Minimization of Harmonics In Shunt Active Power Filter Using Fuzzy Logic Controller

Ashokkumar.K[1], K Padmanaban[2]
[1, 2] Dept of M.E (PED)
[1, 2] Gnanamani College of Engineering, Namakkal, Tamilnadu, India

Abstract- *Unified Power Flow Controller (UPFC) is a versatile device in the FACTS family of controllers which has the ability to simultaneously control all the transmission parameters of power systems i.e. voltage, impedance and phase angle which determines the power flow of a transmission line. In modern area, the electrical power demand is high and it is still growing therefore it is necessary to utilize the transmission lines up to its maximum loadable limit. The transient stability limits the maximum loading of the power system and it causes the system to become unstable below its steady state stability limit. In this paper, the improvement of transient stability of a taken study system using matrix converter based UPFC is analyzed. Here the matrix converter is controlled using space vector modulation technique. The system has simulated in MATLAB - Simulink under three-phase fault condition with and without matrix converter and the result obtained at both the cases.*

I. INTRODUCTION

POWER FLOW CONTROL IN POWER SYSTEMS

1.1: Power System Operation

A power system is a large interconnected network with components converting nonelectrical energy into the electrical form to meet the demanded high quality power supply to the end users. A power system is an electrical network divided into three sub-systems. The three sub-systems are the generation stations, the transmission systems and the distributed systems. Electric power produced by a generator unit transmitted from generators to loads by transmission system. The transmission systems are the connecting link between generating stations and the distributed systems that leads to other power system over interconnections as shown in the block diagram in Figure 2.1.

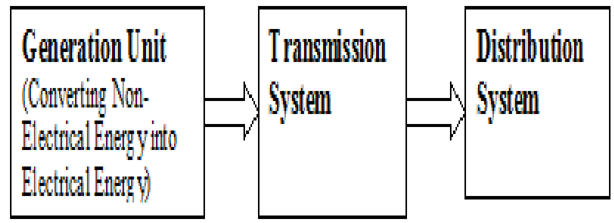


Figure 1.1: Block Diagram of Power System Operation

Generation Unit: The generation unit includes the generating plants that produce energy fed through the transformers to a high voltage transmission network interconnecting to other generating plants. It converts non-electrical energy such as coal, water, natural gas, hydroelectric, solar and geothermal sources etc., into electrical energy.

Transmission Systems: In transmission systems, electricity generated from power generation unit is transferred to substations. It performs voltage transformation, power switching, measurement and control.

Distribution Systems: This is the final stage in the delivery of electricity to the end users. A distribution system carries electricity from the transmission system and delivers it to the end users.

1.2: Power Flow Control

Today most of the electrical power systems in the world are widely interconnected due to economic reasons to reduce the cost of electricity and to improve system stability and reliability. Because of the increasing complexity of power system design, the challenge to meet the high quality power supply in a power system is highly desirable. The factors considered for the smooth functionality of power system operation and control as follows:

Power system operating in a synchronous mode maintains the power quality with a controlled phase between all the interconnected networks.

The voltage level in a power system should maintain within limits. Any variations in the voltage level cause damage to electric motors and dielectric components, which is not acceptable and leads to overloading of many electric components. Transmission lines of power systems should operate with minimum losses by using the most efficient transmission paths capable of handling the loads.

1.3: Power System Limitations

Theoretically, power engineers have taken lot of measures to avoid the limitations and maintain the power system to work with stability and reliability.

Thermal limit: Thermal limits are due to the thermal capability of power systems. As power transfer increases, current magnitude increases which is key to thermal damage

Voltage limit: Power systems are designed to operate at a nominal supply voltage. Variations in nominal voltage can adversely affect the performance as well as cause serious damage to the system. Current flowing through the transmission lines may produce an unacceptably large voltage drop at the receiving end of the power system.

Transient Stability: It is defined as the ability of power system to maintain synchronism when it is subjected to severe transient disturbance. In general, power systems with long transmission lines are most susceptible to transient instability.

1.4: Power Controlling Devices

To overcome the above limitations, power system engineers introduced the concept of advanced controller devices that provide techniques to maintain system stability and reduce losses.

1.5:Phase Shifting Transformer (PST):

Generally, transformers transport electric power between different voltage levels of a power system. Such special transformers are termed as Phase Shifting Transformer (PST). PSTs used to control the power flow through a specific line and line losses in a complex transmission network.

Disadvantages

The speed of the phase shifting transformers to change the phase angle of the injected voltage is very slow and limited to issues with short-circuit current protection.

- ✓ In conclusion, PSTs applied in power system are very limited with slow requirements under steady state system condition.

Figure 1.5: Phase Shifting Transformer (PST) 1.6:High

Voltage Direct Current (HVDC):HVDC systems introduced in 1950's play an important role to improve the reliability of the power system in addition to the power transfer operations. It is the feasible way to interconnect two asynchronous networks, reduce fault currents, power system reliability and utilize long cable circuits. Converting AC to DC terminal referred as rectifier and DC to AC terminal referred as inverter terminal. Figure 2.3 taken from reference gives us the idea of how HVDC converters connected in the interconnected systems.

Figure 1.6: HVDC Converter StationHVDC

Applications: These provide high power flow transfers over long distance using fewer transmission lines than AC transmission lines, with lower system losses by increasing the dc voltage level. HVDC underground cables have no restricted limitation over the distance as in case of ac cables. HVDC cables used with voltage source converter based HVDC transmission systems are lighter and more flexible

Disadvantages:

HVDC system generates harmonics that effect on the power quality of a power system. Normal operation of HVDC requires a reactive power to support hence large reactive source should be installed at the converter stations.

1.7: Flexibility of AC Transmission Systems (FACTS):

The world's electrical power systems today are widely interconnected due to economic reasons to reduce the cost of electricity and to improve the reliability of the system. These interconnected networks are difficult to operate and cannot utilize the full potential of a transmission system.. Later power system engineers introduced the concept of power electronic devices to control the power system limitations known as Flexible AC Transmission System (FACTS) devices.

FACTS Applications: In interconnected as well as in long transmission power systems technical problems occur which limits the load ability and reliability of the system. The best devices for the use in complex systems are the phase angle regulator, the controlled series compensator. In long-distance transmission, TCSC or SSSC offers advantages comparing effectiveness against the rating, complexity and costs [8].

Disadvantages:

Disadvantages Of all the power-controller devices discussed above, FACTS controllers are the most recent and commonly used application in power system operation. In the next chapter, I discussed in detail about the different FACTS Controllers and their characteristics.

II. LITERATURE REVIEW

The technology of power system utilities around the world has rapidly evolved and considerable changes in the technology along with improvements in power system structures and operation. The ongoing expansions and growth in the technology, demand a more optimal and profitable operation of a power system with respect to generation, However, the increasing complexities of large interconnected networks had fluctuations in reliability of power supply, which resulted in system instability, difficult to control the power flow and security problems that resulted large number blackouts in different parts of the world. The reasons behind the above fault sequences may be due to the systematical errors in planning and operation, weak interconnection of the power system, lack of maintenance or due to overload of the network.In order to overcome these consequences and to provide the desired power flow along with system stability and reliability, installations of new transmission lines are required. However, installation of new transmission lines with the large interconnected power system are limited to some of the factors like economic cost, environment related issues. These complexities in installing new transmission lines in a power system challenges the power engineers to research on the ways to increase the power flow with the existing transmission line without reduction in system stability and security. In this research process, in the late 1980's the Electric Power Research Institute (EPRI) introduced a concept of technology to improve the power flow, improve the system stability and reliability with the existing power systems. This technology of power electronic devices is termed as Flexible Alternating Current Transmission Systems (FACTS) technology. It provides the ability to increase the controllability and to improve the transmission system operation in terms of power flow, stability limits with advanced control technologies in the existing power systems. FACTS controllers are advanced in relation to mechanical control switched systems that are controlled with ease. They have the ability to control the power flow and improve the performance of the power system without changing the topology. Since 1980s, a number of different FACTS controllers with advanced control techniques proposed as per the demand of the power systems. Unified Power Flow Controller (UPFC) is one among the different FACTS controllers introduced to improve the power flow control with stability and reliability. It is the most versatile device introduced in early 1990s designed based on the concept of combined series-shunt FACTS Controller. It has the ability to simultaneously control all the transmission parameters affecting the power flow of a transmission line i.e. voltage, line impedance and phase angle.

2.2: FLEXIBLE ALTERNATING CURRENT TRANSMISSION SYSTEMS

According to the IEEE definition, FACTS is defined as "The Flexible AC Transmission System(FACTS) is a new technology based on power electronic devices which offers an opportunity to enhance controllability, stability and power transfer capability of AC Transmission Systems".Power systems today are highly complex and the requirements to provide a stable, secure, controlled and economic quality of power are becoming vitally important with the rapid growth in industrial area. To meet the demanded quality of power in a power system it is essential to increase the transmitted power either by installing new transmission lines or by improving the existing transmission lines by adding new devices. Installation of new transmission lines in a power system leads to the technological complexities such as economic and environmental considerations that includes cost, delay in construction as so on. In this research process, in late 1980s Electric Power Research Institute (EPRI) came up with the concept of Flexible AC Transmission Systems (FACTS) technology, which enhances the security, capacity and flexibility of power transmission systems. It was the new integrated concept based on power electronic switching device and dynamic controllers to enhance the system utilization and power transfer capacity as well as the stability, security, reliability and power quality of AC transmission Systems. The controllers designed based on the concept of FACTS technology known as FACTS controllers.

2.3: Introduction to FACTS controllers:

The controllers that are designed based on the concept of FACTS technology to improve the power flow control, stability and reliability are known as FACTS controllers. These controllers were introduced depending on the type of power system problems. Some of these controllers were capable of addressing multiple problems in a power system but some are limited to solve for a particular problem.

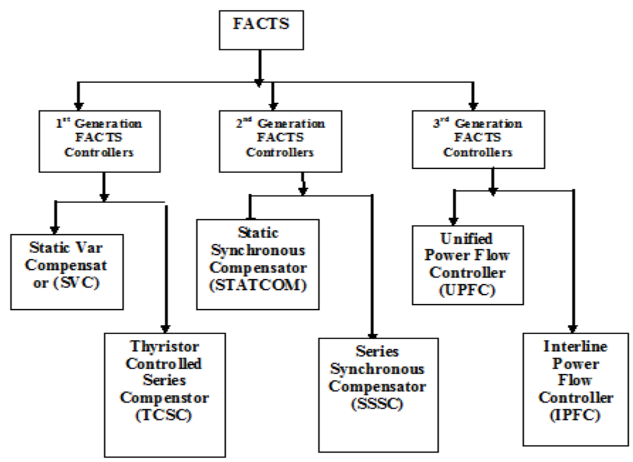


Figure 2.3: Block Diagram of FACTS Controllers

2.4: Different FACTS Controllers: First Generation of FACTS Controllers: These categories of controllers are designed based on thermistor based FACTS technology.

Static Var Compensator (SVC): It is the first device in the first generation of FACTS controller introduced to provide fast-acting reactive power compensation in the transmission network. **Circuit Description:** Static Var Compensator as shown in Fig 3.2 composed of thyristor controlled reactor (TCR), thyristor switched capacitor (TSC) and harmonic filters connected in parallel to provide dynamic shunt compensation. The current in the thyristor controlled reactor is controlled by the thyristor valve that controls the fundamental current by changing the fire angle, ensuring the voltage limited to an acceptable range at the injected node.

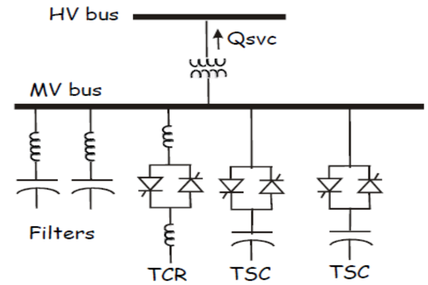


Figure 2.4: Circuit Diagram of Static Var Compensator (SVC)

Characteristics of SVC:

SVC placed in a transmission network provides a dynamic voltage control to increase the transient stability, enhancing the damping power oscillations and improve the power flow control of the power systems.

In real time scenario, it effectively controls the reactive power, improves the power factor, reduces the voltage levels caused by the nonlinear loads, improves the power quality and reduces the energy consumption.

Thyristor Controlled Series Compensator (TCSC): It is designed based on the thyristor based FACTS technology that has the ability to control the line impedance with a thyristor-controlled capacitor placed in series with the transmission line. It is used to increase the transmission line capability by installing a series capacitor that reduces the net series impedance thus allowing additional power to be transferred.

Circuit Description: TCSC device consists of three main components: Capacitor bank, bypass inductor and bidirectional thyristors SCR1 and SCR2 as shown in the Fig 3.3.

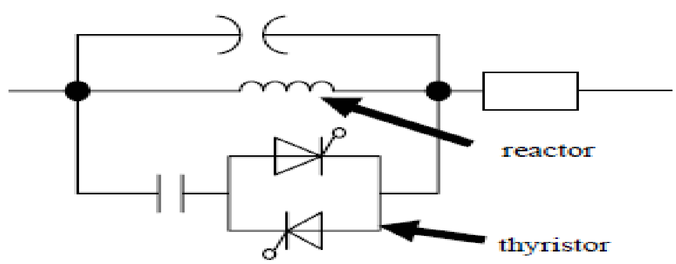


Figure 2.5: Circuit Diagram of Thyristor Controlled Series Compensator (TCSC)

Characteristics of Thyristor Controlled Series Compensator (TCSC): TCSC placed in a transmission network provides the power flow control in a power system improving the damping power oscillation and reduces the net loss providing voltage support.The thyristors in TCSC device offers a flexible adjustment with the ability to control the continuous line compensation

2.6:Static Synchronous Series Compensator (SSSC): Static Synchronous Series Compensator is based on solid-state voltage source converter designed to generate the desired voltage magnitude independent of line current.

Circuit Description:SSSC consists of a converter, DC bus (storage unit) and coupling transformer as shown in Figure 3.4. The dc bus uses the inverter to synthesize an AC voltage waveform that is inserted in series with transmission line through the transformer with an appropriate phase angle and line current. If the injected voltage is in phase with the line current it exchanges a real power and if the injected voltage is in quadrature with line current it exchanges a reactive power.

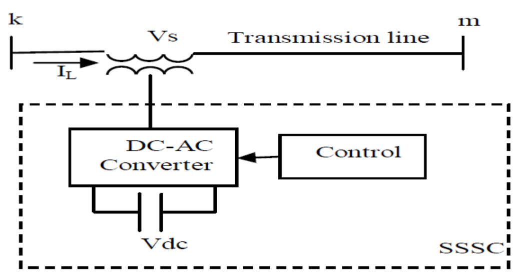


Figure 2.6: Block Diagram of Static Synchronous Series Compensator (SSSC)

Characteristics of SSSC: SSSC in a transmission network generates a desired compensating voltage independent of the magnitude of line current, by modulating reactive line impedance and combining real and reactive compensation it can provide high damping of power oscillation. All the above features of SSSC attract the FACTS device for power flow control, damping of power oscillations and transient stability.

2.7:Static Synchronous Compensator (STATCOM): It is designed based on Voltage source converter (VSC) electronic device with Gate turn off thyristor and dc capacitor coupled with a step down transformer tied to a transmission line as shown in Fig 3.5. It converts the dc input voltage into ac output voltages to compensate the active and reactive power of the system. STATCOM has better characteristics than SVC and it is used for voltage control and reactive power compensation.

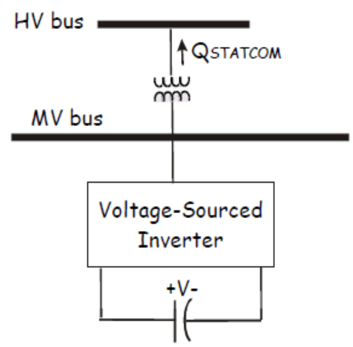


Figure 2.7: Circuit Diagram of Static Synchronous Compensator (STATCOM)

Characteristics of Static Synchronous Compensator (STATCOM): STATCOM placed on a transmission network improve the voltage stability of a power system by controlling the voltage in transmission and distribution systems, improves the damping power oscillation in transmission system, provides the desired reactive power compensation of a power system.

Third Generation of FACTS Controllers: The third generation of FACTS controllers is designed by combining the features of previous generation's series and shunt compensation .

Unified Power Flow Controller (UPFC): It is designed by combining the series compensator (SSSC) and shunt compensator (STATCOM) coupled with a common DC capacitor. i.e. voltage, impedance and phase angle.

Circuit Description: s As shown in Fig 3.6 it consists of two converters – one connected in series with the transmission line through a series inserted transformer and the other one connected in shunt with the transmission line through a shunt transformer. The DC terminal of the two converters are connected together with a DC capacitor. Power flows on the transmission line. Hence the series converter will exchange active and reactive power with the line.

Characteristic of UPFC:

The concept of UPFC makes it possible to handle practically all the power flow control and transmission lines compensation problems using solid-state controllers that provide functional flexibility which are generally not obtained by thyristor-controlled controllers.

2.8: Interline Power Flow Controller (IPFC): It is designed based on Convertible Static Compensator (CSC) of FACTS Controllers. As shown in Fig 3.7, IPFC consists of two series connected converters with two transmission lines. It is a device that provides a comprehensive power flow control for a multi-line transmission system and consists of multiple number of DC to AC converters, each providing series compensation for a different transmission line. The converters are linked together to their DC terminals and connected to the AC systems through their series coupling transformers. With this arrangement, it provides series reactive compensation in addition any converter can be controlled to supply active power to the common dc link from its own transmission line.

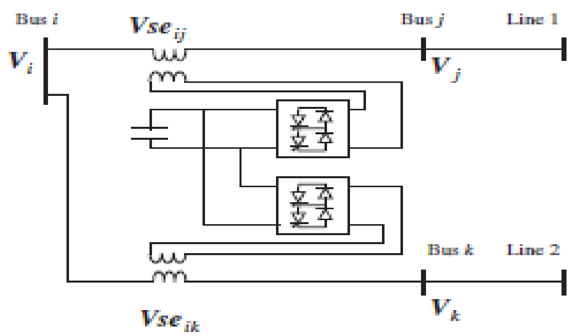


Figure 2.8: Circuit Diagram of Interline Power Flow Controller

Characteristics of IPFC: To avoid the control of power flow problem in one system with synchronous of power in other system, installation of IPFC system in additional parallel inverter is required to meet the active power demand.

Generalized Unified Power Flow Controller (GUPFC):
It has been proposed to realize the simultaneous power flow control of several transmission lines. It is designed by combining three or more dc to ac converters working together extending the concepts of voltage and power flow control of the

Equivalent Circuit Operation of UPFC

As shown in Fig 4.2, the two-voltage source converters of UPFC can modeled as two ideal voltage sources one connected in series and other in shunt between the two buses. The output of series voltage magnitude V_{se} controlled between the limits $V_{se\max} \leq V_{se} \leq V_{se\min}$ and the angle θ_{se} between the limits $0 \leq \theta_{se} \leq 2\Pi$ respectively. The shunt voltage magnitude V_{sh} controlled between the limits $V_{sh\max} \leq V_{sh} \leq V_{sh\min}$ and the angle between $0 \leq \theta_{sh} \leq 2\Pi$ respectively. Z_{se} and Z_{sh} are considered as the impedances of the two transformers one connected in series and other in shunt between the transmission line and the UPFC as shown in the Fig 4.2 which is the UPFC equivalent circuit [11].

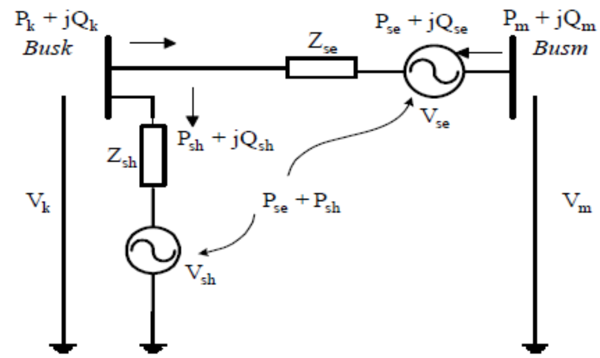
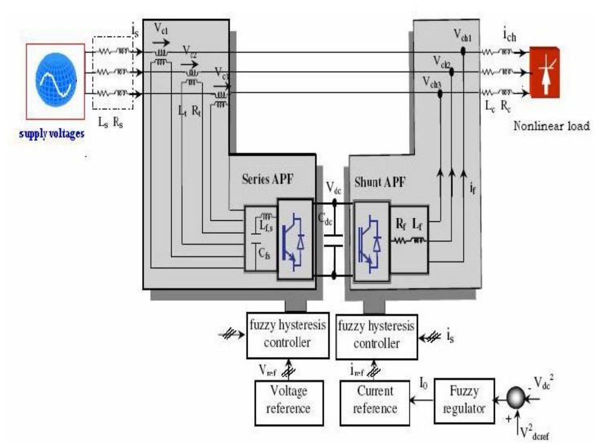
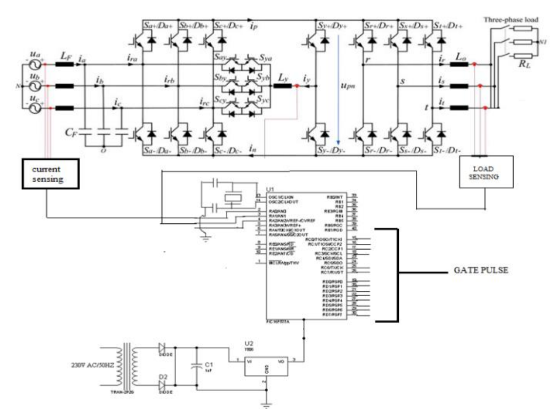


Figure 4.2: Equivalent circuit of UPFC

PROPOSED SYSTEMBLOCK DIAGRAM



CIRCUIT DIAGRAM



III. PROPOSED CONTROL TECHNIQUEFUZZY LOGIC

Fuzzy logic has rapidly become one of the most successful of today's technologies for developing sophisticated control system. The reason for which is very simple. Fuzzy logic addresses such applications perfectly as it resembles human decision making with an ability to generate precise solutions from certain or approximate information. It fills an important gap in engineering design methods left vacant by purely mathematical approaches (e.g. linear control design), and purely logic-based approaches (e.g. expert systems) in system design.

What does it offer?The first applications of fuzzy theory were primary industrial, such as process control for cement kilns. However, as the technology was further embraced, fuzzy logic was used in more useful applications. In 1987, the first fuzzy logic-controlled subway was opened in Sendai in northern Japan. Here, fuzzy-logic controllers make subway journeys more comfortable with smooth braking and acceleration. Best of all, all the driver has to do is push the start button! Fuzzy logic was also put to work in elevators to reduce waiting time. Since then, the applications of Fuzzy Logic technology have virtually exploded, affecting things we use every day.

What does fuzzy mean:

Before illustrating the mechanisms which make fuzzy logic machines work, it is important to realize what fuzzy logic actually is. Fuzzy logic is a superset of conventional (Boolean) logic that has been extended to handle the concept of partial truth- truth values between "completely true" and "completely false". As its name suggests, it is the logic underlying modes of reasoning which are approximate rather than exact.

Fuzzy Sets: Fuzzy Set Theory was formalized by Professor Lofti Zadeh at the University of California in 1965. What Zadeh proposed is very much a paradigm shift that first gained acceptance in the Far East and its successful application has ensured its adoption around the world.

3.2:Fuzzy Set Operations Union :

The membership function of the Union of two fuzzy sets A and B with membership functions μ_A and μ_B respectively is defined as the maximum of the two individual membership functions. This is called the *maximum* criterion.

$$\mu_{A \cup B} = \max(\mu_A, \mu_B)$$

The Union operation in Fuzzy set theory is the equivalent of the OR operation in Boolean algebra

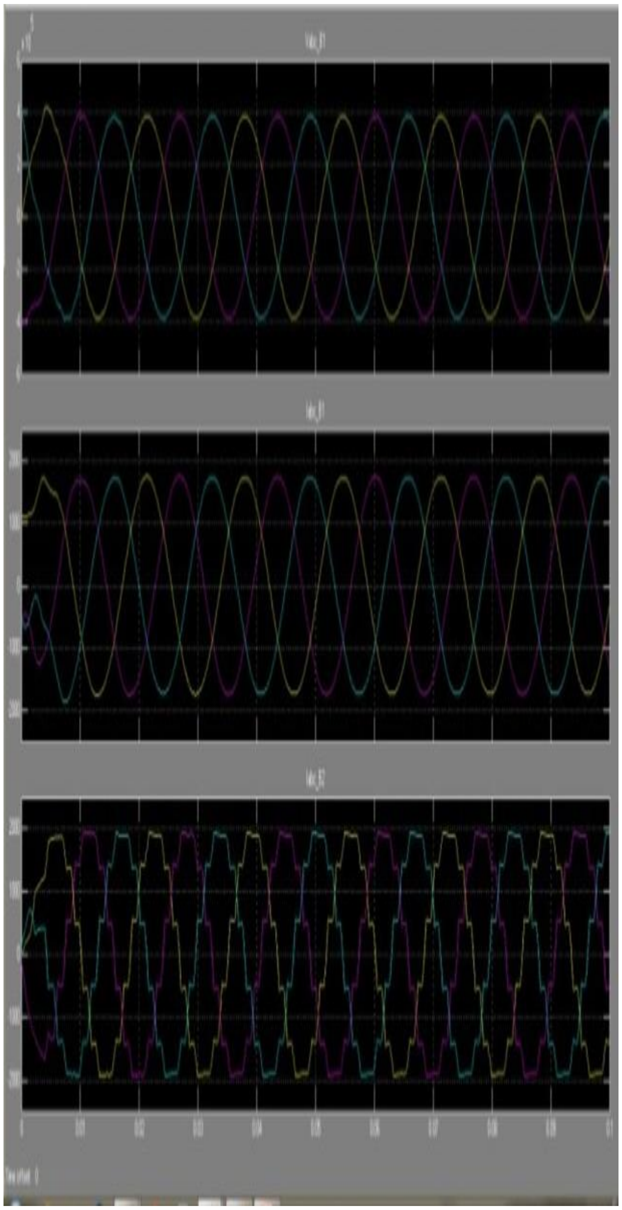
3.3:FUZZY CONTROL

Fuzzy controllers are a class of knowledge-based controllers using artificial intelligence techniques originating in fuzzy logic. Applications of fuzzy controllers have become a well- established practice for manufacturers of control equipment and systems.According to Crowe and Vassiliadis (1995), fuzzy logic seems to be well suited to the nonlinear world of chemical process control. In fuzzy control, control statements are developed in terms of imprecise rules relating the values of measured variables with planned adjustments of the manipulated.

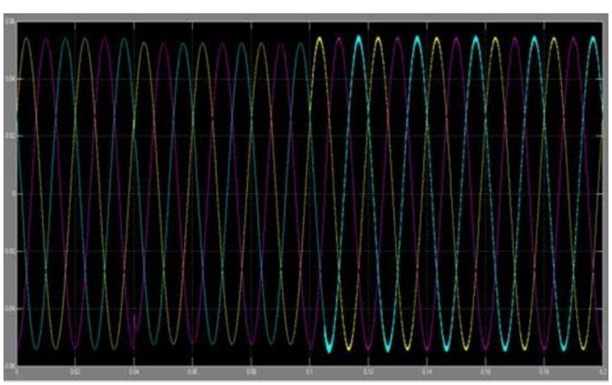
4.1: SIMULATION RESULT

Here the simulation diagram represents the regulation of the source power to load.Both the variation of the power will be varied by without filter and with fuzzy logic controller to reduce the harmonics.At the initial time the harmonics present in the non-linear load is high. After the conversion of series filter total harmonics which is present is low.The variation of the voltage, load voltage .injected voltage is view on the scope of the system.

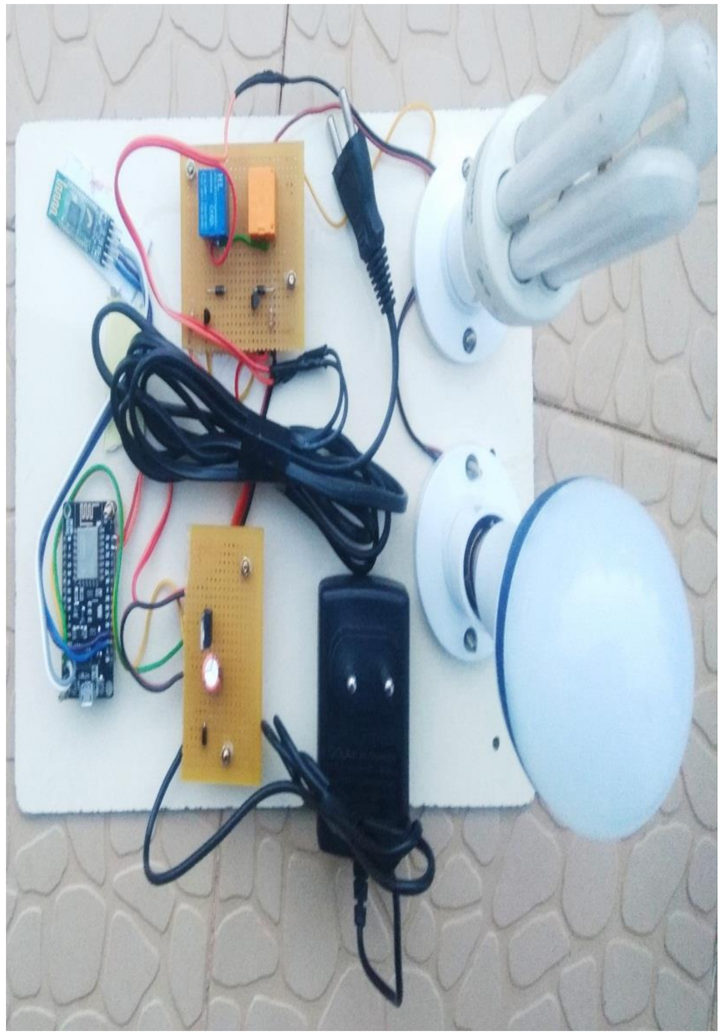
SIMULATION RESULT:



This is the Simulation result of harmonics reduction:



4.2: HARDWARE KIT PHOTO:



V. CONCLUSION

This project deals with the case study of power flow control with the Unified Power Flow Controller (UPFC) that used to maintain and improve power system operation and stability. This paper presents the power flow operation of power systems and its limitations, different devices to control the power flow with the existing transmission lines, types of FACTS controllers used in the power system, basic characteristics and operation of UPFC, fuzzy logic algorithm with UPFC and a case study to study the power flow control with UPFC.

The Unified Power Flow Controller provides simultaneous or individual controls of basic system parameters like transmission voltage, impedance and phase angle there by controlling the transmitted power. UPFC The average operating time of a circuit breaker is 3 cycles and the fault clearing time is nearly 4 or 5 cycles, which include both the relay operating time and the circuit breaker operating time, and so the system without UPFC is definitely out of synchronism.

It is clearly shows that the UPFC absorbs reactive power and supplies real power to support the system under fault condition and thus the transient stability of the system is improved.

REFERENCES

[1] R.Billinton, L. Salvaderi, J.D. McCalley, H. Chao, Th. Seitz, R.N. Allan, J. Odom, C. Fallon, " Reliability Issues In Today's Electric Power Utility Environment", IEEE Transactions on Power Systems, Vol. 12, No. 4, November 1997.

[2] Jinfu Chen, Xinghua Wang, Xianzhong Duan, Daguang Wang, Ronglin Zhang, "Application of FACTS Devices for the Interconnected Line Between Fujian Network and Huadong Network", IEEE.

[3] S. Tara Kalyani, G. Tulasiram Das, "Simulation of Real and Reactive Power Flow Control With UPFC connected to a Transmission Line", Journal of Theoretical and Applied Information Technology, 2008.

[4] S. Y. Ge, T S Chung, " Optimal Active Power Flow Incorporating Power Flow Control Needs In Flexible AC Transmission Systems", IEEE Transactions on Power Systems, Vol. 14, No.2, 2009.

[5] K. R. Padiyar, A. M. Kulkarni, "Flexible AC transmission systems: A status review", Sadhana, Vol.22, Part 6, pp. 781-796, December 1997.

[6] John J. Paserba, "How FACTS Controllers Benefit AC Transmission Systems", IEEE.

[7] N.G Hingorani G. Gyugyi Lazlo " Understanding FACTS: Concepts & technology of flexible AC Transmission Systems" ISBN 0-7803-3455-8.

[8] Nadarajah Muthulananthan, Arthit Sode-yome, Mr. Naresh Acharya, "Application of FACTS Controllers in Thailand Power Systems", Asian Institute of Technology, Jan 2005.

[9] Jody Verboomen, Dirk Van Hertem, Pieter H. Schavemaker, Wil L. Kling, Ronnie Belmans, " Phase Shifting Transfomers: Princples and Application", IEEE.

[10] M. P. Bahrman, P.E., " HVDC Transmission Overview", IEEE.

[11] W. Breuer, D. Povh, D. Retxmann, E. Teltsch, " Trends for Future HVDC Applications", 16th Conference of Electric Power Supply Industry, November 2006.

[12] Rajiv K. Varma, "Introduction to FACTS Controllers", Member, IEEE.

[13] M. Noroozian, C. W. Taylor, "Benefits of SVC and STATCOM for Electric Utility Application".

[14] Mark Ndubuka NWOHU, " Voltage Stability Improvement using Static Var Compensator in Power Systems", Leonardo Journal of Sciences, Issue 14, p 167-172, January-June 2009.