statik Transfer Anahtarı (STA) ve Dinamik Gerilim İyileştirici (DGİ) kullanılarak oluşturulmuştur. STA ve DGİ' nin çalışma prensipleri detaylı olarak anlatıldıktan sonra PSCAD programında modellenmiş ve simulasyon sonuçları incelenmiştir. Özel Amaçlı Güç Parkının STA ve DGİ kısımlarında değişik hatalar uygulanmıştır ve bu hatalara sistemin tepkisi incelenmiştir.

Anahtar Kelimeler: Güç Kalitesi, Özel Amaçlı Güç Parkı, Dinamik Gerilim İyileştirici, Statik Transfer Anahtarı

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CONTENT **PAGE**

LIST OF FIGURES **PAGE**

LIST OF ABBREVIATIONS

AF	:	Alternate Feeder
BBM	:	Break Before Make
CPP	:	Custom Power Park
DC	:	Direct Current
DG	:	Diesel Generator
DVR	:	Dynamic Voltage Restorer
IEEE	:	Institute of Electrical and Electronics Engineers
IGBT	:	Insulated Gate Bipolar Transistor
MBB	:	Make Before Break
PF	:	Preferred Feeder
PLL	:	Phase Locked Loop
PQ	:	Power Quality
PI	:	Proportional – Integral
PWM	:	Pulse Width Modulation
STS	:	Static Transfer Switch
THD	:	Total Harmonic Distortion
UPS	:	Uninterrupted Power System

1-) INTRODUCTION

Custom power is the employment of power electronic or static controllers in medium voltage distribution systems for the purpose of supplying a level of reliability and/or power quality that is needed by electric power customers sensitive to power quality variations. In other words custom power is intended to protect the customers from interruptions and voltage reductions originating in the utility system as well as those transfered to customers from other customers via the utility system and even internal disturbances. Custom power devices, or controllers, include static switches, DVRs, injection transformers, energy storage modules that have the ability to perform current interruption and voltage regulation functions in a distribution system to improve reliability and/or power quality (Daniel and Sannino, 2003).

The last decade has seen a marked increase on the deployment of end-user equipment that is higly sensitive to poor quality control electricity supply. Several large industrial users are reported to have experienced large financial losses as a result of even minor lapses in the quality of electricity supply. A great many efforts have been made to remedy the situation, where solutions based on the use of the latest power electronic technology figure prominently. Indeed, custom power technolgy, the low-voltage counterpart of the more widely known flexible ac transmission system technology, aimed at high-voltage power transmission applications, has emerged as a credible solution to solve many of the problems relating to continuity of supply at the end-user level (Anaya-Lara and Acha, 2002).

Electric power is a form of energy we have come to depend on, so much so, that in many automated product line businesses can not tolerate its loss for even a few tens of milliseconds. With the ever-increasing role of electricity in improving the quality of life, productivity of manufacturing and service industries, and efficient energy use, power electronics will play significant part (Narain G, 1998).

Custom Power is a concept based on the use of power electronic controllers in the distribution system to supply value-added, reliable, high quality power to its customers. For many customers this is a preferred alternative to the customer improvising utility power by their own means, mostly in a band aid manner with numerous uninterruptable power supplies, as is done now. Many utilities are moving in the direction of value-added Custom Power service to their large customers.

Custom Power means that the customer recieves specified power quality form a utility, which includes an acceptable combination of following features.

- No power interruption
- Magnitude and duration of voltage reductions within specified limits.
- Magnitude and duration of overvoltages within specified limits.
- Low harmonic voltages
- Low phase unbalance

This can be done on the basis of an individual, large customer, industrial / commercial park or a supply for a high technology community on a wide area basis (Narain G, 1998).

Until recently, voltage reductions and short term outages were not an issue, the number of cumulative hours of interruptions per year has been the benchmark measure for reliability has been changing, and the pace of change has accelerated.

Studies of cumulative monitoring of events at a large number of distribution substations show that most of the sag events are of short duration of a few cycles and less than 40% voltage reduction and only 1% of events with voltage reduction of less than 80%. With the availability of two independent feeders at the distribution substation, and high speed solid state transfer switches, a large percentage (70–90%) of the events can be eliminated in a much more efficient and economical manner than the customers own solutions.

Custom Power is intended to protect the customers from interruptions and voltage reductions originating in the utility system as well as those transferred to customers from other customers via the utility system and even internal disturbances (Narain G, 1998).

The needs for the Custom Power concept are given. These are;

- Most of the interruptions and voltage reductions occur in the utility system on account of lightning faults on transmission and distribution lines, low

- frequency dynamic swings of the transmission system, trees touching the wires, equipment failure, switching, etc.
- Impulses, switching surges and overvoltages affecting the insulation, would most likely result from lightning strikes and switching events in the transmission and distribution system.
- Temporary overvoltages lasting from several seconds would largely result from large load changes, capacitor switching, transformer switching, dynamic stability swings, excessive leading-VARs during light loads, etc. in the utility system.
- Voltage unbalances in a three-phase supply would occur mostly due to large unbalanced phase impedances.
- Harmonics would most likely be the consequence of high harmonics in the customer load, or the saturation of a utility's transformers. These harmonics would then be amplified by the natural resonances in the utility system and customer system(Narain G, 1998).

Compared to voltage reductions, overvoltages are less common and do not affect customer productivity unless the overvoltages cause equipment failure.

Simulation study of a custom power park (CPP) is presented. It is assumed that the park contains unbalanced and nonlinear loads in addition to a sensitive load. Two different types of compensators are used seperately to protect the sensitive load terminal voltage. Additional issues such as the load transfer through a static transfer switch, detection of sag/fault etc. are also discussed. The concepts are validated through PSCAD/EMTDC simulation studies on a sample distribution system.

2-) LITERATURE SURVEY

In this chapter a literature survey of CPP operation, modeling and control will be studied. The CPP is composed by DVR and STS. There are many articles regarding the modelling of DVR and STS but there are not many articles about CPP. The basic aim of this thesis is to develop simulation models of Custom Power Park. This thesis deals with the modeling of Custom Power topologies in PSCAD/EMTDC.

In reference (A. Ghosh, July 2005), the simulation study of a costom power park (CPP) is presented. It is assumed that the park contains unbalanced and nonlinear loads in addition to a sensivite load. Two different types of compensators are used separately to protect the sensitive load against unbalance and distortıon caused by the other loads. It has been shown that a shunt compensator can regulate the voltage of the CPP bus, whereas the series compensator can only regulate the sensitive load terminal voltage. Additional issues such as the load transfer trough a static transfer switch, detection of sag/fault etc. are also discussed. The concepts are validated PSCAD/EMTDC simulation studies on a sample distribution system.

In reference (Olimpo Anaya-Lara and E. Acha.,2002), this paper addresses the timely issue of modeling and analysis of custom power controllers, a new generation of power electronics-based equipment aimed at enhancing the reliability and quality of power flows in low-voltage distribution networks. The modeling approach adopted in the paper is graphical in nature, as opposed to mathematical models embedded in code using a high-level computer language. The well developed graphic facilities available in an industry standard power system package, namely PSCAD/EMTDC, are used to conduct all aspects of model implementation and to carry out extensive simulation studies. Graphics-based models suitable for electromagnetic transient studies are presented for the following three custom power controllers; the dynamic voltage restorer (DVR), stating transfer switch (STS). Comprehensive results are presented to assess the performance of each device as a potential custom power solution.

In reference (John Godsk Nielsen, Michael Newman, 2004), the dynamic voltage restorer (DVR) has become popular as a cost effective solution for the protection of sensitive loads from voltage sags. Implementations of the DVR have been proposed at both o low voltage (LV) level, as well as a medium voltage (MV) level; and give an opportunity to protect high power sensitive loads from voltage sags.

In reference (M. A. Hannan and A. Mohamed, 2002), the dynamic voltage restorer (DVR) is a power guality device that has gained an increasing role in protecting industries against disturbances such as voltage sags and swells related to remote system faults. This paper present a simulation study on the interaction between the DVR and the distribution system. The multilevel, twenty-four pulse DVR model is used in the simulations which are implemented in PSCAD/EMTDC program. For the DVR control strategy, the sinusodial pulse width modulation technique is used. Various issues have been addressed in the simulation studies such as, the effectiveness of DVR in mitigating voltage sags. impact of phase shift during a voltage sag on sizing of DVR, harmonic reduction in the DVR and influence of induction motor loads on the voltage sag compensation cabability.

In reference (Sang-Young Park and Jong-Keun Park, 2001), in the field of custom power device application, the modeling of power converter is very diffucult and important. The shunt type custom power devices are based on the high frequency carrier voltage source converter. In this paper, we propose two measuring methods of AC side modeling by the dead time voltage and the semiconductor device loss. One is the open loop. Another is the closed-loop test.

In reference (Narain G. Hingorani, Hingorani Power Electronics, 1998), electric power is a form of energy we have come to depend on, so much so, that in many automated product line businesses can not tolerate its loss for even a few tens of miliseconds. With the ever-increasing role of electricity in improving the quality of life, productivity of manufactuaring and service industries, and efficient energy use, power electronics will play a significant part. The power electronics building block concept sponsored by the Office of Naval Resaurce has played a key role in acceralating the trend towards reduced cost, losses, weight, volume, and much lower engineering effort to design applications of power electronics. One of the growing power electronics applications power quality.

In reference (Chunhong He and Feng Li, 2004), due to the growing reguirement for process controls in automated plants, electirical consumers are becoming increasingly more sensitive to the quality and reliability of the power supplies. Thyristor–based Static Transfer Switches (STSs) are able to provide critical loads with a fast transfer to a backup auxiliary source when the main source fails. In this paper, a Static Tranfer Switch model in EMPT-Works RV is developed. Results from three test cases concerning the system are presented.

In reference (M. N. Moschakis and N.D. Hatziargyriou, 2003), an effective way to improve power quality and reliability of sensitive customers is to use a static transfer switch. This device enables a very fast change in the supply of the customer to an alternate feeder providing adequate power conditioning for several power quality problems, such as voltage sags, swells, and interruptions. An analytical model of STS is proposed and its performance is verified using the electromagnetic transient simulation package. Simulations using this model are performed in order to handle voltage sags based on real measuruments on an actual industrial customer’s supply voltage. Different phase angles and magnitudes of the two alternate source prefault voltages and different fault instances are considered.

The stability study is discussed in dynamic voltage restorer.(Chi-Seng Lam, Man-Chung Wong) A series compensation device is mainly used to mitigate voltage sags. Based on the appropriate modeling of the DVR system, the detailed stability analysis of the DVR system is performed. This research work is an attempt to obtain mathematical interactions between the DVR and linear loads. In this paper, theoretical study of different linear load effects on the system stability will be proposed and analyzed, in which the stable operation range of the DVR is investigated. Moreover, a significant reduction of inverter gain in the situation of over-modulation can strongly affect the system stability

3-) POWER QUALITY PROBLEMS

Power quality can be defined as having a bus voltage that closely resembles a sinusoidal waveform of required magnitude. Increasing number of sensitive devices to variations, the requirement for reducing losses and the behaviors of interconnected networks are some reasons which increase the importance of power quality concept. In the industry, power quality polluting loads are increasing day by day. The main reasons for concern with power quality (PQ) are as following (Dong, 2004):

- § End user devices become more sensitive to PQ due to many microprocessor based controls.
- § Complexity of industrial processes; the re-startup is very costly.
- § Large computer systems in many businesses facilities.
- § Power electronics equipment used for enhancing system stability, operation and efficiency. They are major source of bad PQ and are vulnerable to bad PQ as well.
- § Deregulation of the power industry.
- § Complex interconnection of systems, which results in more severe consequences if any one component fails.
- § Continuous development of high performance equipment; Such equipment is more susceptible to power disturbances.

The users demand higher power quality to use more sensitive loads to automate processes and improve quality. Some basic criterions for power quality are constant rms value, constant frequency, symmetrical three-phases, pure sinusoidal wave shape and limited total harmonic distortion (THD). These values should be kept between limits determined by standards if the power quality level is considered to be high. Power quality covers several types of problems of electrical supply and power system disturbances. The cost of power interruptions and disturbances can be quite high as a result of the important processes controlled and maintained by the sensitive devices.

The power quality issues are vital concerns to the majority of industries today. The power quality is an index to quality of current and voltage available to industries, commercial and household consumers of electricity. The quality of voltage waveform at the entry point of a consumer premise depends upon the types of loads within that premise. These loads may be linear (nonharmonics producing) and nonlinear (harmonics producing) in nature. For linear loads, any distortion in the voltage waveform should be responsibility of the supply authority. Contrary to this, for nonlinear loads, any deviation from no load to full load voltage waveform is responsibility of consumer itself. Therefore, the quality of current exactly depends upon the quality of voltage with the non-harmonics producing loads.

3.1) Voltage sag and swell

Voltage sag is a fundamental frequency decrease in the supply voltage for a short duration (5 cycles to one minute).

Voltage swell is defined as the increase of fundamental frequency voltage for a short duration.

The definitions of sags and swells have evolved over the past fifteen years, as have the power quality instruments that measure them. Voltage sags, or voltage dips as they are referred to in the European communities, were initially any reduction in voltage below a user- defined low limit for between one cycle and 2.55 seconds.
Voltage swells, originally referred to as voltage surges, were similar to voltage sags, except that the voltage exceeded a user defined high limit. While various definitions relative to the amplitude and duration are still in use, the IEEE 1159-1995 Recommended Practice on Monitoring Electric Power Quality has defined them as follows;

Voltage sag (dip) is a decrease to between 0.1 and 0.9 pu in rms voltage or rms current at the power frequency for durations of 0.5 cycles to 1 minute.

Voltage swell is an increase to between 1.1 pu and 1.8 pu in rms voltage or rms current at the power frequency durations from 0.5 to 1 minute.

3.2) Interruption

An interruption occurs when the supply voltage (or load current) decreases to less than 0.1 per unit for a period of time not exceeding 1 minute.

Figure 3.1 shows the common voltage disturbances.

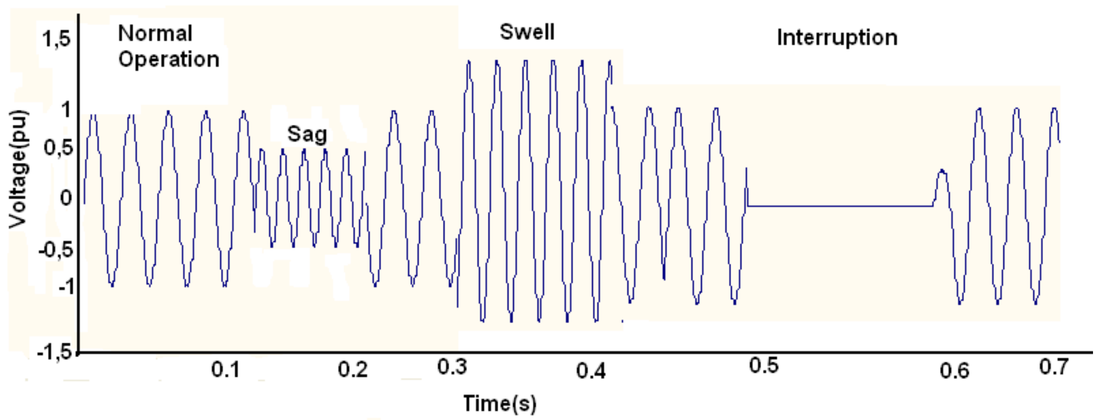

Figure 3.1. Voltage Disturbances (Ghosh, 2005)

3.3) Harmonics

For a fundamental frequency f_0, harmonics are the component of the voltage or current which have frequency different than fundamental frequency f_0. Harmonics can be classified into 3 groups.

a) Integer harmonics: integer harmonics have frequency components that are integer multiples of f_0, i.e., nf_0 where n is a positive integer. Integer harmonics are produced by power electronics equipment and loads, like uninterruptable power supply (UPS) etc.

b) Subharmonics: subharmonics are those components that are below the fundamental component, i.e., mf_0 for $0 < m < 1$

c) Interharmonics: interharmonics are those components that are above fundamental component but are not integer multiple of the fundamantal

d) frequency, i.e., mf_0 for non-integer m >1. Cycloconverters mainly cause interharmonics and it is difficult to detect.

A measure of harmonic content in a signal is the total harmonic distortion (THD). The percentage THD in a voltage is given as;

$$THD = \frac{\sqrt{\sum_{n=2}^{\infty} V_n^{\ 2}}}{V_1} \qquad (1)$$

Where V_n denotes the magnitude of the n^{th} harmonic voltage and V_1 is the magnitude of the fundamental voltage.(Fig. 3.2)

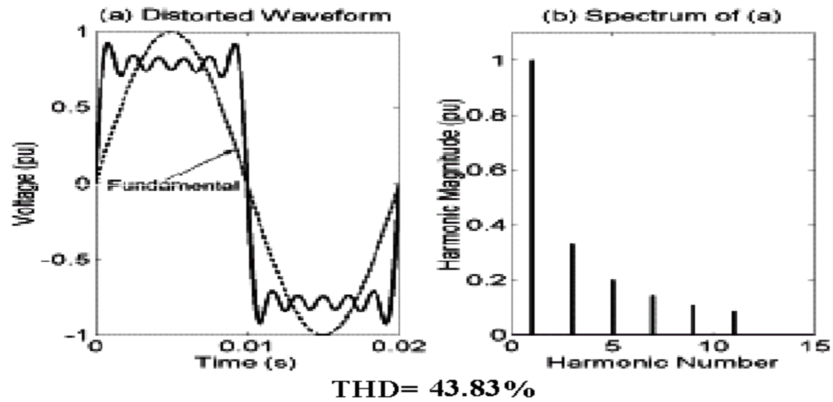

Figure 3.2 Voltage waveform with harmonics and spectrum of the waveform (Ghosh, 2005)

3.4) Sustained Interruption

When the supply voltage is zero for a period of time in excess of 1 minute, the long duration voltage variation is called sustained interruption. Human intervention is required during sustained interruptions for repair and restoration.

3.5) Voltage Flicker

A very rapid change in the supply voltage is called voltage flicker. This is caused by rapid variations in current magnitude of loads such as arc furnaces in which a large inrush current flows when the arc strikes first causing a dip in the bus voltage.

3.6) Notching

Notch occurs when current commutates from one phase to other causing a momentary short circuit between two phases. The maximum voltage during notches depends on the system impedance. The frequency components that are associated with notches are usually high.

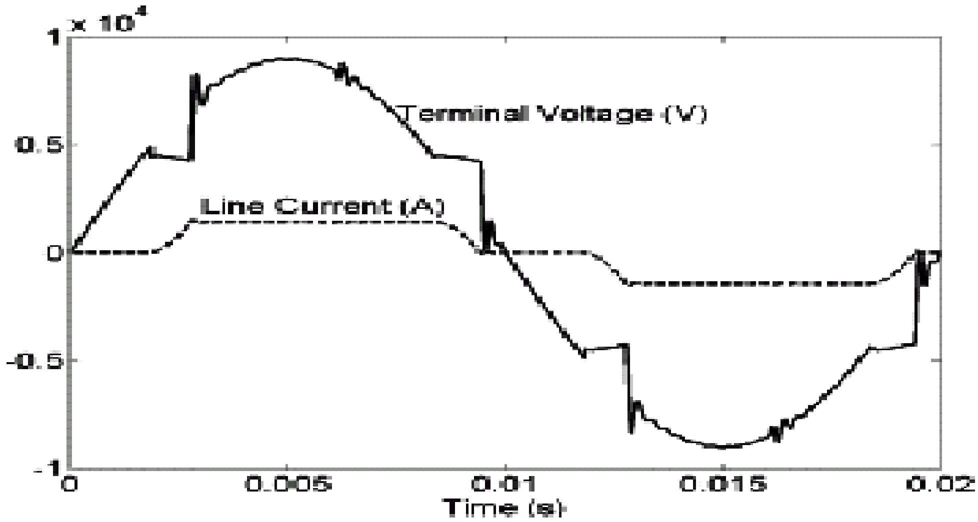

Figure 3.3. Notching (Ghosh, 2005)

4-) CUSTOM POWER PARK CONCEPT

All the consumers of a custom power park (CPP) benefit from a high-quality power supply which, in the basic form, is superior to the normal power supply from a utility. Two feeders from two independent substations can supply power to the park. However, the power is normally supplied by the so called preferred feeder (PF) while the other feeder, called the alternate feeder (AF), is kept as a backup. Both the PF and AF are joined together via a static transfer switch (STS), which can make a sub-cycle transfer from the PF to the AF during a voltage dip or fault in the PF. In addition, a CPP contains a power-converter-based device to eliminate harmonic current and/or to correct voltage sag/swell. A diesel generator (DG) is also kept in a standby to supply power when a catastrophic failure causes both the incoming feeders to trip (Ghosh, 2005).

4.1) Structure of Custom Power Park

The layout of the custom power park is shown in Fig.4.1. The power to the park is supplied either by source v_{s1} through the preferred feeder or through the source v_{s2} through the alternate feeder. Of these, during normal operations, v_{s1} supplies power through the preferred or primary feeder (PF). During a fault or long duration voltage sag in the preferred feeder, the STS rapidly transfers the supply to v_{s2} through the alternate feeder (AF).

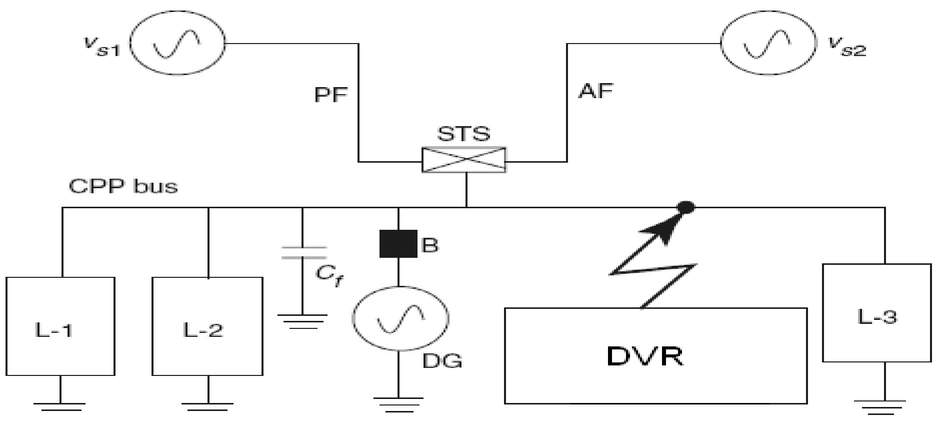

Figure 4.1 Layout of Custom Power Park (Ghosh, 2005)

The loads in the park are divided into three categories. Load L–1 is unbalanced, load L–2 is a rectifier load, which draws harmonic current, and load L-3 is both balanced and harmonic free. Load L–3 is sensitive or critical, and needs continuous uninterrupted supply. To facilitate this, a power electronic-converter-based device is connected at the CPP bus.

The DVR can inject a voltage in series to cancel the unbalance and harmonics created in the CPP bus so that load L–3 gets balanced supply. Therefore all three loads get balanced voltage irrespective of harmonics and distortion in L–1 and L–2. As a consequence, the current drawn through the feeder is balanced and sinusoidal. The capacitor C_f is provided to bypass the harmonic currents generated by the nonlinear load L-2.

The custom power park is also equipped with a thyristor based STS, which can transfer the CPP load from the PF to the AF in case of a voltage sag or fault in the PF. In case of a catastrophic failure in which both feeders are lost, the diesel generator (DG) set is turned on for auxilary supply. In the interim period when the feeders are off and the DG is not on, the solid state converter based device (DVR) regulates the voltage of the critical load L–3 (Ghosh, 2005).

4.2) Static Transfer Switch

The STS is used in uninterruptible power supply systems and in distribution networks to provide connection to alternate sources of ac power for critical loads when the main sources fail.

The STS can be used very effectively to protect sensitive loads against voltage sags, swells and other electrical disturbances. The STS ensures continuous high-quality power supply to sensitive loads by transferring, within a time scale of milliseconds, the load from a faulted bus to a healthy one.

To ensure continuity of electrical power supply with sensitive process controls, a critical load is normally supplied from two independent sources, one being the primary selection. Tradiationally, the sources are often connected to mechanical switches incorporating controls that can recognize loss of the main power source and then automatically transfer to the alternate source, thus maintainig a highly reliable source of power.

However, as processes and process controls have become increasingly sensitive not only to loss of the power source but also to fluctuations in the voltage supplied (i.e. voltage sags and swells), mechanical transfer switches can not transfer quickly enough to eliminate customer interruptions when such interruptions occur.

The Static Transfer Switch (STS) essentially consists of a pair of back-to-back thyristor switches. It takes the place of the mechanical transfer switch and enables a seamless transfer of energy from the main source to the alternate source in order to avoid service interruption. As a result, this arrangement can provide reliable power to the customer (Mokhtari, Dewan and Iravani, 2002).

4.2.1) Power Circuit of the STS System

The power circuit of STS system is shown in Fig. 4.2 with an equivalent RL load. The STS system is composed of the main source, backup source, STS and a critical three-phase load. Both sources include an internal impedance. The STS consists of two three phase static switches; each switch is comprised of three thyristor module, two sets of thyristor switches are connected in opposite polarity to allow the load current to flow in either positive or negative directions.

The transfer process in each phase is completed when thyristor switches connecting the load to the preferred source are turned off, and thyristor switches connecting the load to the alternate source are turned on. Therefore, parameters which effect the commutation process between the thyristors also effect the transfer time. These include the followings;

- Thyristor gating, which is the strategy of removing gating signals.
- Load type, and characteristics which determine the relative position of phase voltage and line current zero-crossings and the voltage drop across incoming and outgoing thyristors.

- Fault/disturbance characteristics, which determine voltage difference between the sources and the voltage drop across incoming and outgoing thyristors during the transfer process.
- Voltage-detection logic, which determines fault/disturbance detection delay (detection time) (Chunhong and Feng, 2004).

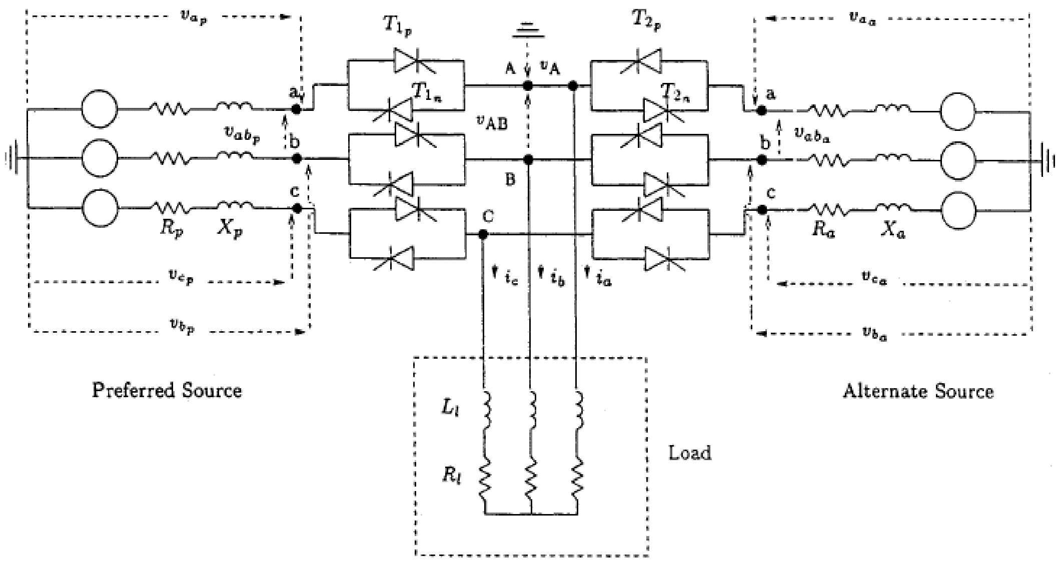

Figure 4.2 Power Circuit of a STS system with an equivalent RL load (Mokhtari, Dewan and Iravani, 2002).

4.2.2) Control Circuit of the STS System

The control circuit of the STS is composed of four sections. There are;

- Voltage detection
- Gating enable generator
- Phase locked loop (PLL)
- Gating signal generator

The block diagram of gating strategy is shown in Fig. 4.3. The control circuit is responsible for monitoring the quality of the main source and performing the transfer of the load from the main to the alternate source, and vice versa. The required input signals to the control circuit are the three phase voltages from each source and phase currents from the load. The outputs of the control circuit are the gating patterns for the main and alternate source thyristor switches.

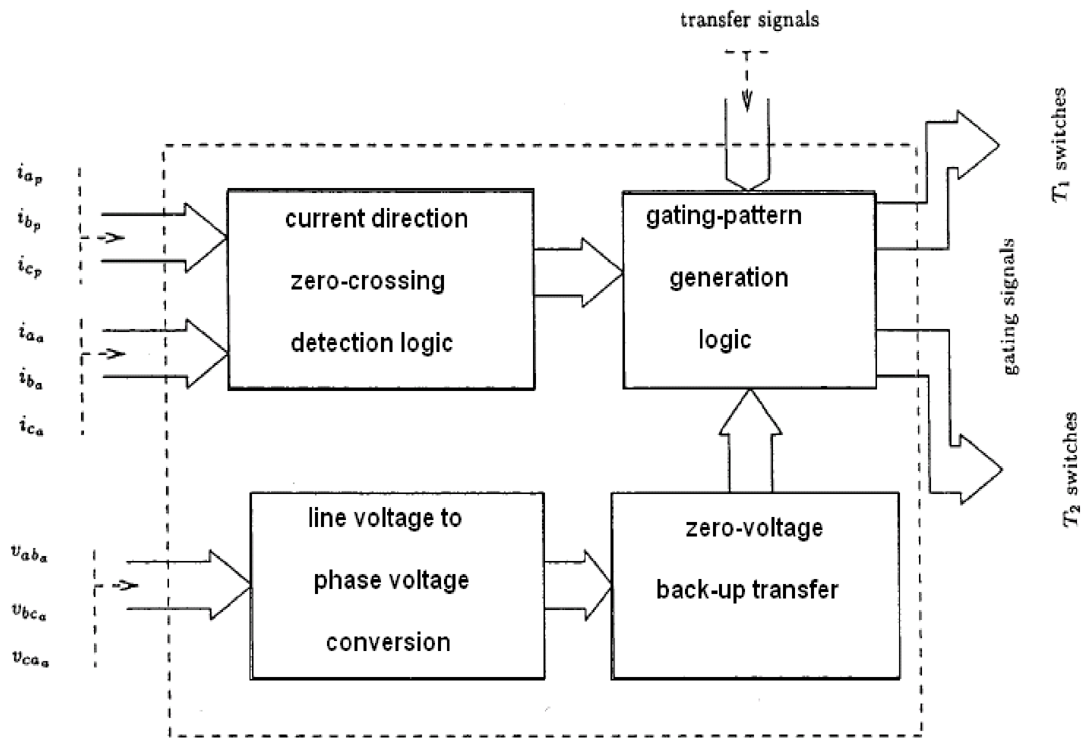

Figure 4.3 Block Diagram of the Gating Strategy (Mokhtari, Dewan and Iravani, 2002)

Current direction and zero crossing detection logic is to detect status of each thyristor switch, i.e., on/off state. This is to avoid paralleling the sources during the transfer process.

Gating-pattern generation logic is to generate selective gating patterns for both T_1 and T_2 thyristor switches. During transfer operation, two scenarios, commutation between the incoming and the outgoing thyristors, e.g., T_{1p} and T_{2p}, begins when a distrubance is detected. In this case, T_{2n} is triggered when the preferred source current drops below, and the alternate source current exceeds, the zero-current threshold limit $i_{zth.}$ The second scenario occurs when commutation between the incoming and outgoing thyristors fails. The outgoing thyristor continues conducting until a zero crossing is reached and commutation begins. Maximum transfer time is determined by the phase in which commutation fails. A turn off time is also considered before gating the incoming thyristor T_{2n} to make sure that the outgoing thyristor has regained its blocking capability.

Line-voltage to phase-voltage conversion and zero-voltage back-up transfer logic is to transfer the load at the zero crossing of phase voltage if the change of current direction/zero-crossing can not be detected. This may occur for low values of line current, e.g., no-load conditions, due to inaccuracies of current measurement devices (Mokhtari, Dewan and Iravani, 2002).

The STS can ensure a fast response due to the phenomenon of fast switching, usually referred to as ‘‘Make-Before-Break’’ switching (MBB),(Figure 4.4) This takes place when the thyristors of the secondary-source static switch are fired, thus initiating the transfer, before the current through the primary-source switch has reached zero. Depending on the circuit conditions, a current starts flowing in the secondary-source switch in a direction such that it forces the primary-source switch to turn off very quickly. Transfer times of less than one quarter of cycle are quite common for MBB transfer.

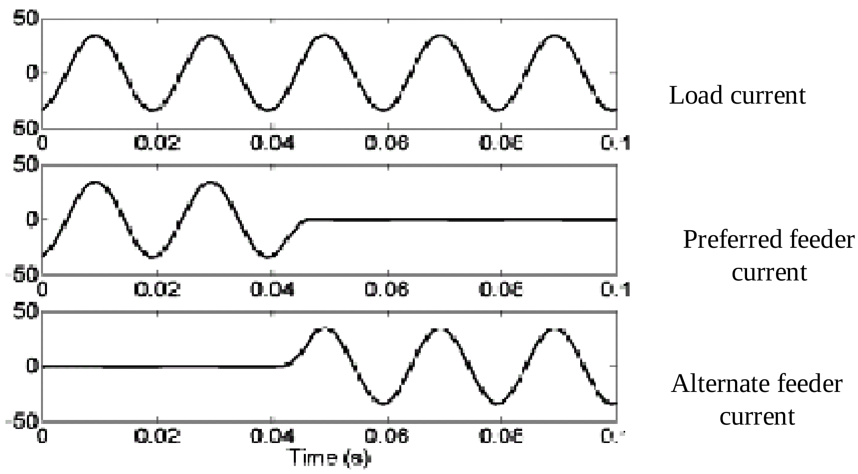

Figure 4.4. MBB Operation (Ghosh and Lendwitch, 2002)

An example of the dip mitigation performance of the STS is given in Fig.4.5 (a) which shows the source voltages together with the response of the detection system, denoted as ‘‘fault signal’’, for a 70% dip (single-phase). The dip is detected in about 1 ms and the transfer occurs immediately after.

As a result, only a notch of very short duration affects the load voltage (Fig. 4.5 (b)). However, MBB transfer must be inhibited when this would lead to a circulating current between the two sources, thus spreading the fault to the healthy portion of the system. In this case, the control system must inhibit firing and wait until the current through the thyristors in the faulted source switch has become zero, thus realizing a slow or ‘‘Break-Before-Make’’ transfer (BBM). This result is accomplished by monitoring the load current, together with the voltages of the two sources. The performance of the STS concerning transfer time has been analyzed. Results presented allow concluding that in general the speed of operation of a STS is high enough to realize a seamless transfer for sensitive loads. Note, however, that the transfer time increases even more in case of regenerative load, e.g. induction motors. In industrial plants with high percentage of rotating load, a specific performance study could be needed to assess the actual improvement obtained with installation of the STS (Sannino, 2001). MBB switching method is used in this thesis.

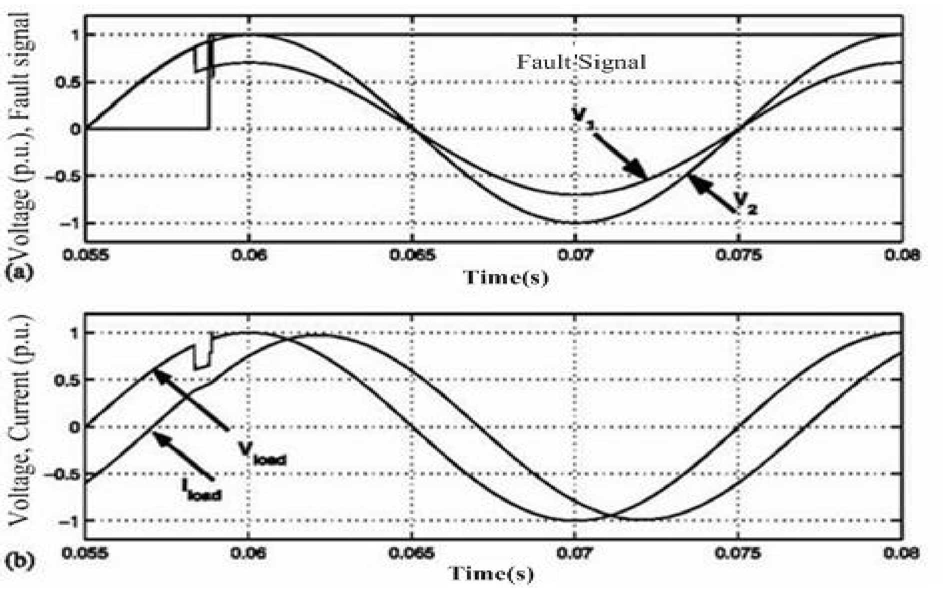

Figure 4.5. (a) Source voltages and fault signal,**(b)** Load voltage and current for a 70% dip (Sabin and Sannino, 2003)

4.2.3) Voltage Detection Logic

Fig 4.6 shows the block diagram of the voltage detection circuit. Based on Park transformation, the instantaneous three phase voltages of the main source are transformed into a syncronously rotating frame.

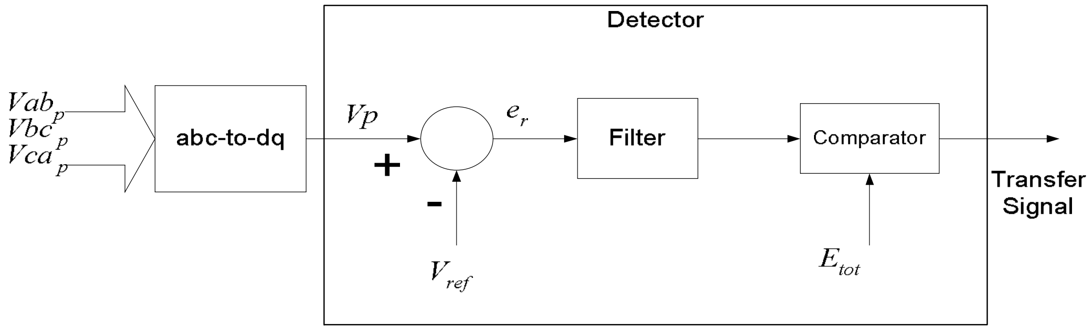

Figure 4.6 Voltage Detection Circuit Block Diagram (Mokhtari, Dewan and Iravani, 2002)

$$V_{dq0_p} = K_s V_{abc_p} \tag{2}$$

where:

$$(V_{dq0_p})^T = \lfloor V_{d_p} \quad V_{q_p} \quad V_{0_p} \rfloor \tag{3}$$

$$(V_{abc_p})^T = \lfloor V_{ab_p} \quad V_{bc_p} \quad V_{ca_p} \rfloor \tag{4}$$

$$K_s = \frac{2}{3}\begin{pmatrix} \cos(q) & \cos(q-120) & \cos(q+120) \\ \sin(q) & \sin(q-120) & \sin(q+120) \\ 1/2 & 1/2 & 1/2 \end{pmatrix}$$

$$q(t) = q(0) + \int_0^t w(x)dx \tag{5}$$

where

V_{ab_p} V_{bc_p} V_{ca_p} ; *are* the preferred source line voltages,

V_{d_p} V_{q_p} V_{0_p} ; *are* the dq0 components of the preferred source voltage in the rotating frame,

ω is the rotating frame angular frequency

$\theta(0)$ is the initial value of θ.

The *rms* value of V_{qp} and V_{dp} will then be calculated as:

$$V_P = \sqrt{V_{d_p}{}^2 + V_{q_p}{}^2} \tag{6}$$

The output of the ***abc-to-dq0*** transformation block, V_P is compared to a dc reference, V_{ref}. The error e_r is passed through a low-pass filter which attenuates impacts of voltage transients. The filter introduces a certain amount of delay to the error signal which is determined by the filter cut-off frequency *(f_c)*. The filter output is then compared to a tolerance limit E_{tot}. Output of the comparator is the transfer-signal which initiates a transfer process if the preferred source fails. Two identical logics have been used for both sources

If the utility system operates in normal condition, or if any symmetrical fault occurs, then V_{d_p} and V_{q_p} are found only DC quantities. If any unsymmetrical fault occurs, the resulting voltage sag is unbalanced and contains both positive sequence and negative sequence component. The synchronous frame voltages V_{d_p} and V_{q_p} then have DC components and ripples. Voltage sags will certainly lead to the reduction of the positive sequence voltage component, which is used by the proposed STS controller to identify voltage sags.

The detection time is shorter for a more severe fault. The response of the voltage detection logic is mainly determined by the filter cut-off frequency f_c. The higher the f_c the faster the detection circuit and the shorter the detection time. However,increasing f_c makes the logic more sensitive to voltage transients, e.g., capacitor switchings. Therefore, a trade-off needs to be made between the speed of the detection logic and its sensitivity to voltage transients.

The transfer time is determined by gating strategy, load type, fault type, fault instant and system configuration. Each phase has its own transfer time, and the maximum transfer time occurs in the phase for which the commutation process fails. Commutation fails when the voltage drop across the incoming thyristor is negative (Chunhong and Feng, 2004).

4.3) Dynamic Voltage Restorer

The dynamic voltage restorer (DVR) is a power quality device that has gained an increasing role in protecting industries against disturbances such as voltage sags and swells related to remote system faults.

Power quality has become an increasingly important topic in the performance of many industrial applications. One of the major issues in improving power quality in distribution networks is the mitigation of voltage sags. The effect of voltage sag can be very expensive for the customer because it may lead to production downtime and equipment demage. Voltage sag can be mitigated by voltage and power injections into the distribution system using power electronics based devices. Different approaches have been proposed to limit the cost causes by voltage sag. One approach to address the voltage sag problem is the use of dynamic voltage restorer (DVR) which is a custom power device employing gate turn off thyristors. During a sag disturbance, the DVR uses a power electronic inverter to inject voltage in series with the source. The amplitude and the phase angle of the injected voltages are variable thereby allowing control of the real and reactive power exchange between the device and the distribution system. Short time energy storage is used to provide the supplemental energy through the inverter to keep the load voltage at acceptable levels.

The voltage sensitive equipment in industrial sector has made industrial processes more vulnerable to supply voltage deviations. Such voltage deviations in the form of voltage sag, swell or temporary outage cause severe process disruptions resulting in millions of dollars of loss of revenue. Therefore power supply authorities as well as customers have been desperately looking for a cost effective solution currently to ride through momentary power supply disturbances. As such, the preposition of a novel custom power device called dynamic voltage restorer (DVR) for compensating voltage disturbances in distribution systems has generated a great deal of interest recently. Apart from the DVR, some researchers have proposed several other devices to mitigate momentary disturbances.

The DVR usually consists of an injection transformer, which is connected in series with the distribution line, a voltage sourced PWM inverter bridge which is connected to the secondary of the injection transformer and an energy storage device connected at the dc-link of the inverter bridge. A typical schematic of the DVR is shown in Fig.4.7. The inverter bridge output is filtered before being fed to the injection transformer in order to nullify switching frequency harmonics. The series injected voltage with a variable amplitude, phase and frequency of the DVR is synthesized by modulating pulse widths of the inverter bridge switches. The injection of an appropriate series voltage component in the face of a voltage disturbance requires a certain amount of real and reactive power supply by the DVR. The real and reactive power supplied by the DVR however depends on the type of voltage disturbance experienced as well as the direction of the DVR injected voltage component with reference to pre-sag voltage. The idea of advancing the injected voltage in order to minimize the real power supplied by the DVR has generated a great deal of research interest recently (Hannan and Mohamed, 2002).

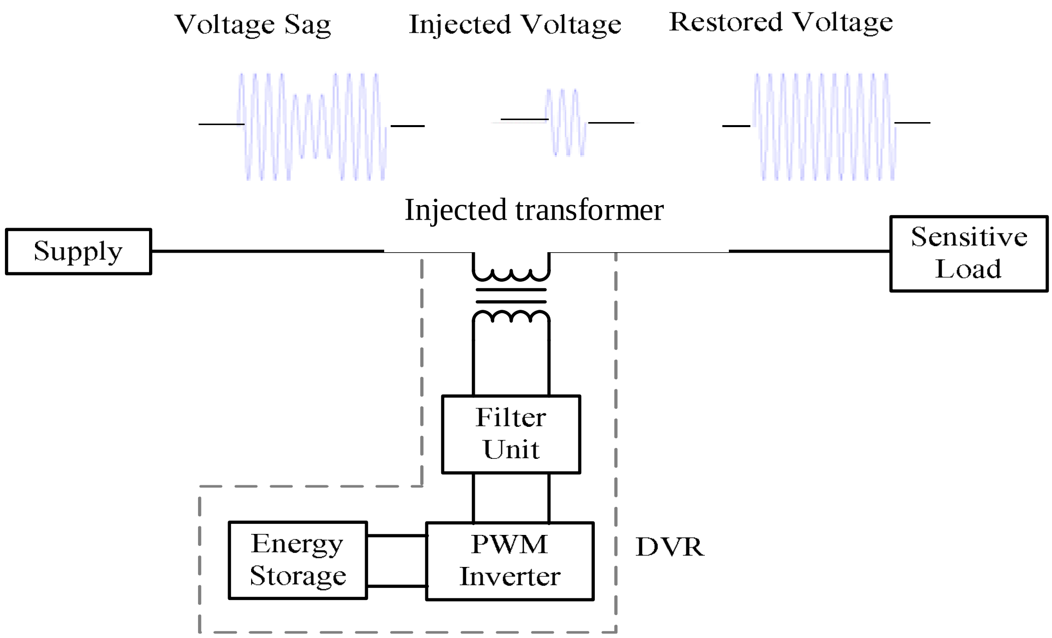

Figure 4.7 Dynamic Voltage Restorer Operation (Choi, Li and Vilathgamuwa, 2000)

The fidelity of the DVR output voltage depends on the accuracy and dynamic behavior of the pulse width modulated (PWM) synthesis scheme and the control system adopted. Traditionally, closed loop control PWM schemes have been used for various types of ac power conditioning systems. The general requirement of such control scheme is to obtain an ac waveform with low total harmonic distortion and good dynamic charecteristics against supply and load disturbances. Although conventional sinusoidal PWM schemes and programmed optimal PWM schemes have performed reasonably well for linear loads, the voltage waveforms tend to get distorted for nonlinear loads (Nielsen, Newman and Blaabjerg, 2004).

4.3.1) Principles of the DVR Operation

The DVR is connected in series with power distribution lines shown in Fig.4.8 The DVR is able to control the voltage across a sensitive load by injecting an appropriate voltage phasor through an injection transformer. As a result, any voltage disturbance appears in up-stream can be compensated through the DVR and the disturbance is unseen to the load.

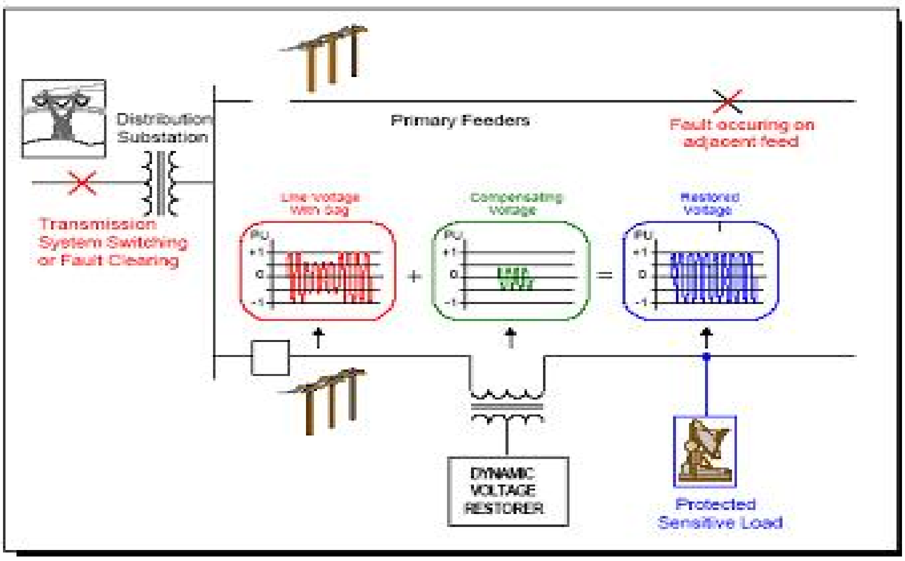

Figure 4.8 The DVR is connected in series with power distribution lines (Woodley, Morgan and Sundaram, 1999)

Figure 4.9 shows the schematic diagram of a typical DVR used for voltage correction. When the supply voltage V_s changes, the DVR injects a voltage V_i in such a way that the desired load voltage magnitude can be maintained. The DVR is simply a voltage source inverter that produces an ac output voltage and injects in series with the supply voltage through a booster transformer. To correct a given voltage drop, not only voltage injection but also active and/or reactive power injection are needed. The DVR itself is capable of generating the reactive power, however,but the injected active power must come from the energy storage part of the DVR. Thus minimization of active power injection is essential to increase the life of the energy storage.

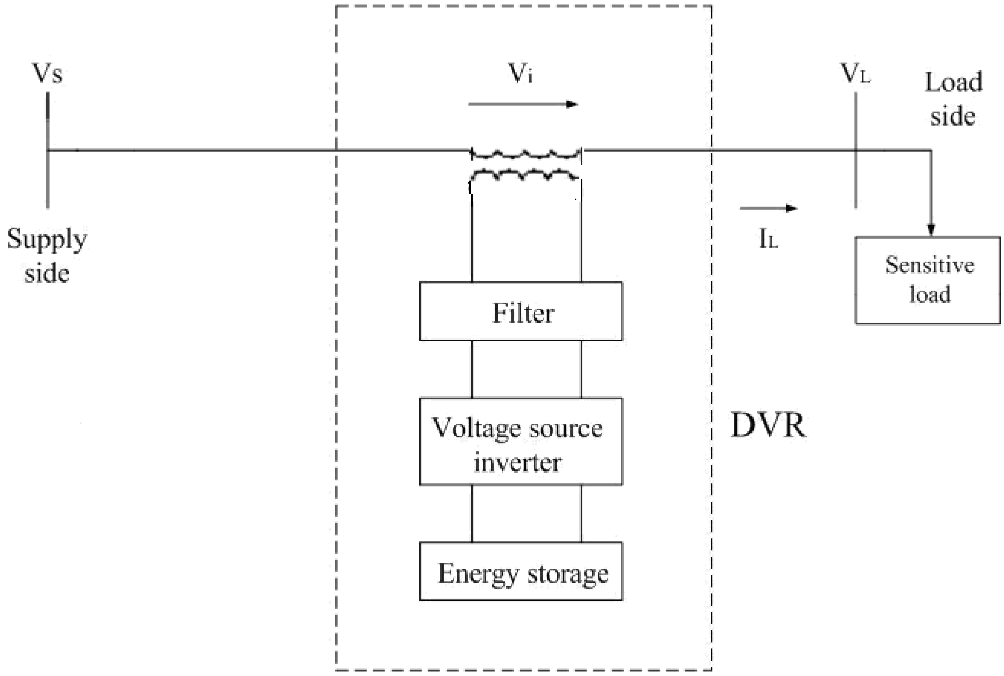

Figure 4.9. Schematic diagram of a typical DVR (Vilathgamuwa, Perera and Choi, 1999)

4.3.2) Injected Power

The active power flow at the load and supply sides of the system can be written as

$$P_L = V_L I_L \cos q_L \tag{7}$$

$$P_S = V_S I_L \cos q_S \qquad (8)$$

Here q_L and q_S are the angle between V_L and I_L and V_S and I_L respectively. Note that q_L is a load power factor angle and I_L is the current in both load and source sides. The DVR injected active power P_i can be found as the difference between P_L and P_S.

$$P_i = (P_L - P_S) = V_L I_L \left(\cos q_L - (\frac{V_S}{V_L}) \cos q_S \right) \qquad (9)$$

Consider the load voltage magnitude, V_L, and load apparent power, $V_L I_L$ as base quantities. Thus, the injected power in pu can be written as

$$P_i = \left(pF_L - V_S \cos q_S \right) \qquad (10)$$

For given values of load power factor and supply voltage magnitude, the injected power is minimum when

$$\cos q_S = 1$$

In other words, when $q_S = 0$ or V_S and I_L are in phase. Thus, V_L must lead V_S by the power factor angle q_L (for lagging power factor) and it can be realized by careful injection of V_i. The main purpose of the DVR is to maintain the desired load voltage magnitude (say 1.0 pu) despite a supply voltage drop of V_d pu. In this case, the supply voltage magnitude in pu can be written as

$$V_S = (1 - V_d) \qquad (11)$$

Using the equations the minimum active power injection $P_i^{\min}$ of DVR can be written as

$$P_i^{\min} = V_d - (1 - pF_L) \tag{12}$$

Equation indicates that, when $Vd \leq (1 - pF_L), P_i^{\min}$, becomes negative and thus the power flows in reverse direction (from the system to DVR). The DVR may not cater to reverse power flow, however. Such a situation can be avoided by adjusting the value of q_S, (instead of zero) so that the power flow becomes zero. The value of q_S for zero power flow can be obtained from $P_i = \left(pF_L - V_S \cos q_S\right)$ and is given by

$$q_S = \arccos\left(\frac{pF_L}{1 - V_d}\right) \tag{13}$$

4.3.3) Injected Voltage

It is demonstrated in the previous section that, when $Vd \leq (1 - pF_L)$ the voltage correction can be made without injecting any active power but the phase shift between V_S and I_L must be governed by $q_S = \arccos\left(\frac{pF_L}{1 - V_d}\right)$. On the other hand, when $V_d > (1 - pF_L)$, injection of active power is required to correct the voltage but its value can be minimized if V_S and I_L are kept in phase. Thus the voltage correction requires careful determination of injected voltage so that the desired phase shift as well as load voltage magnitude can be maintained.

When $Vd \leq (1 - pF_L)$

In this case, the DVR should inject a voltage in such a way that is satisfied as well as the desired load voltage magnitude (1.0 pu) is maintained. The injected voltage V_i can be written as

$$V_i = V_L - V_S \tag{14}$$

Consider V_S as reference. Thus V_L must have an angle of $q_L - q_S$ to avoid reverse power flow. Note that the angle between V_L and I_L is the power factor angle q_L. Thus in polar form, it can be written as

$$V_i \angle b = 1\angle(q_L - q_S) - (1 - V_d)\angle 0^o \quad (15)$$

Here V_i and b are the magnitude and angle, respectively, of the injected voltage. After some mathematical manipulations, V_i and b can be expressed as

$$V_i = \sqrt{V_d^{\,2} + 2(1 - V_d)[1 - \cos(q_L - q_{S)}]} \quad (16)$$

$$b = \arctan\left[\frac{\sin(q_L - q_S)}{\cos(q_L - q_S) - (1 - V_{d)}}\right] \quad (17)$$

When $V_d > (1 - pF_L)$

In this case, the DVR should inject a voltage in such away that V_S and I_L are kept in while maintaining the desired load voltage magnitude. Since V_S is considered as reference, the angle of both V_S and I_L should be zero. To satisfy the power factor angle, however, V_L must lead V_S by q_L (for lagging power factor) Thus in polar form, it can again be written as

$$V_i \angle b = 1\angle q_L - (1 - V_d)\angle 0^o \quad (18)$$

After some mathematical manipulations, the magnitude and angle of the injected voltage can be expressed as

$$V_i = \sqrt{V_d^{\,2} + 2(1 - V_d)[1 - \cos q_L]} \quad (19)$$

$$b = \arctan\left[\frac{\sin q_L}{\cos q_L - (1 - V_{d)}}\right] \quad (20)$$

The expressions for the injected voltage magnitude and angle that minimize the active power injection are derived. It has been found that a voltage drop of less than or equal to (1-pF) pu can be corrected without drawing any power from the energy storage of the DVR. In this case, only reactive power injection is required to correct the voltage and which can be generated by the DVR. For higher voltage drop, however, both active and reactive power injections are required to correct the voltage. In this case, taking as much power as possible from the supply can minimize the amount of active power drawn from the energy storage. This can be achieved by maintaining unity power factor at the supply side (Vilathgamuwa, Perera and Choi, 2003).

4.3.4) Control of the DVR

The main considerations for the control system of a DVR include: detection of the start and finish of the sag, voltage reference generation, transient and steady-state contro of the injected voltage, and protection of the system. The control system presented in Fig.4.10.

It requires measurement of four parameter groups.

1-) Three phase-voltages before DVR (u_{supply}) to detect a voltage sag and for feed-forward control of the output voltage.

2-) Three- phase voltages after the DVR (u_{load}) for feed-back control of the output voltage

3-) Three currents in the converter (i_{conv}) to protect the DVR by both saturation control and overcurrent.

4-) The DC-link voltage for DC voltage compensation (to decouple the controller from variations in the DC-link voltage), for converter protection, and to provide energy storage information.

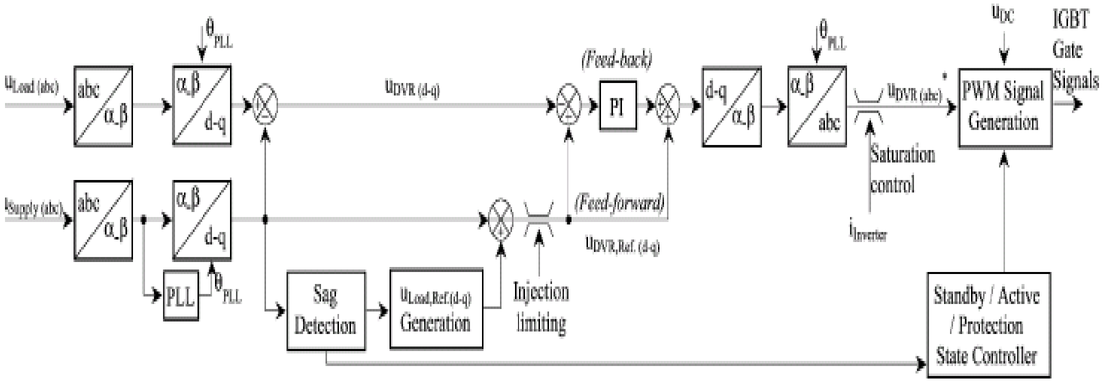

Figure 4.10. Control structure of the combined feed-forward/feed-back DVR (Nielsen, 2002)

With the grid voltage in its normal level the DVR is held in a null state to keep the losses to a minimum. Once a voltage sag is detected the DVR converts into active mode to react as fast as possible and inject the required ac voltage to the grid.

4.3.5) Voltage Sag Detection

An essential part of the control of the DVR is the sag detection circuit. A voltage sag must be detected fast and corrected with a minimum of false operations. The voltage sag detection method used is based on the rms of the error vector, which allows for detection of symmetrical and asymmetrical sags, as well as the associated phase jump.the detection formula is given by (Nielsen, 2002);

$$\left|U_{error,dq}\right\rangle U_{Threshold} \quad (21)$$

Where the rms of the error is

$$\left|U_{error,dq}\right| = \sqrt{(U_{ref,d} - U_{\sup ply,d})^2 + (U_{ref,q} - U_{\sup ply,q})^2} \quad (22)$$

4.3.6) Load Voltage Referance Generation

The next stage of the controller is to determine the desired load voltage reference. A software-based phase-locked-loop (PLL) is used to create sinusoidal load voltage references for the d-q coordinate system of the controller. The desired response from DVR PLL system is quite different from other applications. This is because the phase of the supply voltage prior to the sag is generally preferrred, and if the PLL reacts too quickly to changes in the phase during a voltage sag, the post-sag phase may be used. Therefore, the DVR would not be able to compensate for this phase jump. Conventionally, once a sag is detected, the target phase of the voltage reference is fixed to the pre-sag phase, to ensure that if the reference is faithfully tracked, then the load voltage phase will remain unaffected.

For the experiental system presented here, the phase is not frozen to the pre-sag phase, but instead the PLL response is significantly slowed. Once a sag event occurs, the phase will therefore very slowly shift from the pre-sag phase, to the post-sag phase. This gives the benefit of improved series voltage injection utilization of in-phase compensation, but without any sudden jump in voltage phase as seen by the load.

4.3.7) Combined Feed-Forward/Feed-Back Controller

The primary control structure is based on a combination of supply voltage feed-forward and PI d-q load voltage feedback. The feed-forward component provides the required transient response, and uses the dc-link voltage to calculate the required modulation depth to inject the difference between the supply voltage (u_{supply}) and the load reference voltage ($u_{supply,ref}$). However, this doesn't account for the voltage drop across the filter inductor and other parameters such as the transformer. Therefore, a closed loop load voltage feedback is added, and is implemented in the d-q frame to minimize any steady state error in the fundemental component. The synchronous d-q frame implementation also allows for simpler clamping of the injection voltage, to enable the DVR to partially compensate for deep sags whilst still maintaining a sinusoidal injection profile (Nielsen, Newman and Blaabjerg, 2004).

5-) MODELING OF CPP BY USING PSCAD/EMTDC

Fig.5.1 shows the PSCAD modeling of Custom Power Park. The power to the park is supplied either by source v_{s1} through the preferred feeder or through the source V_{s2} through the alternate feeder, the STS rapidly transfers the supply to V_{s2} through the alternate feeder. The DVR can inject a voltage in series to cancel the unbalance and harmonics created in CPP. The custom power park also equipped with a thyristor based STS, which can transfer the CPP load from the preferred feeder to the alternate feeder.

System Quantities	**Values**
System frequency	50 Hz
Source V_{s1}	12 kV (L-L), phase angle 0^o
Source V_{s2}	12 kV (L-L), phase angle 0^o
Preferred feeder (PF) impedance	0.05 + j0.0048 Ω
Alternate feeder (AF) impedance	0.05 + j0.0048 Ω

5.1) PSCAD/EMTDC Simulation Tool

PSCAD/EMTDC is an industry standard simulation tool for studying the transient behaviour of electrical networks. Its graphical user interface enables all aspects of the simulation to be conducted within a single integrated environment including circuit assembly, run-time control, analysis of results, and reporting. Its comprehensive library of models supports most ac and dc of power plant component and controls, in such a way that, custom power systems can be modeled with speed and precision. It provides a powerful resource for assessing the impact of new power technologies in the power network. Simplicity of use is one of the outhstanding features of PSCAD/EMTDC. Its great many modeling capabilities and highly complex algorithms and methods are transparent to the user, leaving him free to concentrate his efforts on the analysis of results rather than on mathematical modeling. For the purpose of system assembling, the user can either use the large base of built-in components available in PSCAD/EMTDC or to its own user defined models (Anayara-Lara and Acha, 2002).

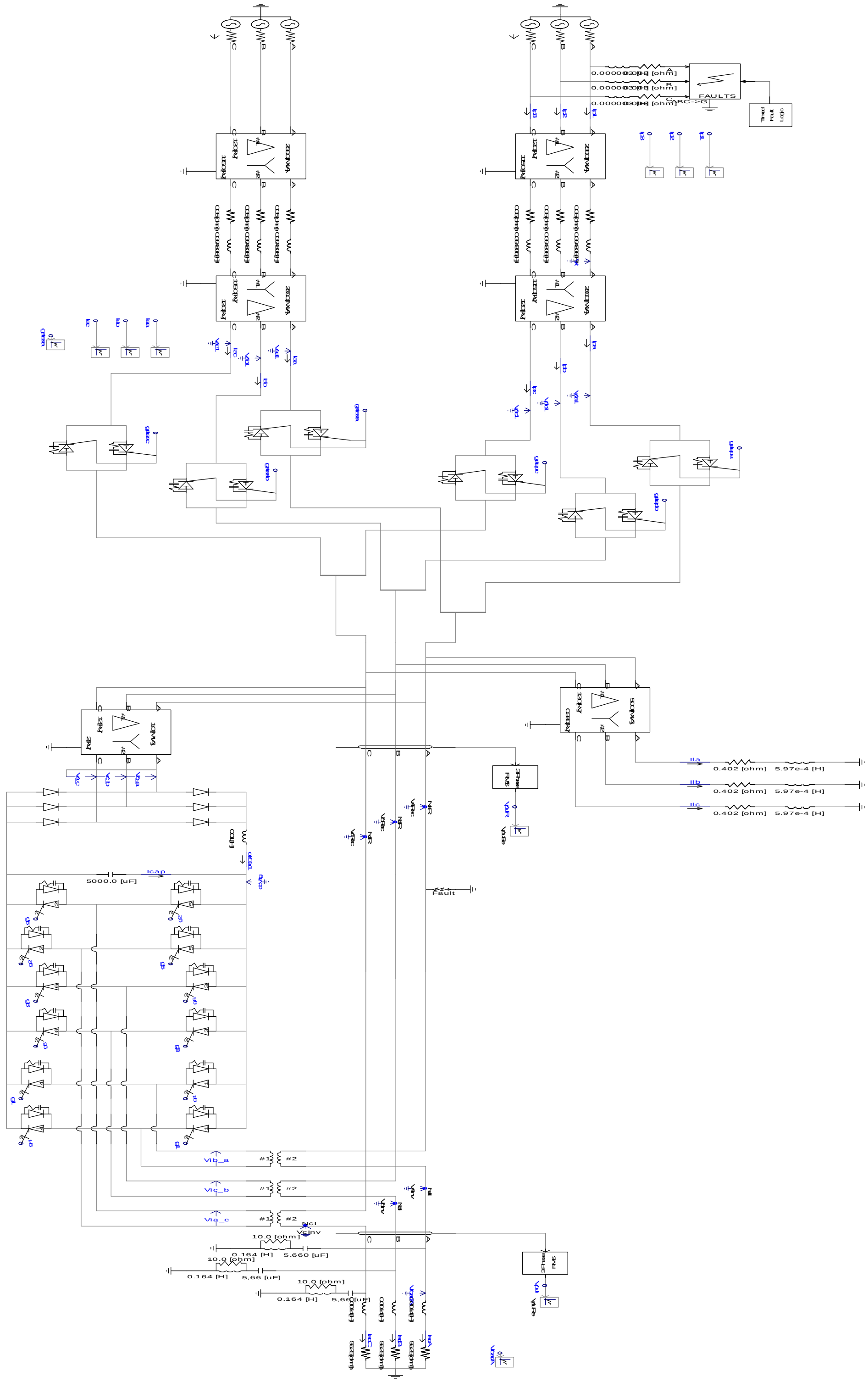

Fig. 5.1) CPP Model in PSCAD

5.2) STS Part of CPP in PSCAD

STS can be used very effectively to protect sensitive loads against voltage sags, swells and other electrical disturbances. The STS ensures continious high-quality power supply to sensitive loads by transferring, within a time scale of miliseconds, the load from a faulted bus to a healty one. The basic configuration of this device consists of two three-phase solid-state switches, one for the main feeder and for the alternate feeder. Which is shown in Fig. 5.2

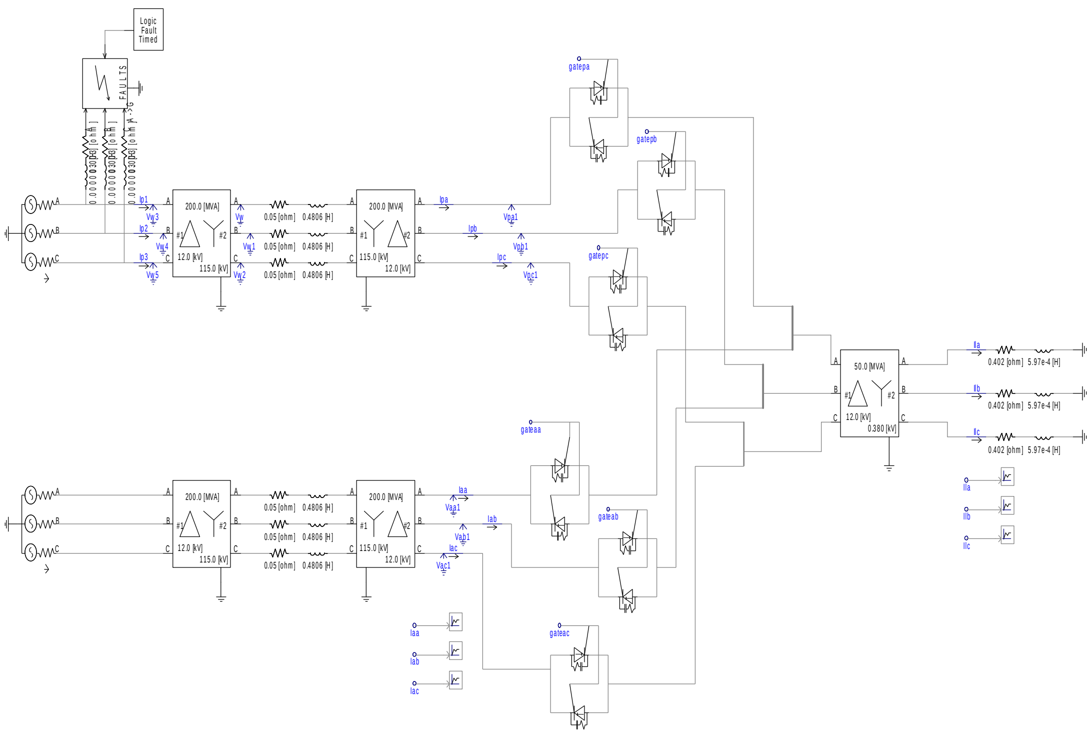

Fig 5.2 STS Model in PSCAD

Each time a fault condition is detected in the main feeder, the control system swaps the firing signals to the thyristors in both switches, switch in the main feeder is deactivated and switch in the alternate feeder is activated. The control system measures the peak value of the voltage waveform at every half-cycle and checks whether or not it is within a prespecified range. If it is outside limits, an abnormal condition is detected and the firing signals to the thyristors are changed to transfer the load to the healty feeder.

5.2.1) Transfer and Gating Strategy

The proposed transfer strategy is based on a selective gating scheme during the transfer. The scheme is to transfer the load within the shortest possible time and prevent the sources from being paralleled during the transfer process. The selective gating strategy relies on the polarities of the line currents. The following steps summarize the principles of operation of the gating logic during the load-transfer process:

1) When a disturbance/fault in the preferred source is detected, the gating signals are removed from "gatepa" switches. As shown in Fig. 5.3

2) Then, the logic checks the line current, and depending on the polarity of the line current, triggers one of the "gateaa" switches.

3) If commutation is successful and the preferred source current drops below a certain limit (zero-current threshold limit), the other "gateaa" switch) is also gated and the transfer process is completed

4) When the faults are cleared, after 10 cycles delay, load is transferred back to preferred source as using the same transfer process.

Fig. 5.3 shows the gates positions at the fault time and normal operation. It is clearly seen that “gateaa” is “on” and “gatepa” is “off” at the fault time. After fault Gates are turned their initials values.

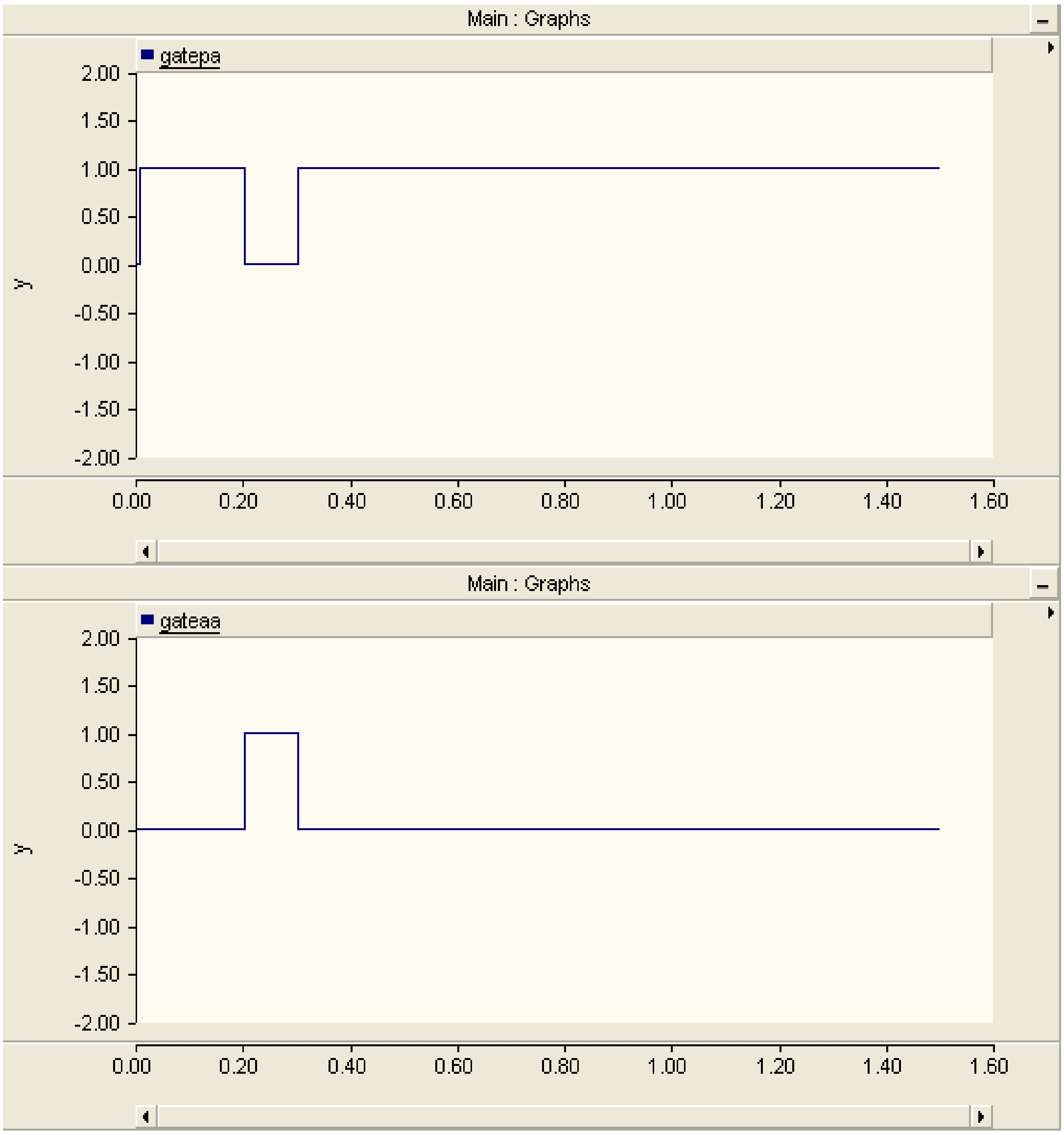

Fig 5.3 Firing signals at the fault time

5.2.2) Simulation Results of STS Part

Figure 5.4 shows the addition of line currents of preferred source and alternate source which were measured from the high voltage side of the transformer. In the figure the first graph represents preferred source currents and second graph represents alternate source currents. It is seen that load is feed from only one of the sources, there isn't any source paralleling and there is not any cross currents. The critical load is supplied from the alternate feeder at the fault time.

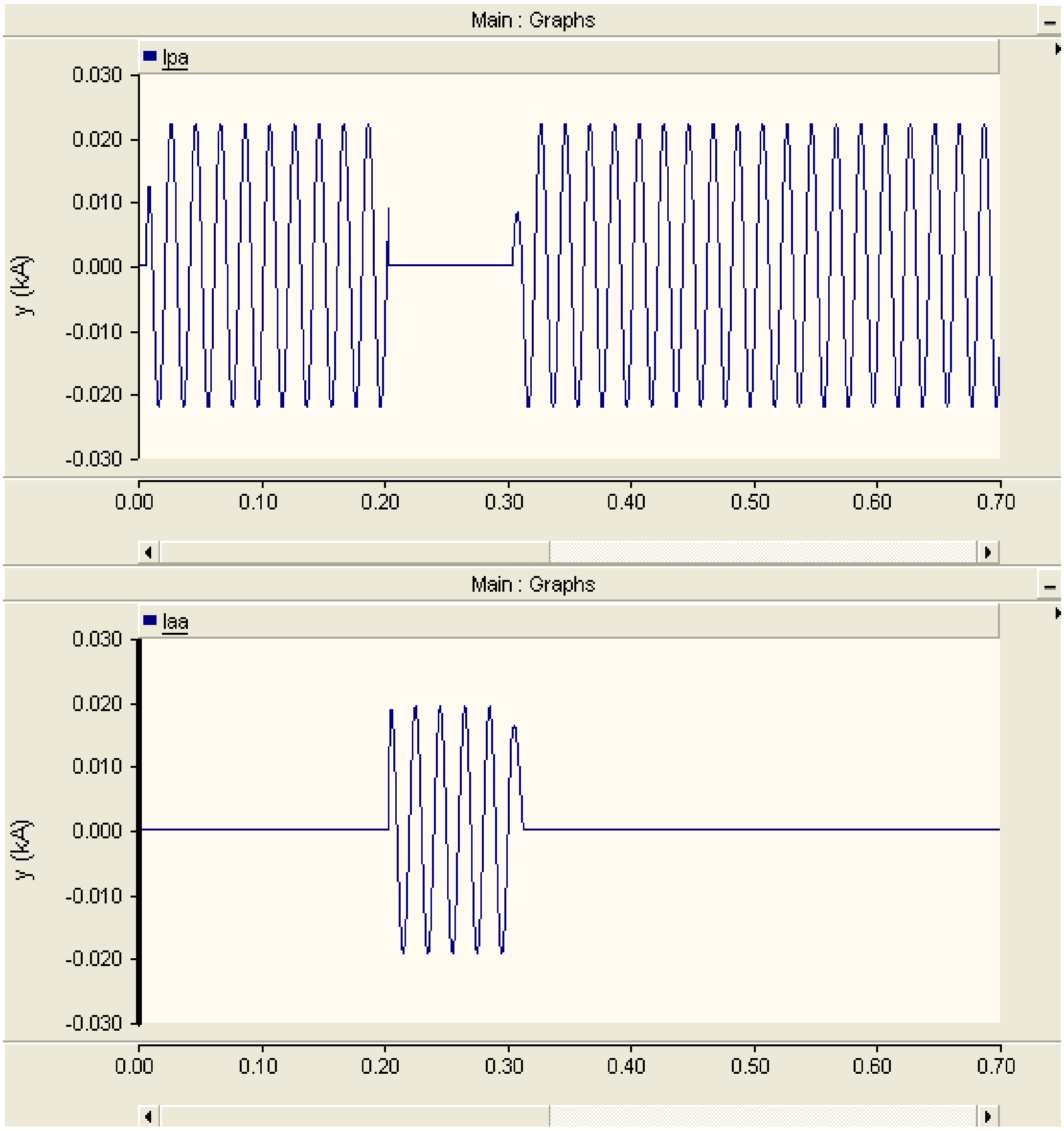

Fig. 5.4 Preferred and Alternate phase currents

Fig. 5.5 shows the load current which is measured the low voltage side of load transformer. The critical load is supplied from the preferred feeder normal operation, but it is supplied from alternate source at the fault time.

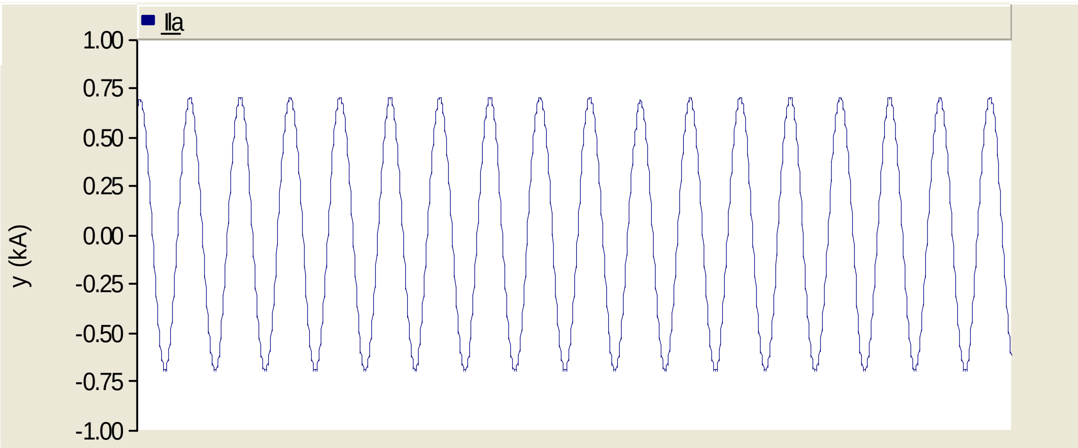

Fig.5.5 Load Current

Figure 5.6 shows the preferred and alternate current at the fault time.

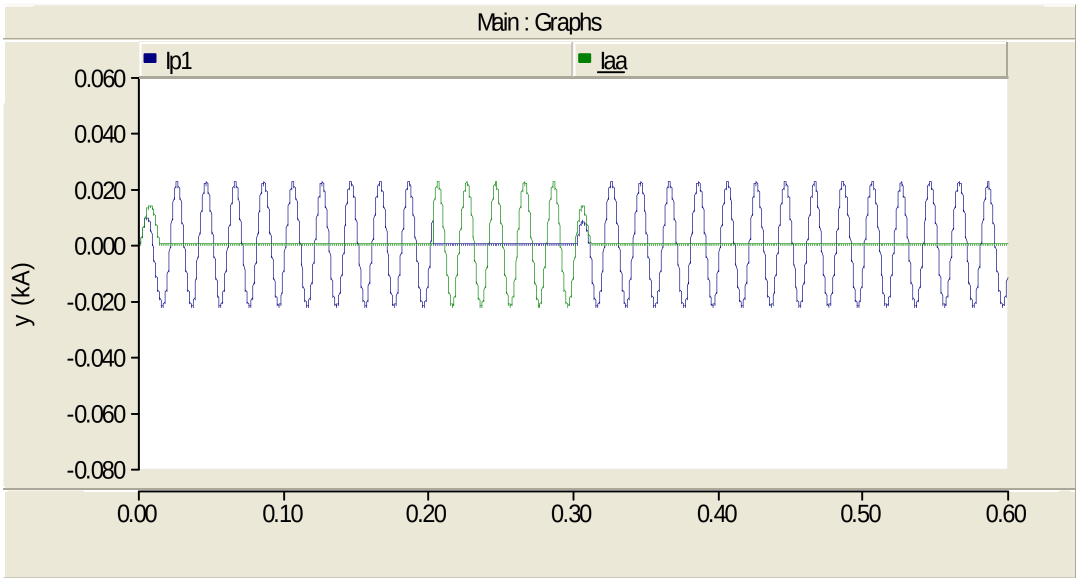

Fig.5.6 Preferred and Alternate Current at the Fault Time

Fig. 5.7 shows the error signal. Error signal is generated at fault time. Fig. 5.8 shows the error signal and V_{prf} signal. It is clearly seen that V_{prf} signal is " off " at the fault time.

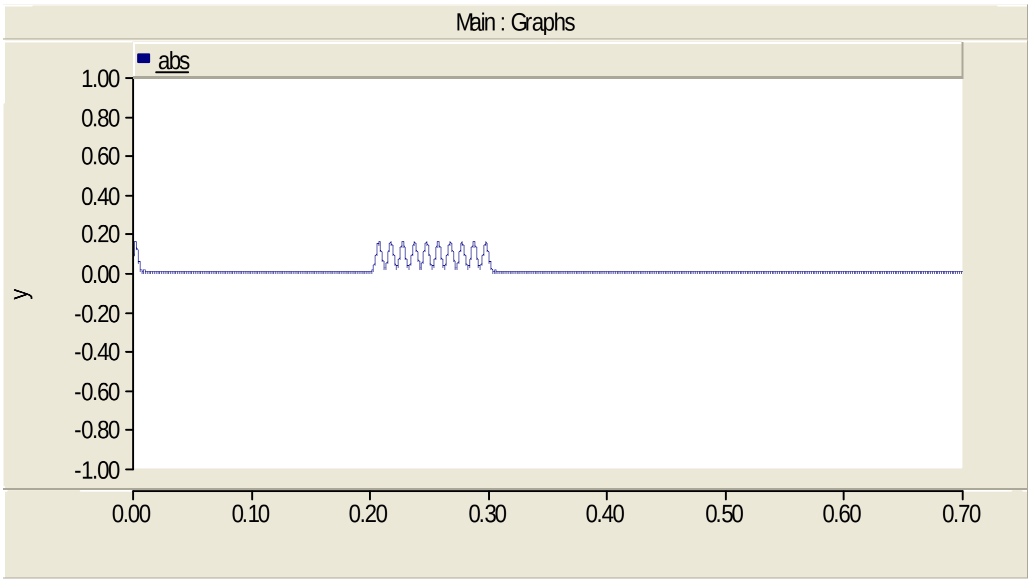

Fig.5.7 Error Signal at the fault time

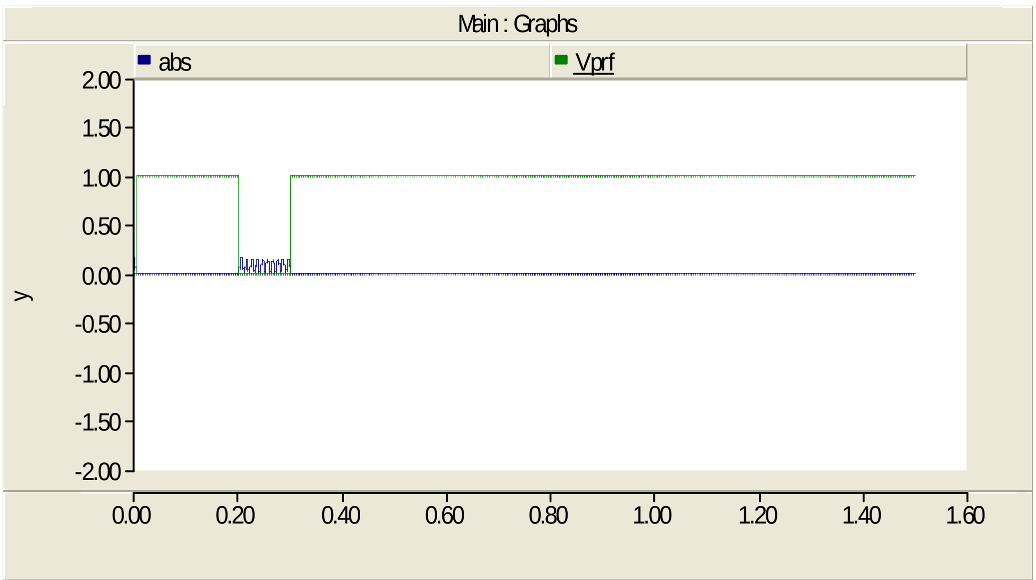

Fig.5.8 Error and Vprf Signal at the fault time

Fig 5.9 shows the V_{alt} signal at the fault time. V_{prf} is “off ” and V_{alt} signal is “on” at the fault time. After fault they return their initial values

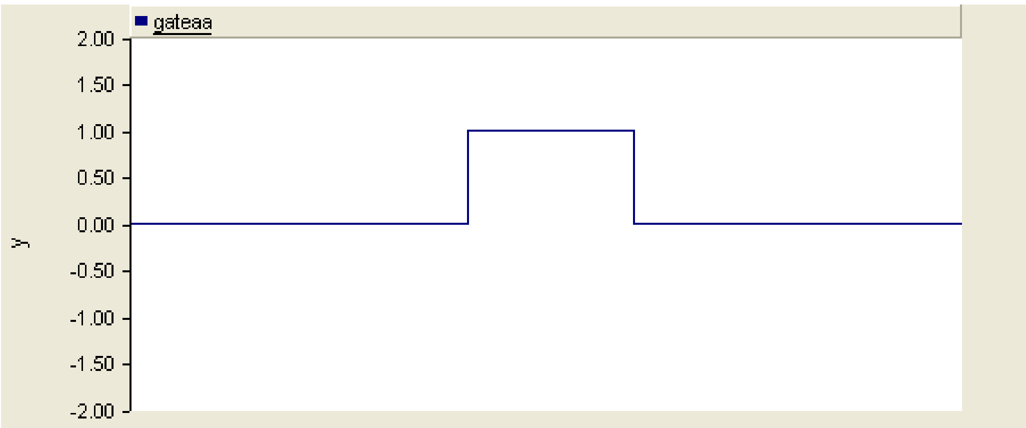

Fig.5.9 V_{alt} Signal at the fault time

Fig 5.10 shows the preferred phase currents at the fault time. It can be seen from Fig. 5.9 and Fig. 5.10 that even though the interruption occurs at 0.2 s and the transfer signal is generated at the fault time.

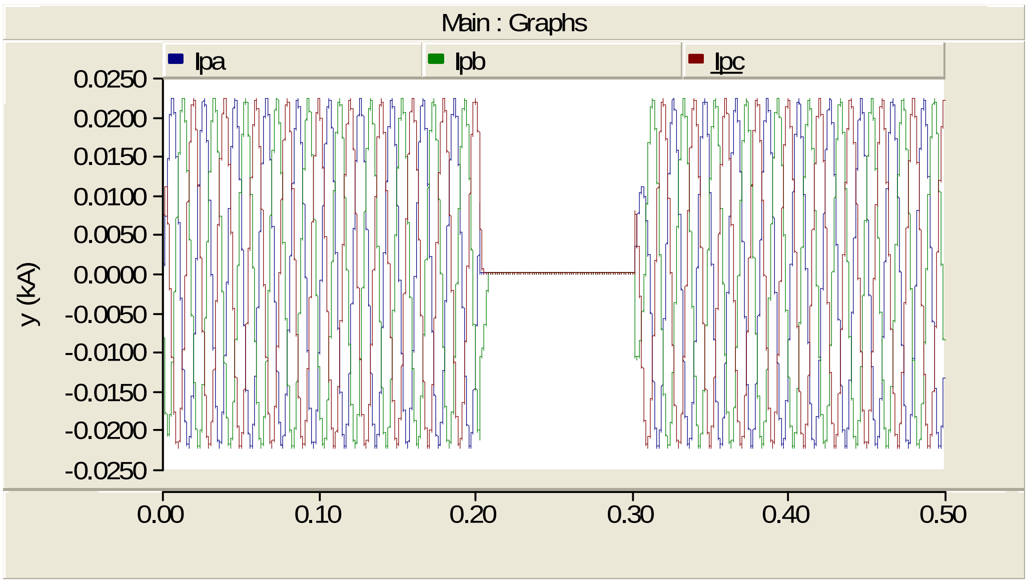

Fig.5.10 Preferred Phase Currents

Fig.5.11 shows the alternate phase currents at the fault time. It is clearly seen that load is supplied from alternate feeder at the fault time. After the fault load is supplied from the preferred feeder.

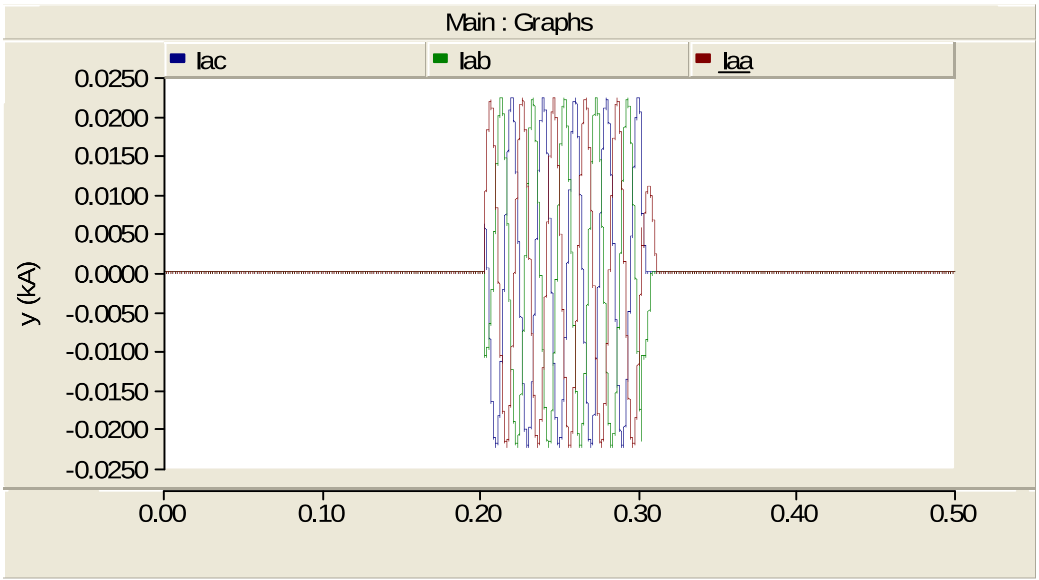

Fig.5.11 Alternate Phase Currents

Fig. 5.12 shows the load phase currents it can be seen that the fault has no effect on the load phase currents.

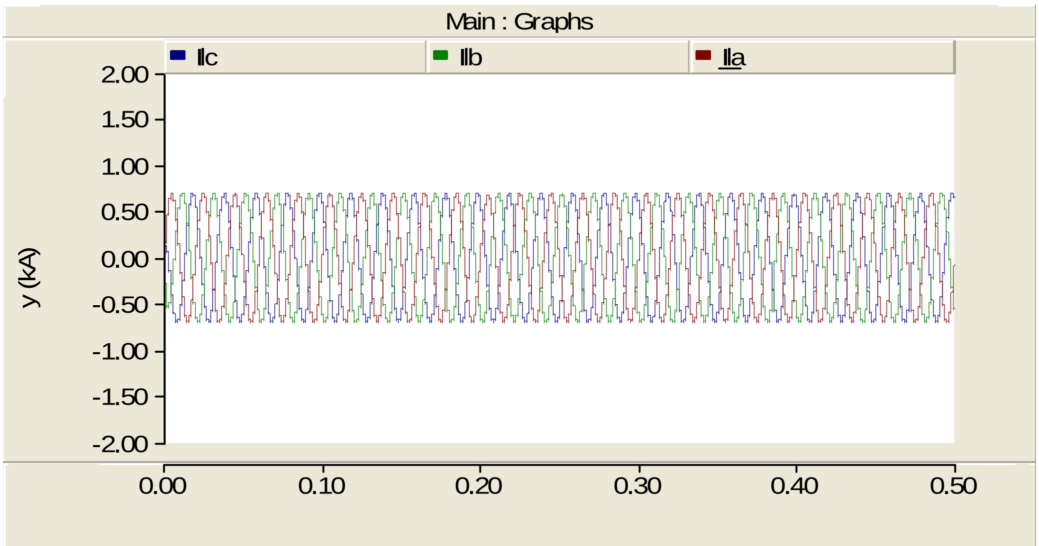

Fig.5.12 Load Currents

The system performance during a fault is shown in Fig. 5.13. It can be seen that the fault has no effect on the CPP bus voltages.

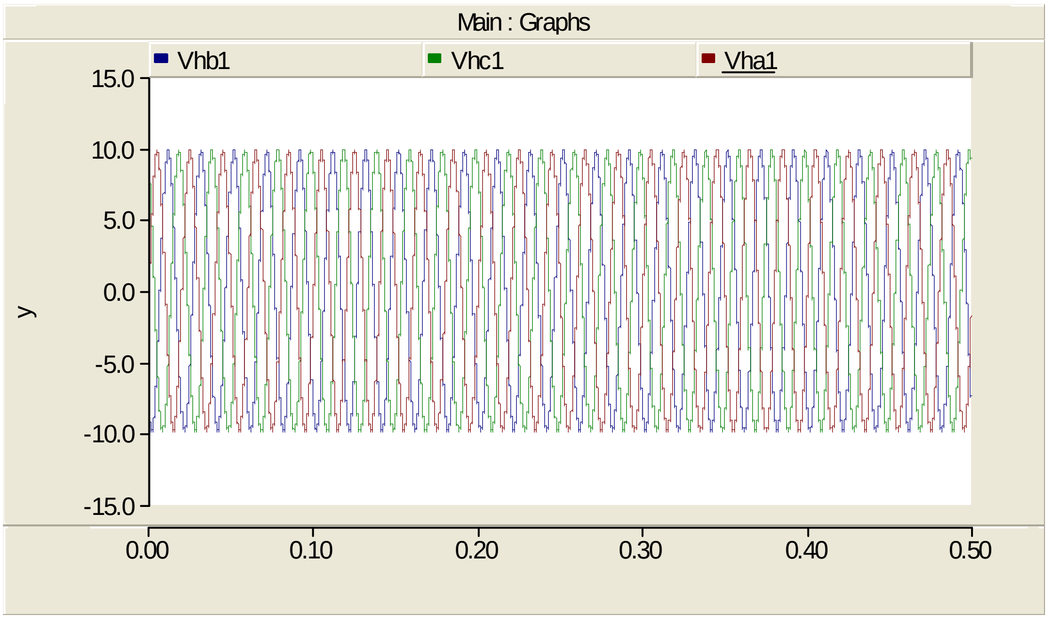

Fig.5.13 Phase Voltages at Output Of STS

5.3) DVR Part of CPP in PSCAD

The DVR is connected to the utility primary distribution feeder in series . The series interconnection as shown in Fig.5.14. It is required to allow the inserted voltage waveform to add to the utility system voltage. The sum of the line voltage and the inserted voltage becomes the restored voltage seen by the sensitive load. When connected in series between a sources and a load, the DVR can control the voltage applied to the load by injecting a voltage of arbitrary amplitude, phase and harmonic content into the line.

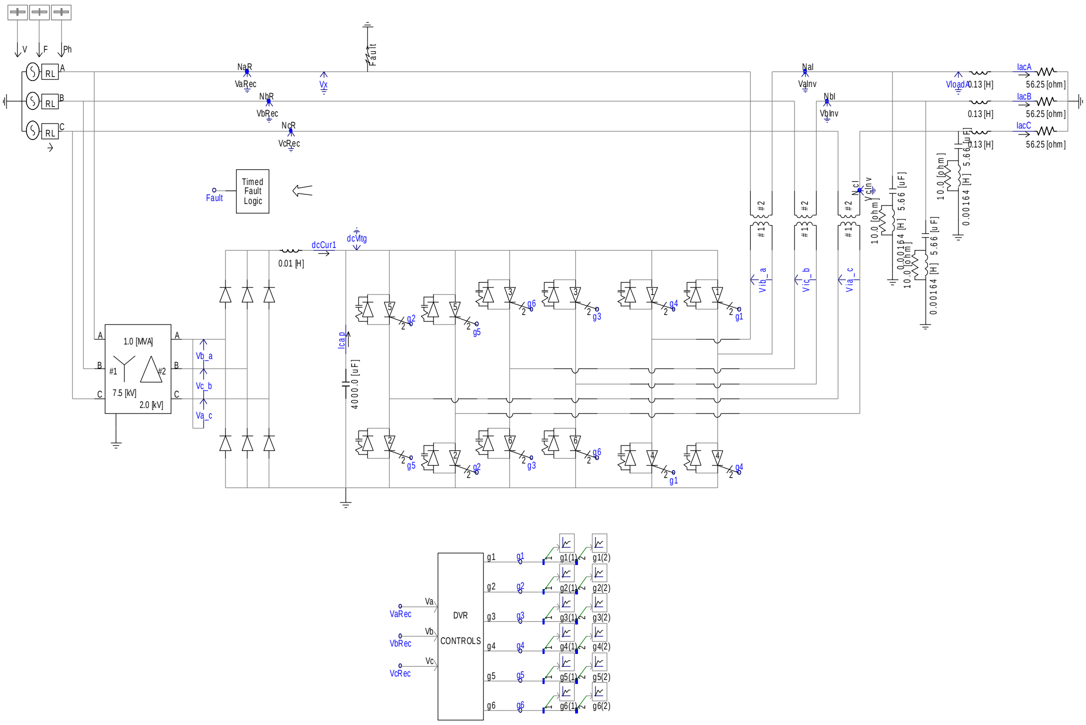

Fig 5.14 DVR Model in PSCAD

5.3.1) Control Unit of DVR in PSCAD

PSCAD modeling of DVR Control unit is shown in Fig.5.15. The main considerations for the control system of a DVR include: Detection of the start and finish of the sag, voltage reference generation, transient and steady state control of the injected voltage, and protection of the system.

Control unit requires measurement of four paramater groups.

1-) Three phase voltages before the DVR (Usupply) ; to detect a voltage sag and for feed-forward control of the output voltage.

2-) Three phase voltages after the DVR (Uload) for feed-back control of the output voltage.

3-) Three currents in the converter to protect the DVR by both saturation control and overcurrent.

4-) The DC link voltage for dc voltage compensation, for converter protection and to provide energy storage information

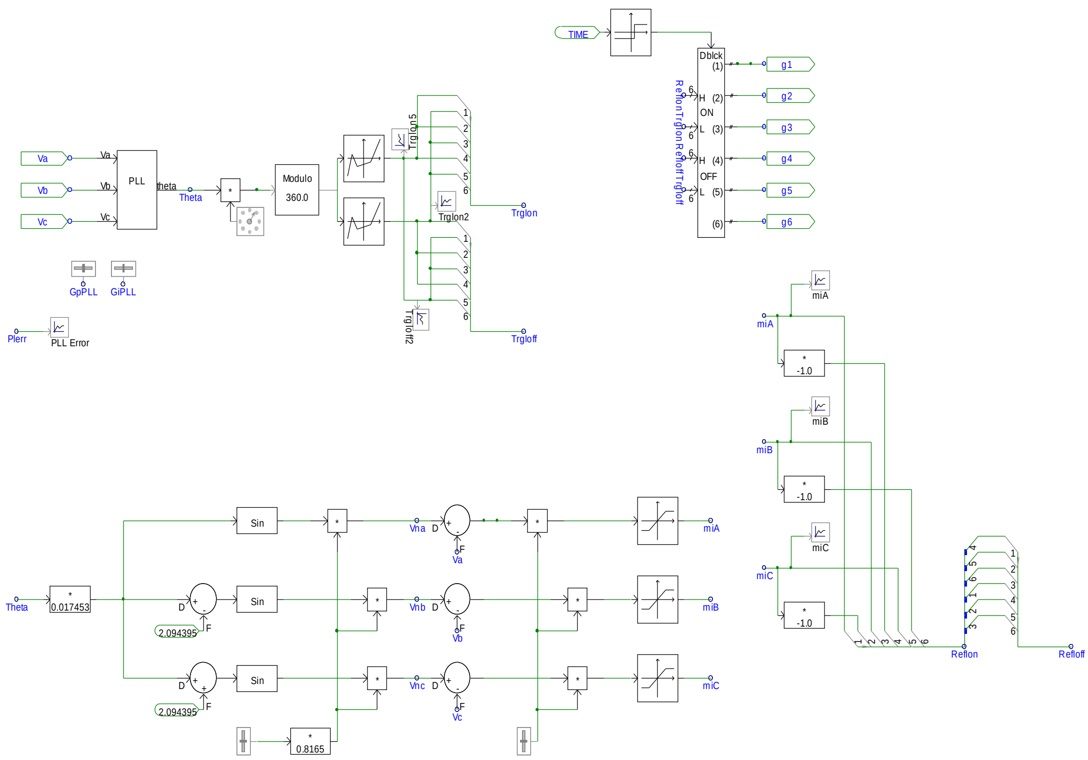

Fig 5.15 Control Unit of DVR in PSCAD

5.3.2) Simulation Results of DVR Part

Fig. 5.16 shows the RMS pu value of the phase voltage. The RMS pu value of the phase voltage is used to form an error signal at the fault time.

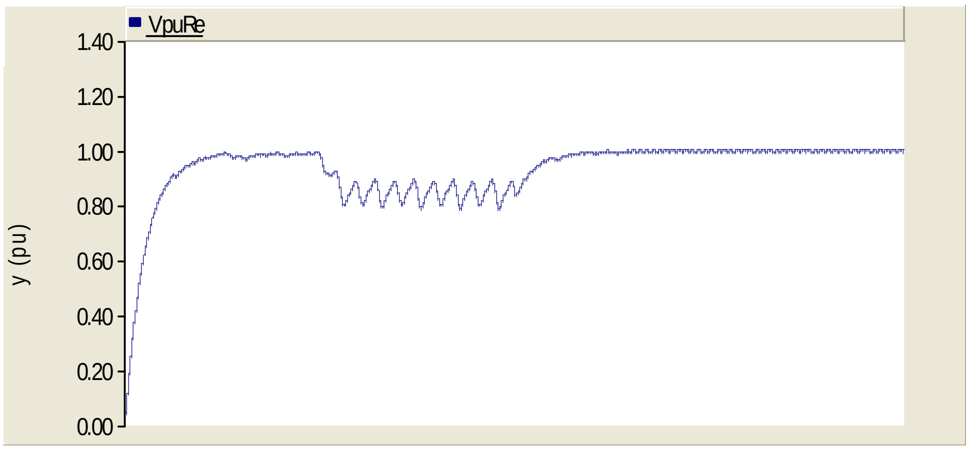

Fig.5.16 RMS pu Value of the Voltage

Fig.5.17 shows the load voltage. There is a fault at 0.16 sec and it is 0.05 sec duration. It is seem that at the fault duration the load voltage is undisturbed. Simulations have been carried out to evaluate the performance of the DVR in a distribution system under various operating conditions. From the simulation results, the designed DVR responded well in compensating voltage sags. The harmonics generated in the DVR can be significantly reduced by connecting a pasive filter to the system.

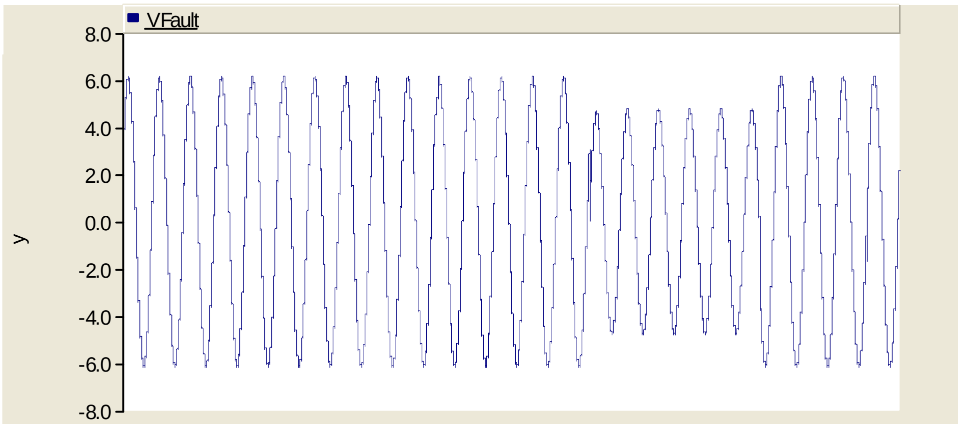

Fig.5.17 Phase Voltage Before DVR

Fig.5.18 illustrates the phase load voltage after the DVR. The result shows that fault has no effect on the CPP load voltage at the fault time. At the fault time DVR injects a voltage to the system.

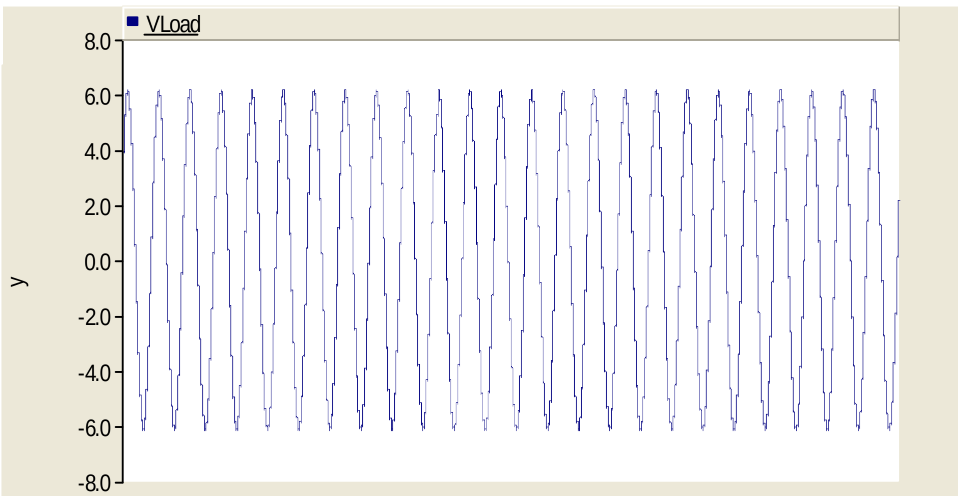

Fig.5.18 Phase Voltage After DVR

6-) CONCLUSIONS

This thesis has presented electromagnetic transient models of a custom power park. The park is composed by STS and DVR. The highly developed graphic facilities available in PSCAD/EMTDC were used to conduct all aspects of model implementation and to carry out extensive simulation studies.

Static Transfer Switch (STS) transfers the load from a preferred feeder to an alternate feeder. The mechanical transfer switch has been used for many years to transfer industrial loads to a backup power source. Due to the nature of the electromechanical switches used in the mechanical transfer switch seamless transfer is not obtainable. But static transfer switch can do this tranfering in 4 msec. When a voltage disturbance is detected, the load is transferred to healthy feeder. Because the transfering time is very short, the load is not effected by the disturbances. The STS performance is simulated for different faults using PSCAD/EMTDC.

Dynamic Voltage Restorer is used in some basic voltage disturbance correction. DVR is especially used for compensating the sags and swells. It is connected in series with a distribution feeder and is capable of generating or absorbing real and reactive power at its ac terminals. The limiting factor for DVR is the energy storage device. Because the missing voltage (for voltage sag) is provided from the storage device. For long sag duration the capacity of storage limits the operation DVR. DVR has been modeled using the PSCAD/EMTDC program.

Custom power park offers to the customer; no interruptions, low harmonic voltages, and acceptance of fluctuating and non-linear loads without effection terminal voltage.

It has been shown that custom power devices provide in many cases higher performance compared with traditional mitigation methods. However, the choice of the most suitable solution depends ultimately on the characteristic of the supply at the point of connection, the requirements of the load and economics, i.e the customer value added by the installation of a power-electronics based device.

In this thesis custom power park concept has been studied. Advantages of custom power devices have been pointed out. CPP has been modeled by using PSCAD/EMTDC program. CPP is composed of Static Transfer Switch (STS) and Dynamic Voltage Restorer (DVR). The operation principles of STS and DVR have been explained in detail and then they have been modeled with PSCAD/EMTDC program. Simulation results have been comprehensively investigated. Different types of faults are applied for STS and DVR in CPP and the response of the system for these disturbances are examined. The methodolgy of the integration of the custom power devices to the park is also discussed.

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BIOGRAPHY

I was born in Adana, Turkey, in 1980. I completed my high school education in Adana and graduated from Kozan High School. I completed university in Electrical and Electronics Engineering from Gaziantep University, Gaziantep, Turkey in 2002. After completion my university, I have started to work Kozan MYO.

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