205. VOLTAGE PROFILE IMPROVEMENT OF AN EHT LINE BY UPFC – Case Study

Mr. Abdullah Munir[a], Mr. M. Ali Raza Khan[b], Mr. Hamza Saleem[b], Mr. Irtiza Hussain[b], Mr. M. Taha Siddiqui[b], Mr. Aitashan Nadeem[b]

[a]Lecturer, Electrical Engineering Department, NED University of Engineering and Technology, Karachi 75270, Pakistan
[b]UG Students, Electrical Engineering Department, NED University of Engineering and Technology, Karachi 75270, Pakistan

Abstract

The growing power demand is pushing the old transmission systems closer to their stability and thermal limits. This problem causes laying of new transmission network which is a constraint on both economy and time. Thus solutions are needed to improve the power delivering capacity and power quality of existing transmission setup. A second generation Flexible AC Transmission System (FACTS) based Unified Power Flow Controller (UPFC) is a versatile and dynamic device that provides real time control of the existing transmission network. It increases the efficiency by controlling the active and reactive power flow without compromising on stability and reliability. In this paper a case study on 100MVA 220KV EHT line carrying a current of 454 A is done on which the hardware of UPFC is modelled and implemented. Direct voltage injection and automatic power flow control mode of UPFC is used to implement its prototype. Hardware methodology along with simulation and real time results are also discussed in detail.

Keywords: *UPFC; FACTS; Hardware; Modelling; Power Flow*

1. INTRODUCTION

Demand for electrical power continues to grow steadily, and is predominantly strong in those countries which are on the threshold of industrialization. Since the transmission systems are brought near to their thermal and stability limits, the major challenge faced by power industry is to supply electrical power to the consumer with the minimum amount of losses while maintaining high quality level. For various reasons, newly implemented transmission lines, are not able to keep up with the increasing power production. Thus, power line construction ties up investment capital that could be used for other projects. For enhanced operating and financial stability, it is evident that more effective utilization and control of the existing transmission network infrastructure is required. The development of Flexible AC Transmission Systems, or FACTS based on high power electronics, offers a powerful means of meeting the challenges [1].

Unified Power Flow Controller (UPFC) is a multipurpose device which belongs to the Power Electronics family of Flexible AC Transmission System (FACTS). UPFC helps in real time control of the existing power transmission setup [2]. It increases the efficiency by controlling the active and the reactive power flow without compromising the reliability and stability.

Out of six control modes of UPFC one main mode of operation i.e. Direct Voltage Injection Mode is selected. The UPFC will able to regulate the transmission line voltage that will be a developed, economical and efficient solution for transmission line parameters

2. WORKING PRINCIPLE

UPFC is a second generation FACTs device that can provide simultaneous control of power system parameters like transmission voltage, impedance and phase angle [3]. The UPFC is composed of two Voltage Sourced Converters (VSC) one of which is connected in series with Static synchronous series compensator (SSSC) and the other one in shunt with Static synchronous compensator (STATCOM) with the transmission line. UPFC combines the unique features of series and shunt compensation. The two inverters are coupled by a common DC link capacitor. The series inverter acting as SSSC, control the main functionality by inserting an AC voltage of controllable magnitude and phase. The injected voltage frequency is same as that of the power line frequency. It acts as a synchronous voltage source. The complete SLD of a UPFC is shown in fig1.

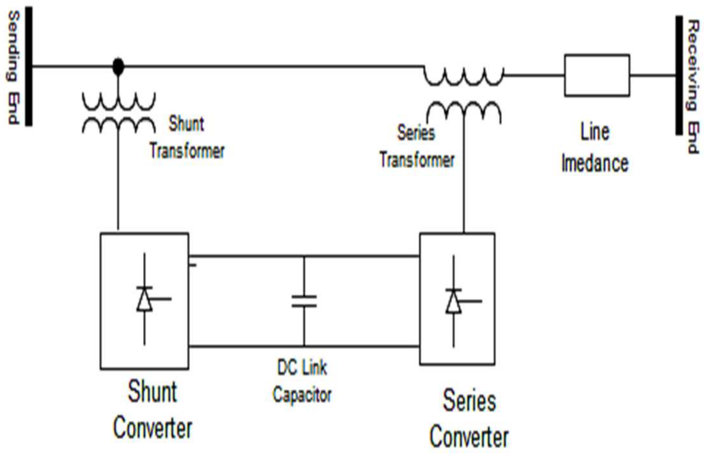


Fig. 1. Single Line Diagram of Unified Power Flow Controller

2.1. CONTROL MODES OF UPFC

UPFC possesses multiple operation modes. Both voltage source inverters can operate independently with respect to one another by isolating the dc part. The shunt inverter is working as STATCOM in such a way that it injects a controllable current into the transmission line. The series inverter is working as SSSC that injects a voltage of controllable amplitude and phase angle in series with the transmission line thus power flow through the transmission line is controlled.

The shunt inverter is driven by two operating modes:

- **Volt Ampere Reactive Control Mode:** The reference is a capacitive or inductive Volt Ampere Reactive (VAR) setting. The control samples set the inverter gate to produce required current. Although, DC feedback is required in this mode.
- **Automatic Voltage Control Mode:** the shunt reactive current is maintained automatically for regulating the transmission line voltages at connection point to a preset quantity. Voltage feedback signal from the sending end bus to feeds the shunt transformer

The series inverter is driven by four operating modes:

- **Direct Voltage Injection Mode:** The reference inputs are directly injected to phase angle and magnitude of series voltage.
- **Phase Angle Shifter Emulation Mode:** The reference input is phase displacement **a**mong sending and receiving end voltages.
- **Line Impedance Emulation Mode:** The reference input is an impedance preset value by inserting in series with the line impedance.
- **Automatic Power Low Control Mode:** The reference inputs are preset values of active power and reactive power for maintaining the parameters of transmission line irrespective of changes in system.

3. METHODOLOGY

A scaled model of UPFC is designed where real transmission line parameters are considered and scaled down to the practical constraints, feasibility and availability of resources. From six other control mode of UPFC one main mode of operation i.e. Voltage Injection Mode is used. In order to improve the power handling capability and voltage profile of a 220kV transmission line, different blocks of UPFC have been designed on PROTEUS 8.1 DESIGN SUITE. These simulation results are further used to design and implement the hardware model of UPFC.

3.1. TRANSMISSION LINE MODEL

The technical data of modeled 220kV transmission line has been collected from National University of Science and Technology (PNEC Karachi) as shown in table 1.

Table 1. Specifications of Transmission Line

Parameter	Rating
Type of conductor	RAIL
Length of transmission line	120 Km
Transmission line rating	100 MVA
Current rating	454 A
Voltage rating	220 KV
Frequency	50Hz
Inductance per Km	0.0166 Henry

The transmission line is a scaled down model of the calibrated values. In order to calibrate it, a factor of 10^5 is chosen for power. This 10^5 factor is divided into 2 factors for voltage and current as 10^3 & 10^2 respectively as shown in table2.

Table 2. Scaled down values of transmission line for hardware implementation

Parameter	Rated Value (Hardware)	Scaling Factor	Real transmission line Values
Power	1 KVA	10^5	100 MVA
Voltage	220 V	10^3	220 KV
Current	4.54 A	10^2	454.4 A

3.2. LOAD BANK

Load Bank consists of Resistive Load (Bulbs) and Induction Motor. The voltage drop and current drawn by the load is summarized in the table 3 and table 4 below:

Table 3. Behaviour of transmission line under resistive load

Power (W)	Current Drawn (A)	Voltage (V)
100	0.41	216
200	0.82	213
300	1.25	210
400	1.66	207
500	1.88	202

Table 4. Behaviour of transmission line under inductive load

Power (HP)	Current drawn (A)	Voltage (V)
0.5	2.46	198

4. HARDWARE DESIGN

4.1. MAIN BLOCKS OF UPFC

For fabrication of UPFC, the main blocks that are designed are as follows:

- Shunt Converter Section
- Series Converter Section
- Main Control System Unit
  - i) Sensing Devices
  - ii) Reference Input System

Fig 2 below shows the approach that has been adopted for fabrication of UPFC. The red blocks are AVR AT mega 16 microcontrollers. Microcontroller 1 is for the shunt converter that generates gated sinusoidal pulse width modulation (SPWM) for driving H-Bridge acting as a rectifier to charge the DC link capacitor according to the active power needs of the series converter. Microcontroller 2 is for the series converter that generates gated SPWM for driving H-Bridge acting as an inverter to inject voltage in series with the transmission line voltage. Micro Controller 3 is for reference input system that takes the input voltage from the user that is to be maintained on the receiving end side i.e. 220 KV. Microcontroller 4 is the main control computer that gets input from the reference input system and the feed-back from the voltage sensor that is connected at the load end. This control computer compares the two inputs and sends the difference in the form of bit patterns to microcontroller 2 which scales the active power from the DC link according to the difference. This voltages is then injected in series with the transmission line in order to maintain and improve the voltage profile of the system.

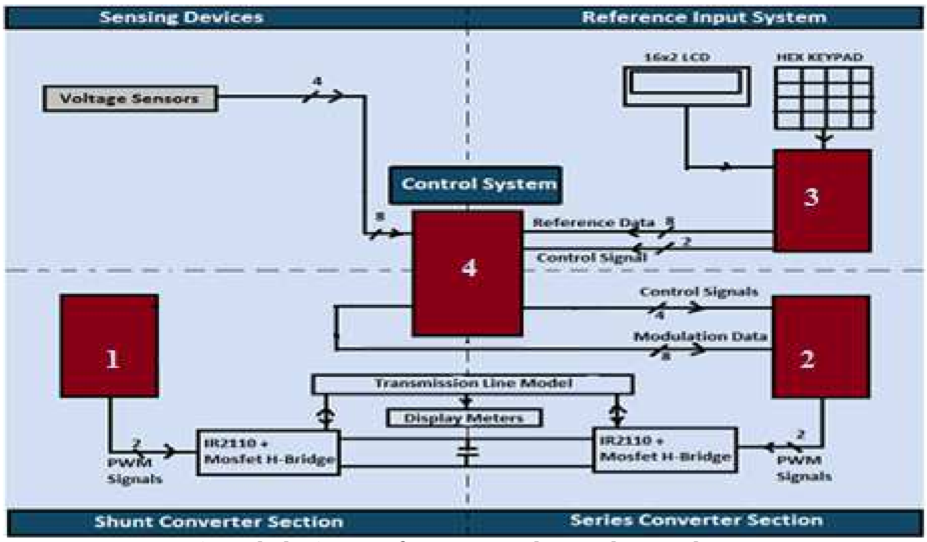


Fig 2. Block Diagram of UPFC as Implemented on Hardware

4.1.1. SHUNT CONVERTER SECTION

The shunt converter is meant to fulfil the active power needs of the series converter. It is an H Bridge MOSFET based rectifier. The gating sequence of the MOSFET Bridge is controlled using ATMEGA 16 micro controller. The MOSFET driver IC IR 2110 is used along with bootstrap circuitry to drive the MOSFET. By varying the modulation index on the control system output of the shunt converter can be changed. Zero crossing detectors are also designed in order to generate PWM pulses. Smoothing capacitors are used at the output to obtain pure DC signal. Shunt Transformer is used to step down the transmission line voltage to meet the required voltage for the STATCOM i.e. 40 V. The voltage ratio of shunt transformer is 220:40.

4.1.1.1. MAIN COMPONENTS OF SHUNT CONVERTER

The main components of Shunt Converter as shown in the block diagram are as follows:

- H-Bridge Inverter
- IR-2110 & Bootstrap circuit
- Zero Crossing Detectors (ZCD)
- A central controlling unit ATMEGA16
- Smoothing capacitors.

The complete block diagram of Shunt Converter is also shown in fig 3.

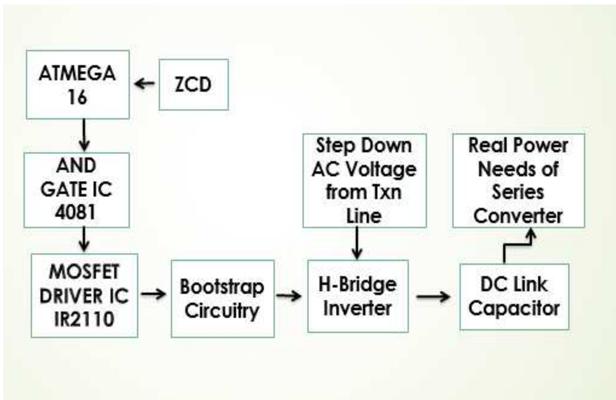


Fig 3. Flow Block diagram of Shunt Converter

4.1.2. SERIES CONVERTER SECTION

The series converter is an H-Bridge MOSFET based inverter. The gating sequence of the MOSFET Bridge is controlled using ATMEGA 16 micro controller. The MOSFET driver IC IR 2110 is used along with bootstrap circuitry to drive the MOSFET. By varying the modulation index on the control system, output of the series converter can be changed. Zero crossing detectors are also designed in order to generate PWM pulses and to ensure the desired phase changes in the output of the signal. RC filters are used to get the pure sine wave at the output of the H-Bridge inverter. The input DC supply is 40 V. Series Transformer is used for the Isolation between transmission line and the device for protection. It is also used for series Voltage injection with the line. The ratio of primary to secondary of the transformer used is 1:1.

4.1.2.1 MAIN COMPONENTS OF SERIES CONVERTER

The main components of Series Converter as shown in the block diagram are as follows:

- Zero Crossing Detector
- AVR Microcontroller (ATMEGA 16)
- AND GATE (CMOS 4081)
- IR-2110 & Bootstrap circuit
- MOSFETs (IRF640)
- RC Filters

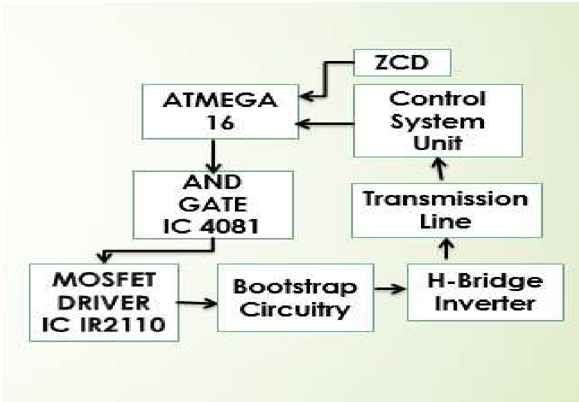


Fig 4. Flow Block Diagram of Series Converter

4.1.3. MAIN CONTROL SYSTEM UNIT

Main control system unit comprises of the following three main blocks.

- MAIN CONTROL COMPUTER: This is the master mind of the entire device. Feedback from voltage sensor is fed into this controller. Now, this will be responsible for generating the required modulation indices for the shunt and the series converter computers by comparing reference and feedback values. Output will be in accordance with the modulation indices.
- VOLTAGE SENSOR: It is basically our feedback system. Measured load end voltage is sent as a feedback to the main control computer.
- REFERENCE INPUT SYSTEM: We designed an interactive input system for our device which will be used to take the reference values i.e. voltage to be maintained at load end for the operation of the device. This is done using a HEX KEYPAD and a 16x2 LCD. The reference value is then sent to the main control computer.

5. OBSERVATIONS

5.1. OUTPUT OF SHUNT CONVERTER

Pulsating DC output is obtained at the output of the shunt inverter Fig 5.(a). DC link capacitor smoothens the output as shown in Fig 5.(b).

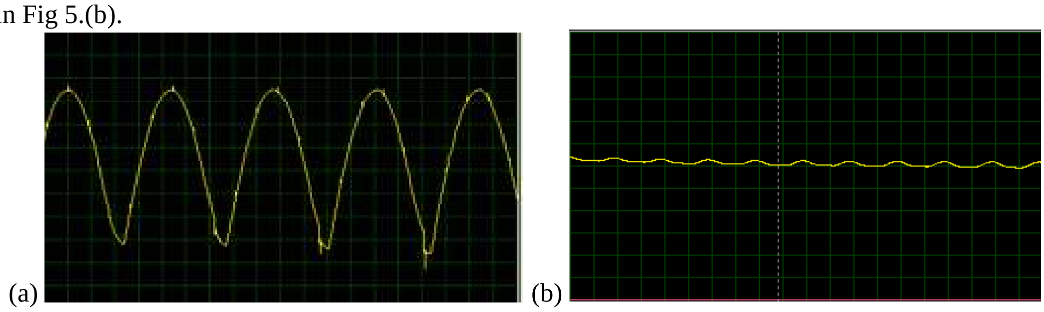


Fig 5. Shunt converter output (a) without smoothing capacitor. (b) with smoothing capacitor

5.2. OUTPUT OF SERIES CONVERTER

5.2.1. SIMULATION RESULTS

Fig 6.(a) shows the high frequency components existing in the sinusoidal wave form which are then filtered by a RC low pass filter as shown in Fig 6.(b).

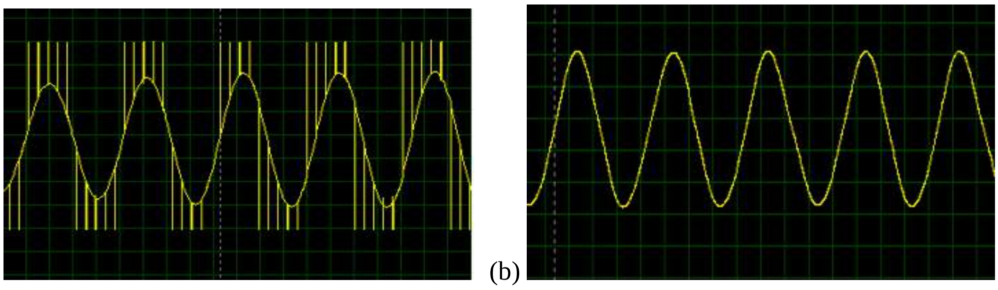
(a)  (b)

Fig 6. Output of series converter (a) without filtering (b) with filtering

5.2.2. HARDWARE RESULTS

Fig7.(a) shows the waveform containing high frequency surges at the output of the series inverter which are then filtered by designing a RC low pass filter in the hardware and the output AC voltage waveform that is to be injected in series with the transmission line voltage is produced as shown in fig 7.(b).

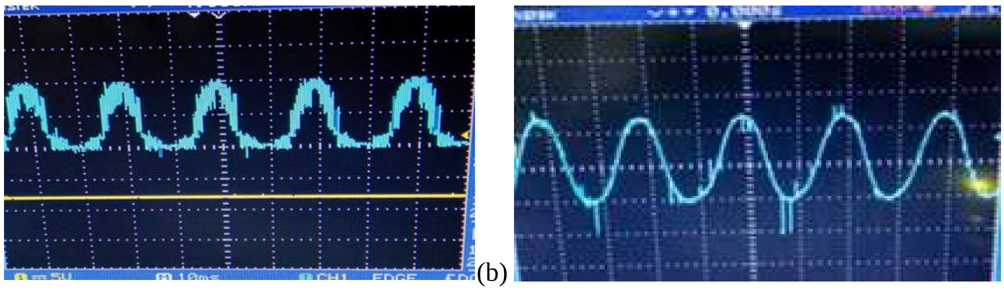
(a)  (b)

Fig 7. Series converter output on hardware (a) without filtering (b) with filtering

6. CALCULATIONS

6.1. DC LINK CAPACITOR

Since the energy stored by any capacitor is given by the equation,

$$W = \frac{1}{2}CV^2 \tag{1}$$

$$V*I*t=\frac{1}{2}*C*V^2 \tag{2}$$

Since, $t=\frac{1}{f}$

$$C=\frac{2*I}{V*f} \tag{3}$$

Here,

I= Scaled down line current = 4.54 A

V= DC voltage across capacitor = 24 V

$$C=\frac{2*4.54}{24*50} \tag{4}$$

$$C=7566.66\mu F \tag{5}$$

The value of DC link capacitor is kept to be 15000μF i.e. double the value of calculated capacitance for safety point of view.

6.2. VOLTAGE INJECTION

The value of RMS voltage at the load end is obtained by scaling the capacitor voltage with the difference generated by the control computer (Microcontroller 4 Fig 2). This voltage adds up in the line voltage resulting in the compensation and thus improving the voltage profile.

6.3. RC FILTER

By designing a first order low pass filter unnecessary components of distorted wave obtained at the output can be eliminated to obtain pure sine wave. Formula for calculation of R and C is as follows.

$$f = \frac{1}{2*\pi*R*C} \tag{6}$$

The values selected are as follows:

f = 50 Hz

R = 145 Ω

Putting these in eq. 6 the capacitor value comes out to be,

C = 22 µF

7. CONCLUSION

This research paper proposes UPFC as one of the effective solution in the reduction of transmission losses occurred in various EHT transmission lines. As the installation of UPFC on 220KV transmission line has improved the voltage profile by 8%. With the improvement in voltage profile, the power flow through the transmission line has been optimized. Consequently, the existing transmission lines can be used at an extending capacity thereby reducing the economic burden of newly erected transmission lines.

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