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Protection and Power Quality Control of Grid-Connected Power Electronic Converters

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Abstract*:* This paper deals with modeling, simulation and implementation of power electronic converter system to improve the power quality. The present work deals with simulation of power system employing shunt active filter (ASF) and Thyristor Switched Capacitor (TSC). The behavior of power system with and without fault are studied are presented in this paper. The prototype module is implemented with the help of solid state circuit breaker.

Key words- Fault location, impedance measurement, power quality, protection, ASF, TSC.

1. INTRODUCTION

As the composition of power systems changes along with the increased use of distributed generation (DG), the ability to maintain a protected supply with high power quality is becoming more difficult. The increased use of power electronic converters as the part of loading system could cause further power quality problems: converters act as strong harmonic current sources. The information on power system parameters (the net power system impedance to sources) at any instant in time is central to addressing these problems. For example power system impedance monitoring is an important invention to active filter control [1]. The impedance calculation can be embedded into the normal operation of grid connected power electronic equipment (PEE) such as sine wave rectifiers [1] and active shunt filters (ASF). PWM harmonics associated with PEE, as measured in the active filter line current or voltage at the point of common connection can provide non-invasive estimation of power system impedance changes, although it is not appropriate enough to provide a suitable value for controlling. A small disturbance introduced by a short modification to the PEE's PWM strategy could be used to excite the power system impedance and the associated voltage and current transients could be used to determine more exactly the supply impedance back to source, the invasive method is only triggered when the non-invasive method determines a significant change. [2]

The previous estimation strategy required that the PEE line current and PCC line voltage be measured for 160ms before the transient injection, and 160ms post-transient in order to get a suitable frequency resolution for impedance measurement . The analysis proposed in the paper would substantially decrease the period for data capturing to 5ms post-transient, and reduce pre-transient data requirement. This is because the Continuous Wavelet Transform (CWT) is used to process current and voltage transient for calculating the supply impedance. The proposed method therefore has the potential to determine the change in the supply impedance within half a supply cycle.

This paper introduces the concept of real-time impedance estimation, and then describes how CWT is used to significant speed up impedance estimation, demonstrating this capability with experimental results. The paper then goes on to describe how this estimation technique may be used to locate faults in a defined power "zone". Fault identification and location is an important application of real-time impedance estimation, and may find use in renewable energy system, and power grids for more-electric aircraft and more-electric ships.

2. POWER SYSTEM IMPEDANCE MEASUREMENT

The power system impedance to source is measured by introducing a disturbance onto the system at PCC and analyzing the transient response using measured voltages and currents. The disturbance in this case is manufactured by manipulating two successive PWM cycles in the operation of pee such that they appear to inject a very short disturbance. For this work, PEE is an active filter as illustrated Figure 1, Figure 2. The presence of the filter inductance results in a short current spike, of approximately 1m long and 20A peak, injected to PCC. The proposed work of this method is used to find the voltage and current value by Continuous Wavelet Transform.

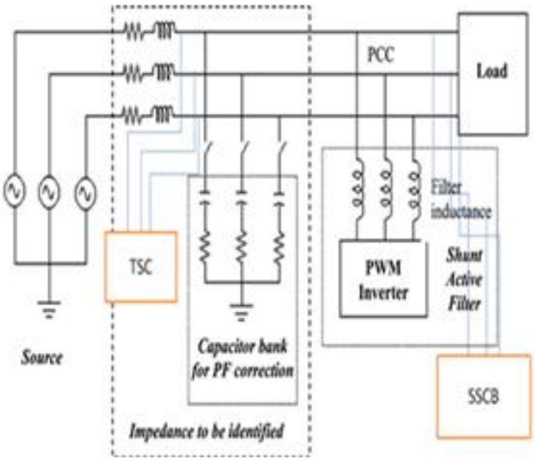

Figure 1. Circuit diagram for power impedance measurement.

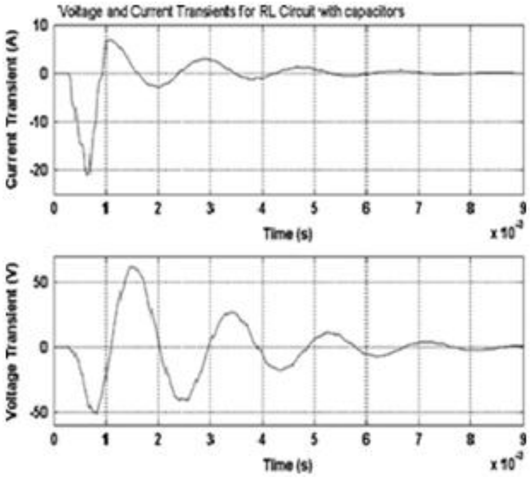

Figure 2. Transient disturbance injected into the circuit.

The impedance estimates at harmonic frequencies are discarded and an interpolation routine is used to determine the impedance to source at similar frequencies[1]. Describes how the estimated impedances at 5th, 7th, and 11th harmonic frequencies are used to generate reference signals for ASF. The excellent control of the filter demonstrates how an active shunt can operate in standalone mode (where sensor less means that ASF does not require an explicit measurement of supply or load currents.)

2.1Continuous Wavelet Transform (CWT)

The method presented here uses CWT. Unlike Fourier transforms, Wavelet transforms does not have a fixed time window, but adjust the window according to the frequency range of interest. CWT is a common signal processing tool for the analysis of non-stationary signal which is defined as the sum over time of the signal multiplied by scaled, shifted versions of the wavelet function. [3]

Unlike the discrete wavelet transform, any scale can be chosen. CWT is also continuous in terms of the shift during computation: the wavelet is shifted smoothly over the full domain of the function. Instead of producing a time- frequency map, a time scale map is produced where the scale represents a frequency range. Although the discrete wavelet transform (DWT) is a powerful signal processing tool, it has disadvantages including the lack of phase information, which makes it unsuitable for the proposed application. [3]

In this paper, the CWT method is used because the traditional DWT is unable to the decompose the measured signals V and I into the wavelet domain without the loss of phase information. In addition, CWT allows a greater control over the selection of scale ranges, which is useful for identifying a resonance peak in system impedance. The complex wavelet transform is used for analyzing power signals. A smooth oscillating function which is analytical and admissive is preferred. The most common choice of analyzing wavelets for modeling transient is a complex *Morletwavelet*, as there is a direct connection between scale and frequency. This wavelet would provide optimally localized filters in time and frequency [3].

The main advantages of CWT for parameter estimation are that it is more efficient than the Fourier transform method, it requires much less data, and noise can be isolated from the signal effectively using its multi-scale noise de-correlation properties. The noise in this system is broadband and hence pre-filtering methods, other than using hardware anti-aliasing filters, does not help.

3. TYPES OF ACTIVE POWER FILTER

Mainly there are three types of active power filter:
Based on the converter type
  VSI Inverter
  CSI Inverter
Based on topology
  Active Shunt Filter
  Active Series filter
  Hybrid Filter
Based on supply system
  1-Phase-2 wire system
  3-Phase-3 wire system
  3-Phase-4 wire system

3.1. SHUNT ACTIVE FILTER

Shunt active filter for a three-phase power system compensate with neutral wire, which is able to compensate for both current harmonics and power factor. Furthermore, it allows load balancing, eliminating the current in the neutral wire. The power stage is, basically a voltage-source inverter controlled in a way that it acts like a current-source [4].

A flexible and versatile solution to voltage quality problems is offered by active power filters. The basic principle of APF is to utilize power electronic technologies to produce specific currents components that cancel the harmonic currents components caused by the nonlinear load. 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 as a controllable current sources and series active power filters operate as a controllable voltage source. Both schemes are implemented preferable with voltage source PM inverters, with a dc bus having a reactive element such as a capacitor. Active power filters can perform one or more of the function required to compensate power system and improving power quality [4].

3.2. Principles of shunt active filter

The principle of active shunt filter is to produce harmonic current equal in magnitude but opposite in phase to those harmonics that present in grids. Phase shift of harmonic current is 180 degree.

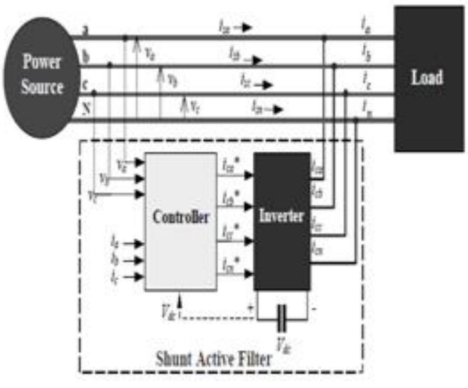

Figure 3. shunt active filter in a three phase power system with neural wire

3.3. THYRISTOR SWITCHED CAPACITOR

Thyristor Switched Capacitor (TSC) system is a type of SVC shunt to the line. Single phase consists of a number of back-to-back connected thyristor pair in series to a capacitor and a reactor as can be seen from Figure.3. The number of branches in one phase depends on the required precision of the reactive power. Due to its countless benefits including simple design and installing, TSC is preferred in many application areas. Some of them can be listed as supply voltage support, reactive power compensation, harmonic filtration etc.

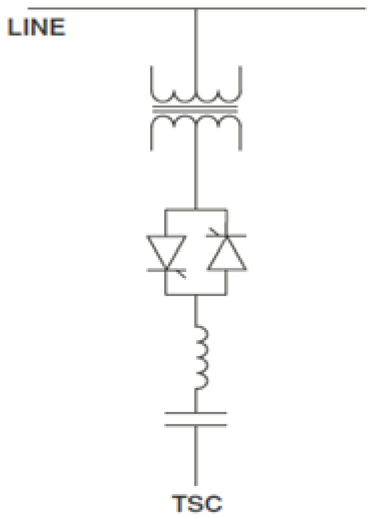

Figure 4. Thyristor switched capacitor

Among these application areas of TSC, the most common one is the reactive power compensation. TSC simply provides capacitive reactive power to the main electricity so that it reduces or cancels the reactive power demands of the large industrial loads.

TSC has been used since early 70s [5]. It was the only tool to improve the transient and to compensate the inductive reactive power efficiently. After investigating the benefits of TSC, many researches have been done about how to improve the transient response of capacitor switching. Since the supply at the instant of turn-on, many methods were improved to obtain a transient- free switching. Some of the researchers tried to obtain this concept without any reactor in series to the capacitor: instead they preferred GTO-thyristor pair brought more complicated control mechanism and increased the cost. As a result of these researchers, the thyristor pair started to be switched on at the instant where the line voltage is equal to the voltage across the thyristor. For the same reason, some other control techniques that support to charge the capacitors before switching on for a better transient response were improved, and new zero-crossing detectors were utilized with the improvement of technology. TSC can be configured in many different topologies such as delta connected capacitors, star connected TSC, thyristor-diode pairs, and etc. the delta connects capacitors banks with different power semiconductor switches [6].

TSC has been used for many applications in different purpose over the time. With chronological order, it was used for voltage regulation in arc suppression and reactive power.

Some commercial TSC systems have been built for different purpose in medium and high voltage levels by ABB and Siemens which are the leading companies in application of these systems. In these systems, connection to the bus baris generally made through a step down power transformer. The examples of such systems built by ABB and their purpose of installation are listed below.

The industry references of Siemens and companies that design commercial TSC systems in low voltage can also be found.

150 MVAr TSC for system stability improvement in Zimbabwe. [7]
94 MVAr TSC for voltage and power quality control in wind power applications. [8]
115 MVAr TSC for enhancing of power transmission capability in Australia. [9]
Relocatable TSC of 70 MVAr in three stages for the national grid company. [10]
400 MVAr TSC in three stages for increased power interchange capability between Canada and USA [11].

3.4 SOLID STATE CIRCUIT BREAKER

Solid state technology applied to this traditional device has resulted in circuit breakers free from arcing and switch bounce, that offer corresponding higher reliability and longer lifetimes as well as faster switching times. A typical solid state circuit breaker will switch in a matter of microseconds as opposed to milliseconds or even seconds for a mechanical version.

Figure.4.Illustrates the most basic configuration. The overcurrent trip point is set via the design equations in this figure. The current sense operates via a comparator which compares the voltages on the sources pin. The current on threshold pin, set by choice of RTH, is mirrored and returned to the source by a 1 kW resistor. This set the tip voltage of the comparator. When a fault condition occurs, an internal current sense latch is set, which turns off the power FET. The control input pin must be toggled low then high by reset switch before FET will be switched on again (after the short has been removed). A 330kW resistor is provided to hold the input low and keep the FET off until the circuit is reset. Advantages of this topology are its simplicity and correspondingly low cost. [12]

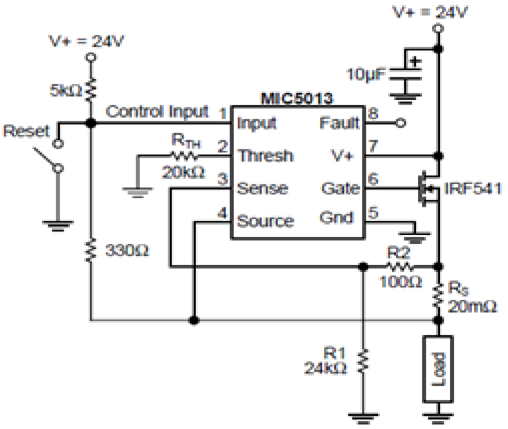

Figure 5. Solid State Circuit Breaker

4.SIMULATION RESULTS

The power system with shunt active filter (ASF) and thyristor switched capacitor (TSC) is modeled and simulated using Matlab as shown in Figure 6.

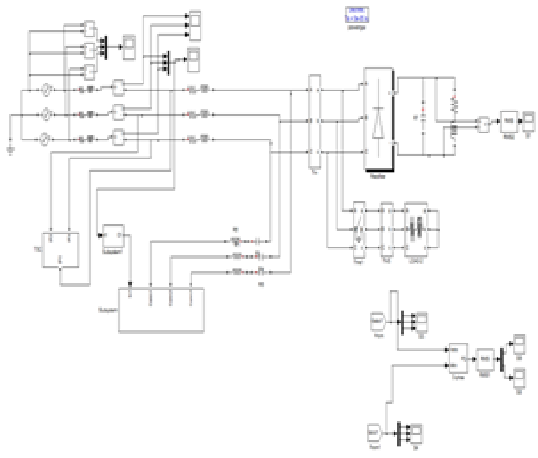

Figure 6. Matlab Model of SAF and TSC

Shunt active filter is used to reduce the harmonics in the alternator. Thyristor switched capacitor is added to improve the voltage and transmission ability of the power system.The sending end voltage is shown in Figure.7.

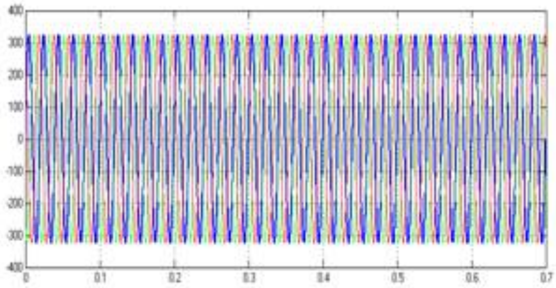

Figure 7. Sending end voltage

The switching pulses for M1, M3 and M5are shown in Figure.8.The delta connected Thyristor switched capacitor is shown in Figure.9.The voltage and current wave forms at the receiving end are shown in Figure.10 and Figure 11. respectively. The real power and reactive power at the receiving end are shown in Figure.12 and 13 respectively. The spectrum for source current is shown in Fig.5h.THD is 5.4% it can be seen that the voltage reaches normal value due to the addition of TSC.

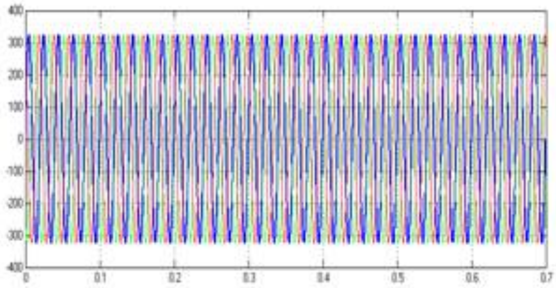

Figure 8. Switching pulse for (M1, M3, M5)

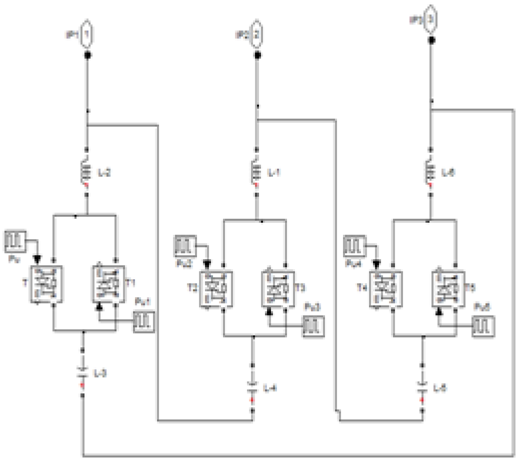

Figure 9. Matlab Model of Delta connected TSC

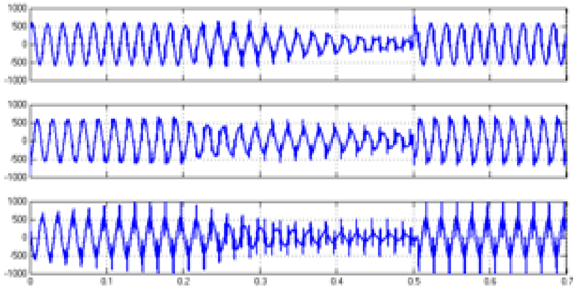

Figure 10. Output voltage

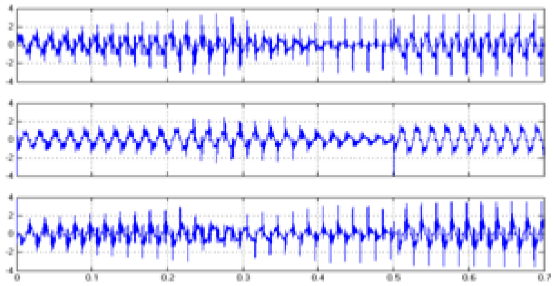

Figure 11. Output current

The output voltage and current waveform as shown in Figure 10, and Figure 11. It shows that the fault in the line has clearly explained in some distortion and it is cleared after some period in ms

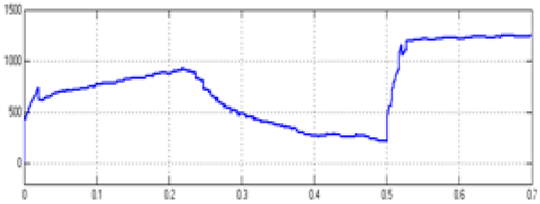

Figure 12. Real power

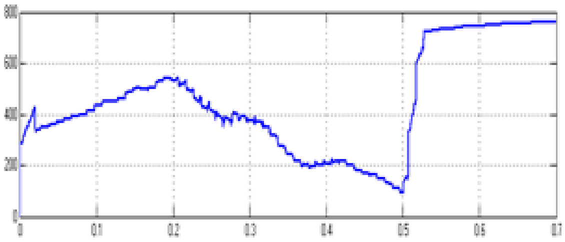

Figure 13. Reactive power

The real and reactive power of the Figure 12 and Figure 13 which shows can get the range up to the level by introducing Shunt Active Filter and Thyristor Switched Capacitor. The THD level will reduce and to meet the power quality byan ASF.

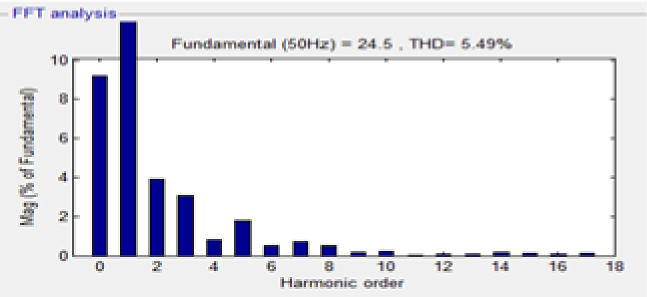

Figure 14. Spectrum for source current

4.1. DURING FAULTY CONDITION

The Simulink model of two bus system with shunt active filter and Thyristor switched capacitor during fault condition is shown in Figure.15.The sending end voltage is shown in Figure.16.

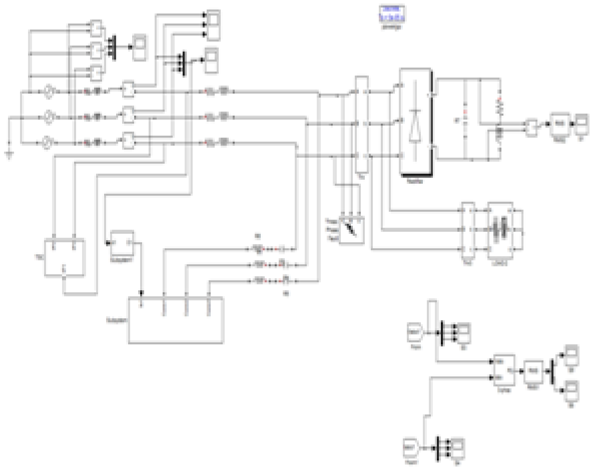

Figure 15. Matlab Model of Two bus system with SAF and TSC during fault condition

The fault is created at t=0.3 sec. The voltage decreases as shown in Figure.18. The load current decreases since the terminal voltage reduces to zero as shown in Figure.19.The real and reactive power are shown in Figures.20 and 21.respectively.The decrease is due to the reduction in the voltage.

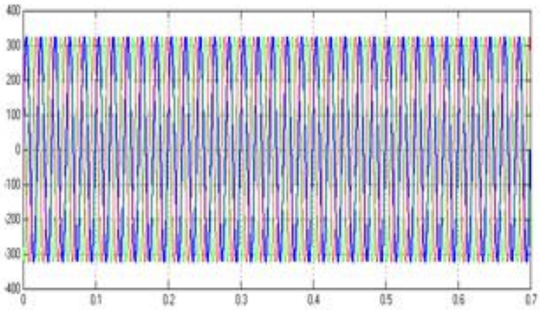

Figure 16. sending end voltage

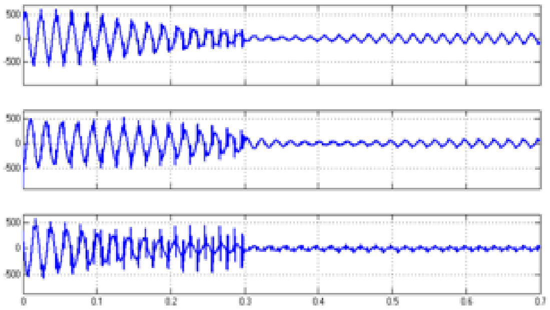

Figure 17. Output voltage fault created at 0.3 sec

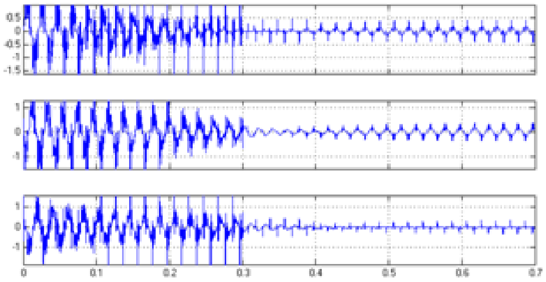

Figure 18. Output current fault created at 0.3 sec

Figure 17 and Figure 18, shows at fault condition, the output voltage and current will start out of distortion and it can be reduced and can get instant clear and by improving the power quality through an ASF and TSC

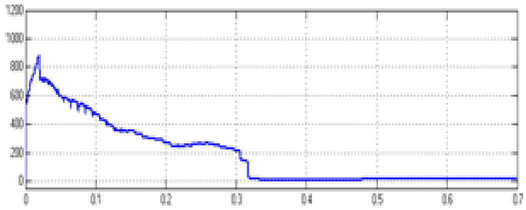

Figure 19. Real power fault created at 0.3 sec

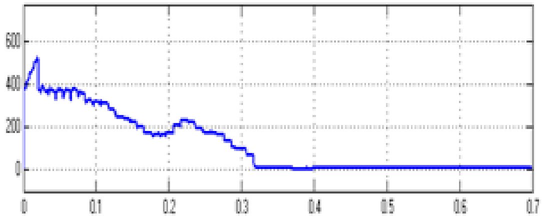

Figure 20. Reactive power fault created at 0.3 sec

Figure 19 and Figure 20. Showsthat, at fault condition the real and reactive power performance will be worst and it should be clear by a reducing harmonic and improving the power quality.

4.2 FAULT ISOLATION CONDITION

The Simulink model with fault being isolated is shown in Figure.21. The fault is isolated using solid state circuit breaker (SSCB). The sending end voltage is shown in Figure.22. The output voltage and current are shown in Figures.23 and 24 respectively. The voltage and current resumes normal value after the fault. The real and reactive power is shown in Figures.25 and 26 respectively.

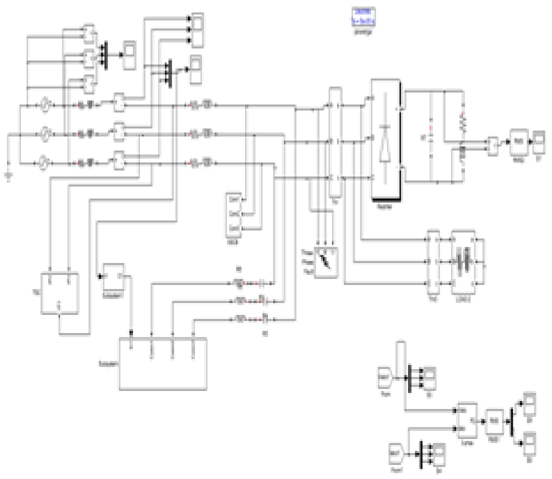

Figure 21. Two bus system with SAF and TSC during fault isolation condition

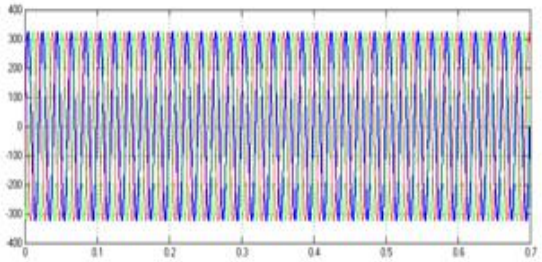

Figure 22. sending end voltage

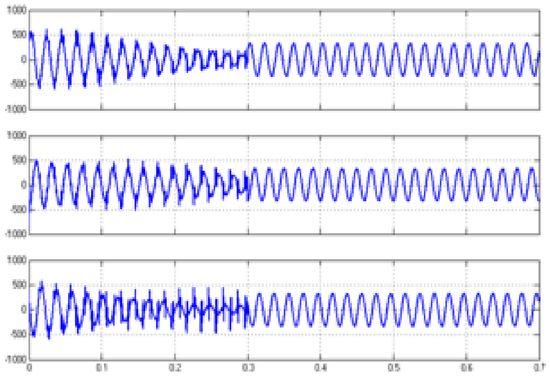

Figure 23. Output voltage with fault isolated at 0.3 sec

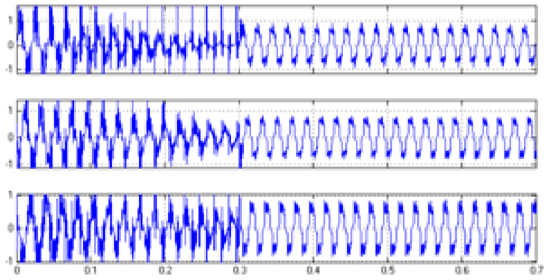

Figure 24. Output current with fault isolated at 0.3 sec

The Figures 23 and 24 will shows that, the output voltage and current will comes out of distortion and after isolating the fault, it made be a clear performance.

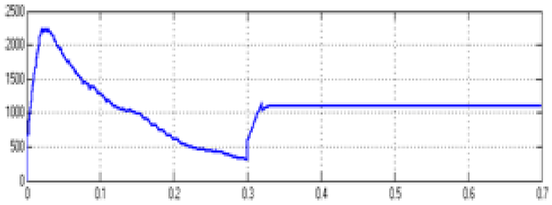

Figure 25. Real power with fault isolated at 0.3 sec

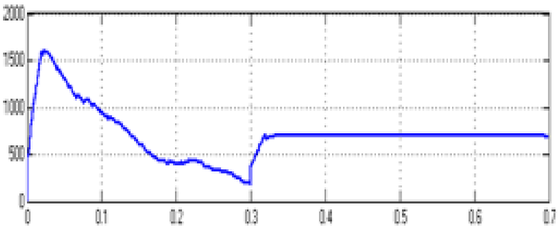

Figure 26. Reactive power with fault isolated at 0.3 sec

The real and reactive power at isolated condition as shown in Figures 25 and 26 it explain by making a fault condition to be isolated as well as the real and reactive power will improve.

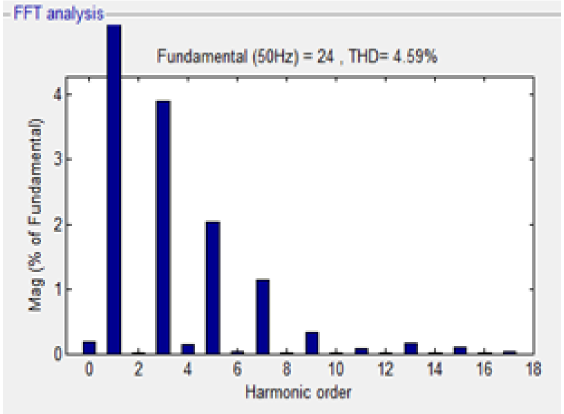

Figure 27. Spectrum for source current.

4.3. PROTOTYPE MODULE

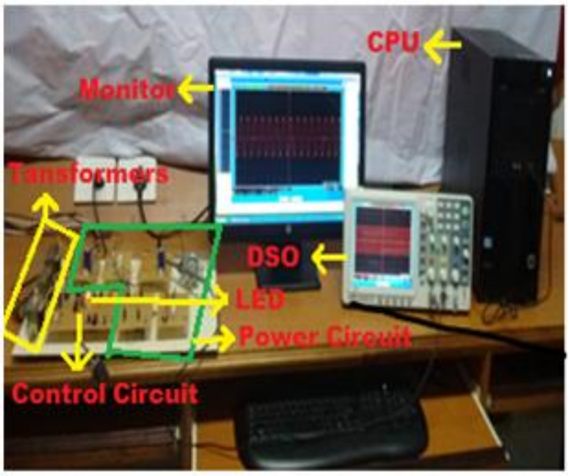

Figure 28. Hardware Diagram

The hardware connection diagram has two major circuits.

1. Control circuit
2. Power circuit

Control circuits consist of power supply,PIC IC 16F84A and Driver IC 1R2110.

PIC IC 16F84A:.It is a 18 pin IC and it is used to Control the Circuit.This have more inbuild memory such as PWM Generator,Comparator and ADC. **Driver IC1R2110:** This is a 14 pin IC and it is used to drive the MOSFET (switches).Accuracy is high and it is used to amplify the pulses.

Power circuit: It consist of Rectifier, RL Load, RLC Load, MOSFET (switches) and Motor.

Rectifier: It converts the AC into DC

RL Load: It act as a Load at the output end

RLC Load: The active and reactive powers absorbed by the load are proportional to the square of the applied voltage.

MOSFET (switches): It is a voltage controlled device.

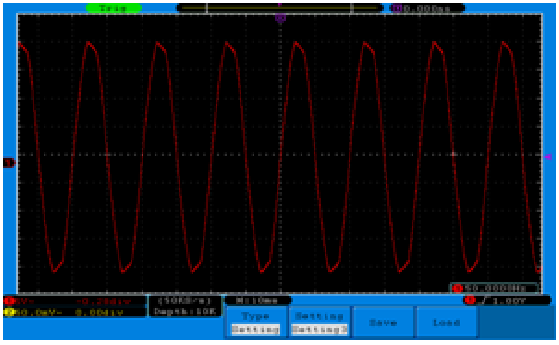

Figure 29. Input Voltage

A 230V Single Phase Input Voltage of a waveform to be taken at the input of the rectifier and it should be in sinusoidal.

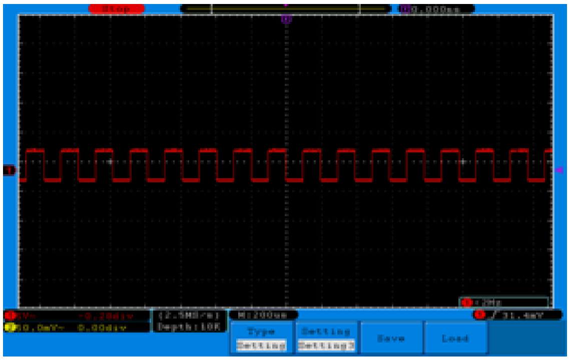

Figure 30. Switching Pulse at 5V

The MOSFET switches at 5V cannot be getting a pulse because the pulse needs a voltage of 10v.

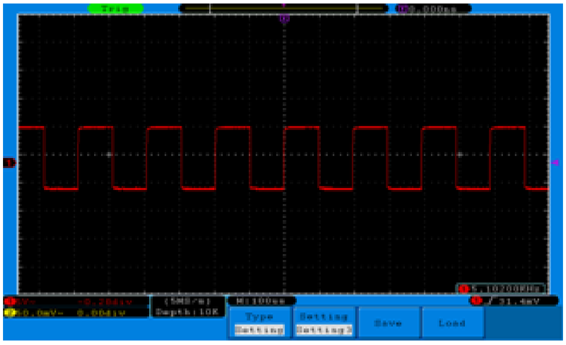

Figure 31. Switching Pulse at 10v

The driver IC is used to amplifying the switching pulse up to 10V to getting a clear pulse.

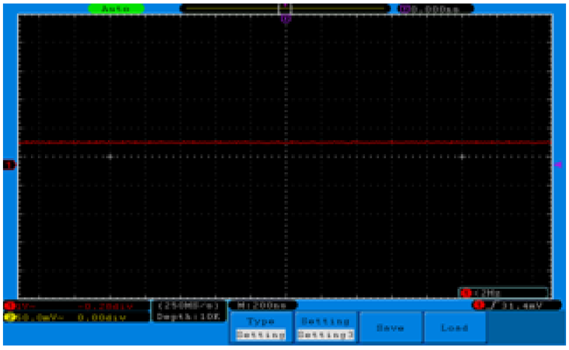

Figure 32. Output Voltage at Fault Condition

At fault condition, the output waveform is shows to get a straight line.

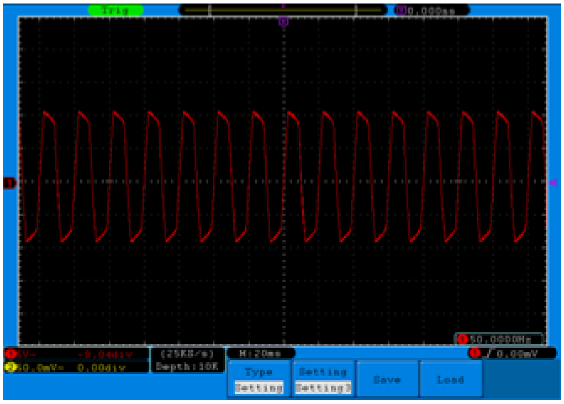

Figure 33. Output Voltage at Fault Isolation Condition

At faulty condition is become too clear as says as fault isolation is to get a waveform resembles to input of sinusoidal.

5. CONCLUSION

Two bus systems with FACTS device like shunt active filter and Thyristor switched capacitor are modeled and simulated successfully. The above system with fault and fault created condition are also simulated and the results are presented. The results indicate that SSCB brings normal condition to the fault isolated system. The advantages of this systemare reduction of heat in the alternator and improvement of receiving end voltage. The cost of the power system increases due to the addition of SAF, TSC and SSCB.

In the prototype module also occurance of fault is isolated with the help of SSCB.Here it is not possible to use solid state circuit breaker,so that introduced three way toggle switch is used and it is act as a SSCB.

This work can be extended to multi bus systems like 8 bus system, 14 bus system and 30 bus systems.

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