Power quality and stability improvement of HVDC transmission System using UPFC for Different uncertainty conditions

Koganti Sri Lakshmi, G.Sravanthi, L.Ramadevi, Koganti Harish chowdary

Abstract— The requirement of delivering economic quality power supply has become a major concern in this developing technology therefore this desired power control at every point of power system is obtained by power controllers like HVDC and FACT devices. Considering the benefits of HVDC like cost, Technical Performance and reliability with full control over the power transmission it is used for long bulk power transmission and asynchronous interconnection. FACTS are power electronic based equipment used to control the power transfer in AC Networks. UPFC is FACT device which can provide power quality and also used for control of active and reactive power flow in transmission line. The main objective of this paper is to improve power transmission capacity and power quality of hvdc transmission using UPFC .The Conventional control scheme cannot control power fluctuations. Here we dealt different types of faults at different locations placing UPFC permanent at receiving end of the line so that the magnitude of fault current and variations of excitation voltage reduced and finally voltage magnitude is improved by UPFC. At the end, Fast Fourier Transformation analysis is carried out to determine total Harmonic Distortion with and without UPFC for different faults.

Keywords—HVDC converter transformer, UPQC, FACTS, FFT.

I. Introduction

The fast development of power system leads to increase in demand of electricity which leads to different technical problems like power quality and stability. However development of SCR, GTO and IGBTS leads to HVDC Technology which is used for long distance bulk power transmission, asynchronous interconnection of two different systems and FACTS devices use to solve AC Transmission problems. This paper gives the application of UPFC on HVDC system for power quality and stability improvement during different types of faults.

In HVDC through the controlled actions of power electronics devices, AC power is converted to DC power and made ready for transmission. For applications of Power transmission via cables, bulk power transmission over long-distance, unsynchronized AC-system connection, power system stability improvement and firewall function against instability spread, HVDC transmission is more advantageous than HVAC transmission.

There are two technologies of HVDC transmission: the LCC-HVDC and VSC-HVDC transmission. The line commutated converter based HVDC is also known as classical HVDC. It is currently a widely used DC transmission system. It uses thyristor based converters. Thyristor converters turning off need the current flow through them to be zero. Hence the switching frequency is system frequency 50 or 60 Hz. This results in production of low order harmonics and a requirement of larger filters for filtering out the generated harmonics. Conventional HVDC always consumes reactive power. This is due to the lagging current which is generated by delayed firing of the converter switches. This reactive power demand is a disadvantage to the surrounding AC network. The reactive power supply is done by shunt capacitors or Static Var Compensators (SVC) installed at the end terminals. In VSC-HVDC transmission the converters are insulated gate bipolar transistors with anti parallel diodes working on a high frequency PWM switching. As a result of high frequency harmonics generation by very fast PWM switching, filter sizes employed are smaller as compared to LCC-HVDC. In this respect, VSC-HVDC is more advantageous than LCC-HVDC. Moreover, unlike classical HVDC they do not want reactive power provision for their operation. This avoids additional costs for reactive power supply equipments. [1], [2].

Pulse Width Modulation is a modulation technique that generates constant magnitude with variable-width pulses to obtain desired smooth analogy signal. In PWM switching scheme a comparison between a fundamental frequency modulating signal and a fixed frequency carrier signal is used to generate firing pulse for VSC converter switching. This comparison produces pulse signals of different width. A desired output parameters from VSC can be generated by varying the magnitude and phase angle of the modulating signal.

FACTS are defined by the IEEE as a power electronic based static system that can provide transient and steady state stability of the system along with power quality improvement [4], [5]. Facts devices are basically of three types:

1. Series connected: These types of devices are used for active power control in transmission system through impedance based on conventional or voltage sourced converter using GTO (GATE TURN OFF THYRISTER) & IGBT. Some examples of SCR based system are Thyristor- Controlled Series Capacitor (TCSC), Static VAR Compensator (SVC) and VSC based devices are SSSC.

ISSN 2229-5518

2. Shunt connected: It is used to control the voltage at the point of PCC by providing leading vars partially meet reactive power demand of the load. There are two types. Conventional system using thyristors like SVC and voltage sourced converter based system using IGBT's and GTO's like STATCOM.
3. Series-shunt connected: It is used to control both active and reactive powers by injecting current and voltage. Some of the examples are UPFC, DPFC and HPFC etc.

II. HVDC

There are three main HVDC schemes. The selection of each scheme at planning stage depends on the operational requirements, flexibility of demand, reliability issue and cost. The following are the most common HVDC configuration schemes [3].

1. Mono Polar: In this configuration scheme a single line is used between the converters and either a positive or negative voltage is used for the transmission. The ground or sea or metal can be generally used as return path. Most HVDC installations start as a mono polar transmission, latter developing to the advanced schemes such as bipolar or homopolar schemes.
2. Bi Polar: Here power transmission is carried out using two conductors of opposite polarity. It is a combination of two mono polar systems. Due to this doubling reliability of the system is increased. When one pole of the transmission is removed the other part resumes the normal operation using ground as a return path.
3. Homo Polar: This is a zero distance transmission. The two converters are connected to each other without any DC line. Back-to-back scheme is applied when two transmission systems of different frequency and different control principle are interconnected. The schematic diagrams of HVDC schemes are shown in fig.2.1.

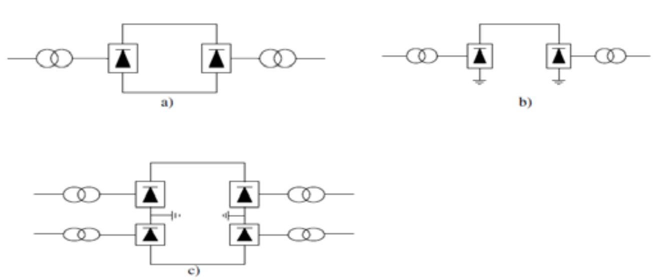

Fig.2.1. Schematic diagrams of HVDC schemes

2.1 VSC-HVDC System:

VSC-HVDC transmission system basically consists of converter valves, phase reactors, filters, power transformers and DC lines. The VSC-HVDC basic system is shown below and brief descriptions and design issues are discussed.

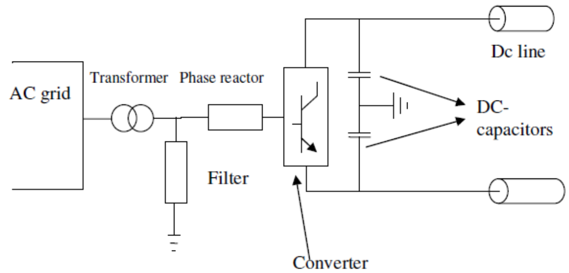

Fig.2.1.1 Schematic diagrams of VSC-HVDC system

Converters: They play the role of converting AC power to DC power or DC power to AC power. The converter valves are built with IGBT power semiconductors.

The IGBT valves are arranged in different ways resulting converter topologies. There are different converter topologies. These topologies are broadly classified as two level topology and a multi level topology. The main aim is To minimize the switching losses of the semiconductors inside the VSC. To produce a smooth sinusoidal voltage waveform. The two level converter topology is the simplest circuit configuration that can be used to construct 3-phase VSC. It consists of six valves and generates only two DC voltage values, ±Vdc and even multi level topology can also be applied [6].

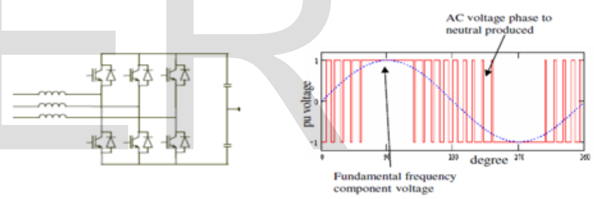

Fig.2.1.2 Three phase two level converter topology and produced waveform

Phase reactors: They are made up of large inductance with small resistance. They are used to regulate the active and reactive power flow to the ac grid. It is also part of low pass filter that prevent high frequency harmonics from entering the transformer. The inductive reactance between rectifier and AC supply is used to limit fault current and to smoothen voltage.

Transformers: Transformers are used for converting the system voltage to a value suitable for the converter. For VSC-HVDC application standard transformers are used. As the filter is located between the transformer and the converter the problem of power loss due to the harmonics in the transformer winding is not a serious problem. Often the transformer is equipped with tap changer on the secondary side to increase the reactive power range.

DC Operating Voltage: Higher voltage levels, which usually chosen for large power transfer, require many valves to be put in series, thus higher costs. Thus the choice of the voltage levels mainly touches economical issues. As a result, the

ISSN 2229-5518

selection of operating voltages constitutes one part economic optimization of VSC-HVDC transmission installations. Fundamental frequency component voltage output of the converter can be related to the DC operating voltage by the following equation.

$$U_{L-L} = \frac{\sqrt{3}M.U_{DC}}{2\sqrt{2}} \approx 0.612\ M.U_{DC}$$

Where, U_{L-L}- Line to Line voltage

U_{DC}- DC voltage

M- Modulation Index

DC Capacitor: The capacitor is designed in a way to achieve a small ripple in the DC voltage. The DC capacitor size is characterized by the time constant t defined as a ratio between the DC powers stored at the DC side of the converter to the converter nominal apparent power. In order to obtain a small ripple in the DC voltage, large DC capacitors are required. However, application of large DC capacitors results in slow changes of the DC voltage in response to changes in power exchanged at the DC side of the converter. On the other hand, application of small DC capacitors results in fast response to changes in instantaneous power exchanged but at the expense of larger ripple in the dc voltage. Thus, the total capacitance of the dc capacitors can be approximated by

$$\tau = \frac{{}^{1}/{}_{2}C_{dc}U_{dc}^{2}}{S_n}$$

Filters: Filters are utilized for the filtering out of the generated harmonics. Together with the phase reactor they form part of the low pass filter. They are tuned for filtering higher frequency harmonics so that the fundamental frequency component is amplified. It prevents harmonics from entering to the AC system. In the case of VSC-HVDC the harmonic generated are of higher order determined by the frequency modulation ratio (mf). Frequency modulation ratio is the ratio of converter switching frequency (*f switch)* to the fundamental frequency (*f fundamental)* given by:

$$m_f = \frac{f_{switch}}{f_{fundamental}}$$

VSC based HVDC System: Through controlled PWM pulse signals that applied to converter switches VSC-HVDC is capable of serving the purpose of grid reactive power support and active power transmission. The working of a VSC-HVDC can be given by treating each terminal as a VSC to an AC network through series reactors. Let consider the following one phase equivalent electrical circuit of VSC-HVDC station [8], [9].

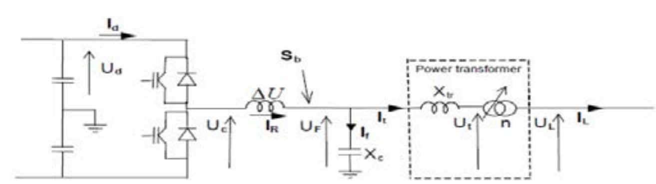

Fig.2.1.3 Circuit diagram of VSC-HVDC converter station

From the circuit diagram 2.1.3, the power between the converter reactor and the filter is calculated as:

$$\overline{S}_b = P + jQ = \sqrt{3}U_F\overline{I}_R^* \quad \backslash$$

Where, S_b- Base apparent power

P-Active Power

U_f- Filter Bus Voltage

I_R^*- Complex conjugate of current through reactor

The active and reactive power between converter and filter bus for a lossless reactor is given by

$$P = \frac{U_F U_c}{X_{reactor}}\sin\delta$$

$$Q = \frac{U_F(U_F - U_C\cos\delta)}{X_{reactor}}$$

Where, U_f- Filter phase voltage

U_c-Converter voltage

III. UPFC:

One of the FACTS controllers in particular, the Unified Power Flow Controller (UPFC) can control transmission line power flows, voltage magnitudes, phase angles in a power system.

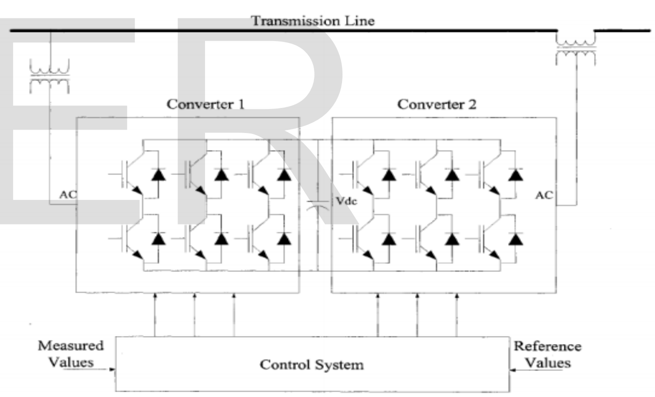

Fig.3.1. UPQC configuration

UPFC consists of two voltage sourced converters. These back-to-back converters, which are “converter 1” and “converter 2”, are operated from a common DC link provided by a DC storage capacitor. This arrangement functions as an ideal ac-to-ac power converter in which real power can freely flow in either direction between the AC terminals of the two converters, and each converter can independently generate or absorb reactive power at its own AC output terminal [7],[10].

Converter 2 provides the main function of the UPFC by injecting a voltage with controllable magnitude and phase angle in series with the line via an insertion transformer. This injected voltage acts essentially as a synchronous AC voltage source. The transmission line current flows through this voltage source resulting in reactive and real power exchange at the AC system. The reactive power exchanged at the AC terminal is generated internally by the converter. The real power exchanged at the AC terminal is converted into DC power which appears at the DC link as a positive or negative real power demand.

The basic function of converter 1 is to supply or absorb the real power demanded by converter 2 at the common DC link to support real power exchange resulting from the series voltage injection. This DC link power demand of converter 2 is converted back to AC by converter 1 and coupled to the transmission line bus via a shunt connected transformer. In addition to the real power need of converter 2, converter 1 can also generate or absorb controllable reactive power, if desired, and there by provide independent shunt reactive compensation for the line. It is important to note that whereas there is a closed path for real power negotiated by the action of series voltage injection through converters 1 and 2 back to the line, the corresponding reactive power exchanged is supplied or absorbed locally by converter 2 and therefore does not have to be transmitted by the line. Thus, converter 1 can be operated at a unity power factor or can be controlled to have a reactive power exchange with the line independent of the reactive power exchanged by converter 2.

IV. SIMULATION CIRCUITS

The test system for the study is an 11 kV, 60 Hz power system consisting of two sources representing two areas connected by an HVDC transmission line of 300 km as shown in Figure 4.1.

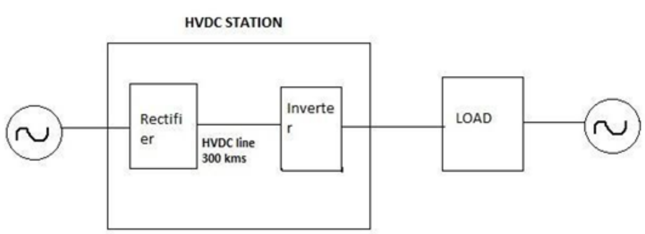

Fig.4.1 Single-line diagram of HVDC system without UPFC

The transmission system is compensated with UPFC at the receiving end of line as shown in Figure4.2.

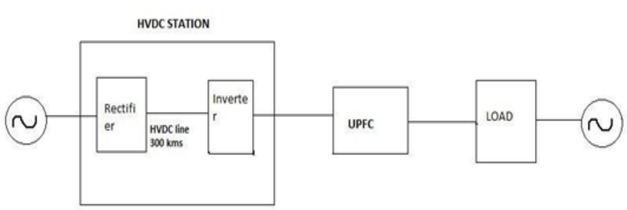

Fig.4.2 Single-line diagram of HVDC system with UPFC

The simulation model with RLC load has been developed using MATLAB simulink to study the effect of UPFC on the HVDC Transmission system. Based on different fault conditions the data has been generated. The simulation configurations for HVDC system with UPQC for RLC load is presented below:

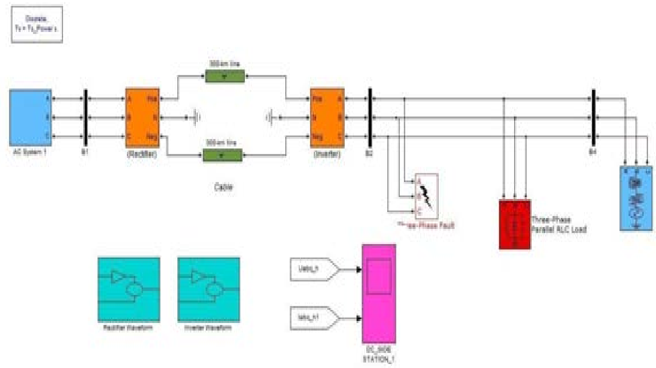

Fig.4.3 Simulation model of HVDC without UPFC for RLC load

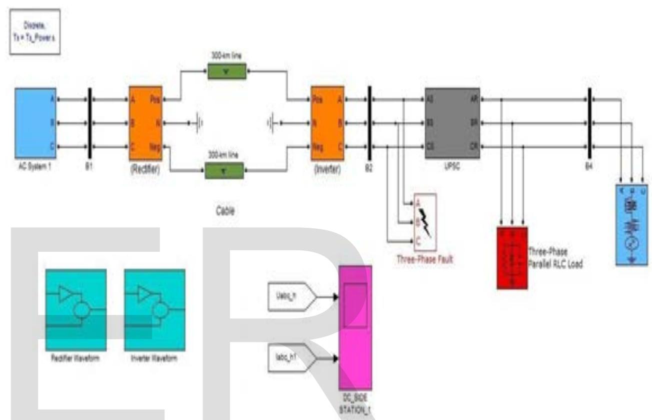

Fig.4.4 Simulation model of HVDC with UPFC for RLC load

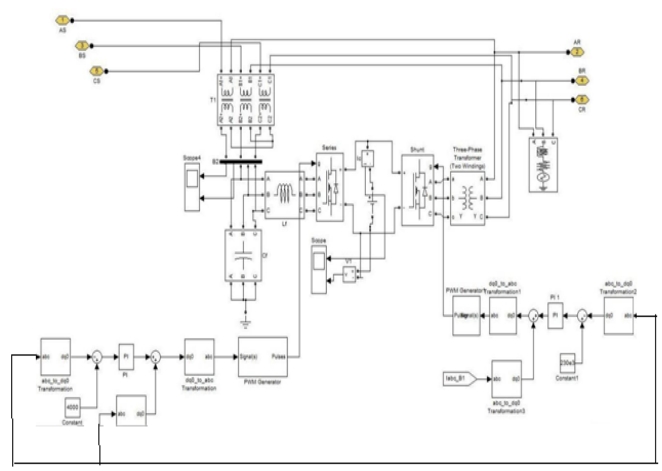

Figure 4.5Simulation model for UPFC with HVDC system

V. RESULTS

Based on different fault conditions, i.e. three phase to ground fault, double line to ground fault, single line to ground fault and line to line fault, the voltage and current waveforms for the HVDC system with UPFC and without UPFC are

ISSN 2229-5518

presented below.

1. Fault analysis for RLC loads:

The voltage and current wave forms for RLC loads without and with UPFC and with different faults are shown in fig5.1, fig5.2, fig5.3 and fig 5.4 respectively.

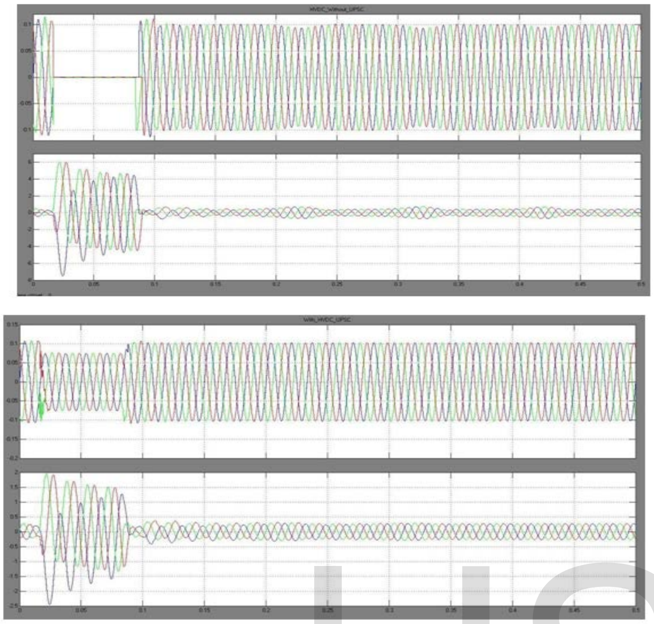

Figure 5.1 Voltage and current waveforms for three phase to ground Fault a) Without UPFC b) with UPFC

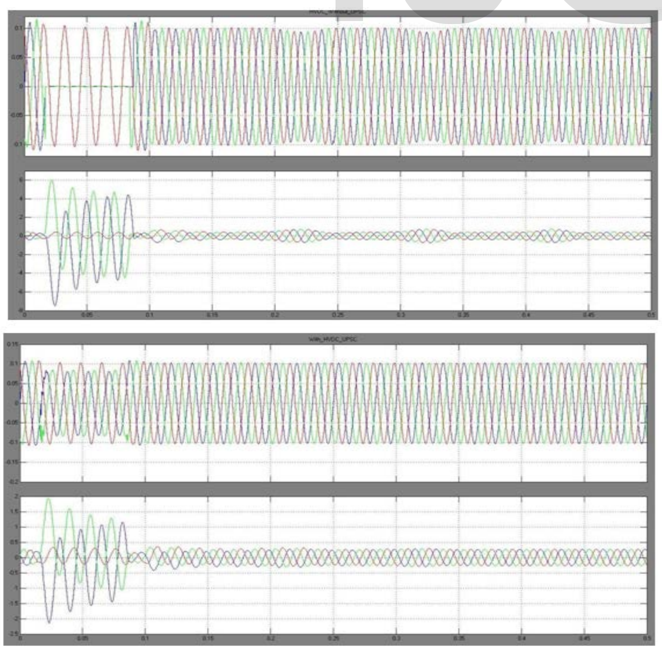

Figure 5.2 Voltage and current waveforms for double line to ground Fault a) Without UPFC b) with UPFC

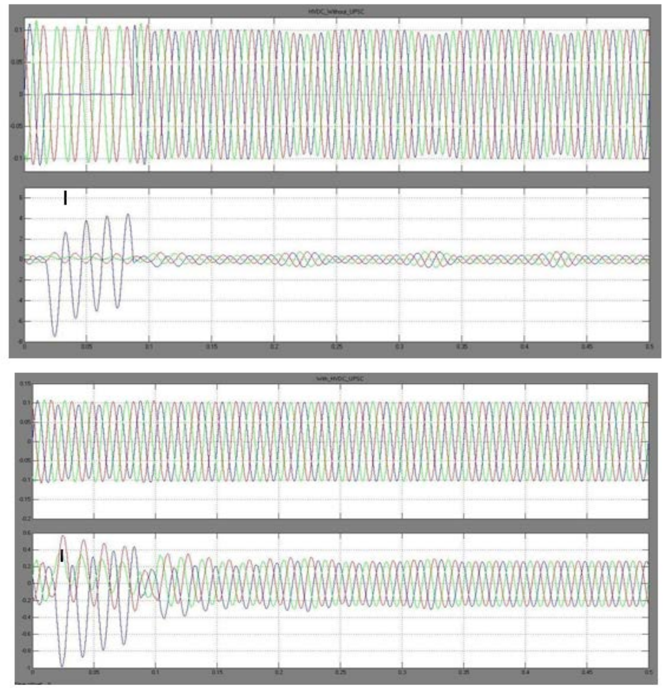

Figure 5.3 Voltage and current waveforms for single line to ground Fault a) Without UPFC b) with UPFC

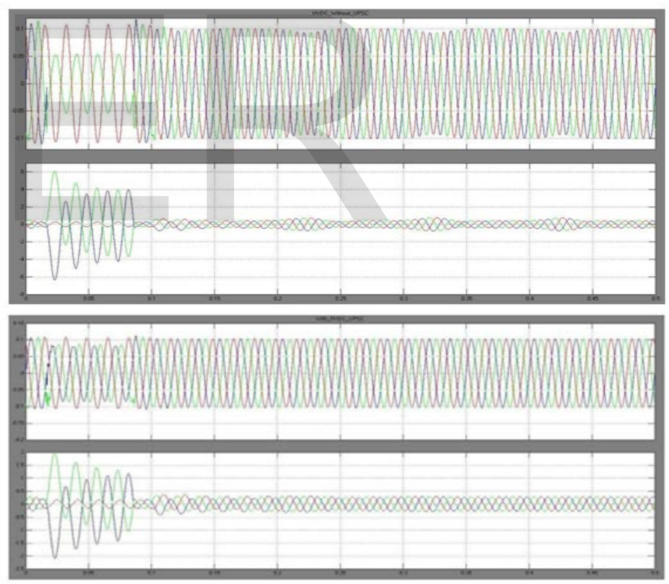

Figure 5.4 Voltage and current waveforms for line to line Fault a) Without UPFC b) with UPFC

The FFT analysis has done to calculate the Total Harmonic distortion (THD) for RLC load with and without UPFC and it is shown in Table5.1. The THD is also calculated for RC and RL loads and tabulated in 5.2 and 5.3 respectively.

Table 5.1 THD calculation for RLC Load for different faults

Type of Fault	Without UPFC	With UPFC
3 phase to ground fault	8.57%	1.01%
Double line to ground fault	8.85%	1.53%
Single line to ground fault	8.82%	0.51%
Line to line fault	5.75%	1.58%

Table 5.2 THD calculation for RC Load for different faults

Type of Fault	Without UPFC	With UPFC
3 phase to ground fault	8.57%	1.04%
Double line to ground fault	8.85%	1.56%
Single line to ground fault	8.82%	0.64%
Line to line fault	5.75%	1.61%

Table 5.3 THD calculation for RL Load for different faults

Type of Fault	Without UPFC	With UPFC
3 phase to ground fault	8.56%	1.07%
Double line to ground fault	8.86%	1.63%
Single line to ground fault	8.81%	0.73%
Line to line fault	5.76%	1.63%

By comparing the voltage and current waveforms from figure 5.1, figure 5.2, figure 5.3and figure 5.4 using without and with UPFC for Three phase to ground fault, Double line to ground fault, Single line to ground fault and Line to line faults, It can be concluded that the magnitude of fault current and oscillations of excitation voltage has been reduced for different loads with using UPFC for the above faults. And the total harmonic distortion (THD) has also been reduced below 3%, which are the normal standards as per IEC shown in table5.1.

VI. CONCLUSIONS

According to the graphs and results it can be concluded that UPFC improves the system performance. However, it can control the power flow in the transmission line, effectively. With the addition of UPFC, the magnitude of fault current reduces and oscillations of excitation voltage also reduce. The total harmonic distortion (THD) is also reduced well below the IEC standards. It is more economical for the HVDC transmission system to transfer more power. UPFC has shown its flexibility promoting a more controllable flow in the lines. HVDC can be very useful for long transmission lines. It is more recommended in networks or interconnected lines that have high variation of power demands and complicated network connections with different power frequencies.

UPFC in general is good for promoting line load-ability and pool through interconnected network buses more effectively. UPFC can be very useful for deregulated energy market as an alternative choice for more power generation to the load area.

VII. REFERENCES

[1] Hideaki Fujita, Member, IEEE, Yasuhiro Watanabe, and Hirofumi Akagi, Fellow, IEEE, “Control and Analysis of a Unified Power Flow Controller” IEEE transactions on power electronics, VOL. 14, NO. 6, NOVEMBER 1999.

[2] E.M. Yap, M. Al-Dabbagh, “Applications of FACTS Controller for Improving Power Transmission Capability,” submitted at the IPEC 2005,IEEE conference, May 2005.

[3] Lee Wei Sheng, Ahmad Razani and Neelakantan Prabhakaran, SeniorMember, IEEE “Control of High Voltage Direct Current (HVDC) Bridges for Power Transmission Systems” Proceedings of 2010 IEEE Student Conference on Research and Development (SCOReD 2010), 13 - 14 Dec 2010, Putrajaya, Malaysia.

[4] N.G. Hingorani, L. Gyugyi, "Understanding FACTS," New York: IEEE Press, 2000, pp. 2, 29, 135, 300 and 417. 4. Padiyar, HVDC Power Transmission System. New Delhi, India:Wiley Eastern, 1993.

[5] J. Arillaga, "Flexible AC Transmission technology,” Y. H. Songs, and
A.T. Johns, Ed. UK: Stevenage, Herts IEE., 1999, pp. 99.

[6] S.H. Hosseini, A. Sajadi and M.Teimouri, “Three phase harmonic load flow in an unbalanced AC system. Including HVDC link,” Power Electronics and Motion Control Conference, IPEMC 2004. The 4th International, vol. 3, pp. 1726-1730, Aug. 2004.

[7] D J Hanson, C Horwill, B D Gemmell, D R Monkhouse, "STATCOM-Based Reloadable SVC Project in the UK for National rid", in Proc. 2002 IEEE PES winter power meeting, New York city, 7-31 january 2002. Uip.2.pd.

[8] X.-P. Zhang, "Multiterminal Voltage-Sourced Converter Based HVDC Models for Power Flow Analysis", IEEE Transactions on Power Systems, vol. 18, no. 4, 2004, pp.1877-1884.

ISSN 2229-5518

[9] F. Schettler, H. Huang, and N. Christl, "HVDC Transmission Systems Using Voltage Sourced Converters: Design and Application. Conference Proceedings, IEEE Summer Meeting 2000, Paper No. 2000 SM-260, vol. 2, pp. 716-720.

[10] R. S. Tenoso, L.K. Dolan, and S. A. Yari, "Flexible AC Transmission systems benefits study," Public Interest Energy Research (PIER), Resource energy, Trn: P600-00-037, California, Oct 1999.

VIII. Biographies

Koganti sri lakshmi was born in India in 1983. She received the B.Tech. and M.Tech. Degrees in electrical engineering from the JNTU University, Hyderabad, A.P., India, in 2006 and 2009, respectively, currently, she is working as Assistant Professor in Electrical Engineering department of SNIST. Her current research interests include Renewable energy, HVDC, Smart Grid, power quality, FACTS, and HVAC.

G. Sravanthi was born in India in 1987. She received the B.Tech. and M.Tech. Degrees in electrical engineering from the JNTU University, Hyderabad, A.P., India, in 2008 and 2010, respectively, currently, she is working as Assistant Professor in Electrical Engineering department of SNIST. Her current research interests include Renewable energy, power quality, FACTS, Power electronics, Smart Grid.

L.Ramadevi was born in India in 1985. She received the B.Tech. Degree in electrical engineering from JNTU University, Hyderabad, A.P., India, in 2006 and M.Tech from Acharya Nagarjuna University, A.P in 2010.Presently she is Persuing Ph.D in Acharya Nagarjuna University, A.P. Currently, she is working as Assistant Professor in Electrical Engineering department of SNIST. Her current research interests include Renewable energy, Optimization techniques, Realiability, Distribution Generation, Smart Grid.

Koganti Harish Chowdary was born India in 1990. He received the B.Tech. and M.Tech. Degrees in electrical engineering from the JNTU University, Hyderabad, A.P., India, in 2011 and 2013, respectively. His current research interests include Renewable energy, power quality, FACTS, Smart Grid, HVAC and HVDC.