Design of a SCADA Power System Monitor & its Application in Power Industry

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***Abstract*:** The Power System Monitor is designed for practical study of power system networks; assembled on scaled down parameters to represent generator, transmission lines and distribution of power to simulate the real time generation and transmission of power in electrical industry. The SCADA architecture transmits the data to computer software and parameters of generation and transmission can be controlled by changing rotary switch positions on the model through PLC and relays by wireless arrangement. Experiments were conducted for Power Flow through transmission line. The results were compared with and without UPFC – Unified Power Flow Controller. This will help to study the efficient and economic management of power generation and transmission during peak loads.

The Power System Monitor developed here demonstrates the application of SCADA architecture for automation. Supervisory Control and Data Acquisition (SCADA) has been demonstrated on the Power System Monitor. One can get clear understanding of how to implement SCADA automation in an industry to improve economic and efficient management of all activities.

The sample software is developed which tries to estimate the peak load of the future on the basis of previously stored peak loads by applying simple logic. Logic was developed, just to show the utility of the "**SCADA power system model**" as a peak load forecaster in Power generation, distribution Industry and not to use it for practical purpose.

Keywords: control, economic management, FACTS, modeling, power transmission, Power System Monitor, (SCADA) Supervisory Control and Data Acquisition, UPFC.

INTRODUCTION

Load Forecasting has become very essential in the current scenario as we can save lot of power loss if we are able to predict the correct load for the upcoming hour. If we are having 3 generators and current load can be satisfied with 2 generators then use of 3rd generator would waste lot of precious power. In reverse if we require all the 3 generators as per the current load and we are not using the 3rd generator then our efficiency decreases. To satisfy the peak loads we use gas turbine as an alternative source as it can start to its normal function in 15-20 minutes so if we are able to predict the peak load 20 minutes before it occurs then our efficiency to satisfy the load would be enhanced.

Simple Logic was developed for Load forecasting based on the previous year data. However this paper doesn't aims to check the efficiency of load forecasting algorithm as there are many algo's available based on Neural N/W techniques and other methods but rather to implement the idea and show the utility of "**SCADA Power System Monitor**" in load forecasting.

This paper also illustrates economic management of transmission of power by using UPFC Device to optimize the power transfer and application of SCADA automation. The experiments have been performed on the Power System Monitor which has features to simulate power generation, load flow through transmission lines of an AC electrical power network system.

[1] Author has discussed Decentralized state estimation of power systems, yielding improved reliability of the decentralized power system monitoring

[2] The paper monitored fluctuated condition of power quality index by means of method of frequency spectrum analysis based on acquisition of time domain signals, and analyzed influence factor of fluctuation of power quality using Power System Monitor.

[3]Yu Chen ; Haijun Zhang designed a kind of new high-voltage electric power equipment monitoring system, that uses low power digital temperature sensor TMP100 to realizing temperature collection, MSP430F149 acts as work slave station to complete signal analysis and process, and signal transmits between work slave station and central station by nRF401 wireless transceiver chip.

[4] Author discussed the methodology for monitoring the power quality (PQ) by implementing the monitoring system that is able to detect the power fluctuation in real-time.

[5] Shu Fan et.al. has discussed multi-region load forecasting techniques as a effective solution to generate more accurate forecasting results.

[6] Pang Qingle & Zhang Min showed that the presented load forecasting based on rough set and neural network can improve the forecasting accuracy significantly.

[7] This paper presents a short-term load forecasting method using pattern recognition which obtains input sets belonging to a multi-layered fed-forward neural network, and artificial neural network in which BP learning algorithm is used to train samples for gaining accuracy.

So, simple logic was developed in view of the above facts which takes into consideration the previous year date and hour wise loads and captures the current year load , find the % growth or decline day and hour wise, average the percentage(which has to be the current trend day and hour wise) and apply the current growth rate on the previous year load to generate the predicted load. As the time passes the algorithm is able to learn more & more of the current trend.

LOGIC USED FOR GENERATING THE PREDICTED LOAD

We have used the range, of the data of the year 2012 collected from the public reports generated by the "Madhaya Pradesh Power Transmission Company Ltd, State Load Dispatch Centre , Jabalpur" as our basis. It was found that peak loads varied from 5000 MW to 9000MW in the whole year.

The programs were developed in C++ for generating the result file containing predicted loads date wise and hour wise. Further Supervisory control is used for transferring the predicted load to the model for setting the RLC switch of the load to the predicted value as per the date and hour of the result file and setting the generator value for generating enough power and putting on the 2nd and 3rd generator if required.

Load & Generator rotary switches can be set in less then half minute as per our requirements in a remotely manner but model takes time of approximately 2 minutes to settle down to a stable state.

We have used one program for generation of Random loads just for testing purpose which ranges from 5000 MW to 9000MW. A file is constructed through the program containing load for each hour from 1st jan 2012 to 31 dec 2012. Fields are like as follows.

Date (dd/mm/yy)	Hour of the day	Load in MW

Hour of the day value- from 12:00 in the midnight to 1:00 am –we assign the hour value as 1, from 1:00am -2:00am –hour value is 2 and so on. so total hour value ranges from 1-24 every day.File name is "**2012 file**" i.e. We will be having 366(days)*24(hours)= 8784 peak load values for the whole year.

We have another file which is of current year and actual peak loads per hour are coming and getting stored there. The fields are similar to the previous file.The file name is "**2013 file**". 2nd program reads the data hour wise from the previous year file and current year file(assume that current year file contains 24 hours data ie of 1st jan 2013 and today is 2nd jan 2013) , calculate the % increase or decrease in the load and store the increment/ decrement percentage in another file called current_trend file. After completing this task it starts reading the "**current_trend**" file percentages and finally it averages the percentage value to find the current trend of Load. 3rd program reads the 2012 data file and start incrementing it with the avg % we got. This incremented load is stored in the "**result file**" hour wise and date wise as the future predicted load.

Next the Supervisory Control is used for controlling rotary switches on the monitor for changing the RLC, to control the flow of power, voltage regulation of generator, load and transmission lines.PLC terminals are connected to mechanical rotary switches and the other end connected to R LC through the relays. The data generated on this Power System Monitor is transmitted through SCADA devices to computer via wireless network for the efficient control and transmission of power.

So we have in total 4 files → (1)2012 file (2) 2013 file (3) current trend file(containing incremented or decremented percentages) (4) Result File(containing forecasted loads datewise and hourwise).The result file is read by the supervisory control 5 minutes before the hour is completed to set the model Generator and Load values(as it takes 3-4 minutes for the model to become stable).

Power flow studies can be made by simulating a given power system on the monitor. Voltage, Current, Active and Reactive Power, Angle and Power Factor can be measured at all nodes through the MFM(Multi Function Meter) provided on the monitor panel at each Generator, Load & Transmission Lines

THE MODEL

LOAD

It is provided with RLC parameters to vary the load according to the requirements. The load is provided with an Auto-transformer (AT) for bucking and Boosting. Current and Power can be increased or decreased by varying R, XL, Xc and Auto-transformer Multifunction meter of the Load indicates the V, I, mVA, VARS, WATTS-&-PF. Load R, XL and Xc provided on rotary switches are marked in per unit value and can be varied to obtain load current in mA / power in mVA and Xc to vary the Power factor.

TRANSMISSION LINE

Each transmission line is provided with rotary switches marked R and XL in per unit parameters of Lines and an adjustable Series coupling capacitor marked in per unit. Each Line is also provided with Auto-transformer marked AT. The multifunction meter reads V, I, mVA, VARS, PF and WATTS.

BUS-BARS

The Bus Bars are located on the Central Panel for inter-connecting generators, loads and transmission lines to form the circuit connection for representing a power system. Both the ends of the generator, loads and transmission lines are brought over to the Central Panel Bus Bars. The interconnection is made by using the patch-chords.

FACTS DEVICE – UPFC

Electronic circuits were assembled to make UPFC device that comprises Converter to obtain DC voltage and Inverter to convert DC back to AC. These were connected in tandem and provided with Tappings on transformer for each unit. The input to the Converter is through the Shunt transformer and output of Inverter is fed to transmission line through Series transformer to control phase angel, voltage magnitude and other function of the device. This can be connected to the monitor through patch chords when required for the study.

The model of Power System Monitor comprises of following hardware components.

GENERATOR

The generator is electronically simulated. It is provided with the facilities of a multifunction meter for measurement of V, I, mVA, VARS WATTS and PF and Auto transformer (AT) for voltage control in steps of 10/20/30/40 volts along with two controls for smooth control of output voltage from the Generator with R & XL as inherent parameters.

SCADA ARCHITECTURE & DEVICES

1. Master Module

Master Module queries each multifunction meter and phase angle meter every second and sends through the USB Port the information to computer

2. Wireless Module

Receives and Sends data to all hardware devices 3) PLC 4) RTU 5) Control Relays 6) Sensors 7) Computer and Software

Supervisory-Control

PC, Control Relays, PLC, RTU, Sensors, wireless system all connected to the Power System Monitor for exerting. The mechanical rotary switches have been supplemented by programmable rotary switches. The equipment has both manual and remote features. Digital sensors and control relays are input/output devices that control the processes of the monitor.

Data Acquisition

The information is collected by the RTUs locally, and then forwarded to the SCADA Master, from where reports and alarms are presented to the user. RTU's interpret information from attached sensors and transmit it to the SCADA master unit. The RTU receives control commands from the SCADA master unit, and forwards these commands to the appropriate control relays. SCADA master unit controls individual operational processes throughout the network from a single location. SCADA system presents data to operators. The master unit continuously monitors all sensors and alerts the operator if there is any Change-of-State (COS) event within the managed system. The control functions respond to COS events anywhere in the system by automatically issuing related or user-specified commands. It would result in instantaneous response to dynamic problems and threats. The block diagram fig 3 highlights the architecture.

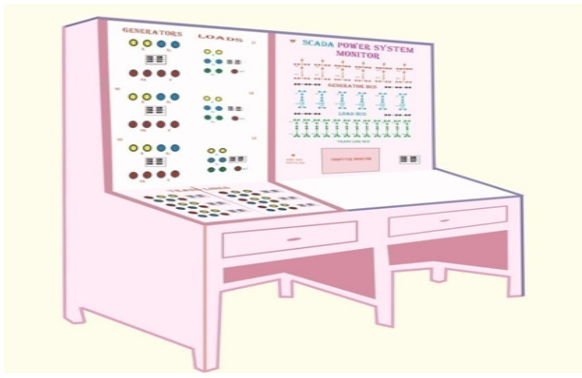

Fig 1:- SCADA Power System Monitor

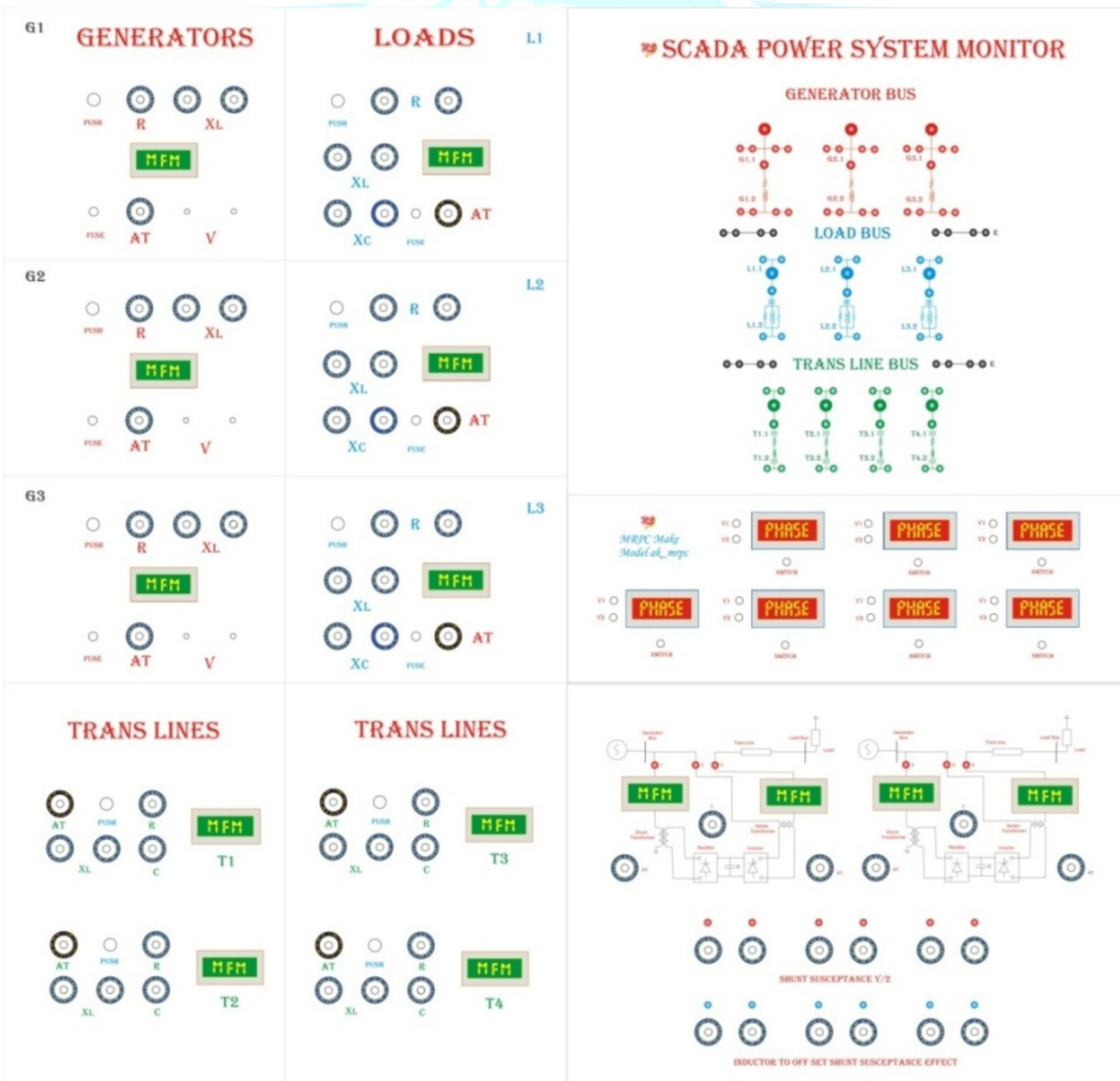

Fig:- 2 –Layout Of Scada Power System Monitor

THE FOLLOWING STUDIES CAN BE MADE ON THE MODEL

1. *P*OWER FLOW

i) voltage magnitude and phase angle of each bus.

ii) real and reactive power flow in each

transmission line.
iii) Power losses and voltage regulation in transmission lines Experiment Fig no: 1 & Table no: 1 illustrates power flow studies.

2.*F*AULT-ANALYSIS

Simulation of network for symmetrical and unsymmetrical fault studies using positive, negative and zero sequences networks for L-G, LL and LL-G faults and three phase faults. These Experiments can be performed on Power System Monitor by representing the single phase circuit. ends to see shunt effect on line and rise of "V" at the receiving end can be seen*(Ferranti effect)*

4.SHUNT-COMPENSATION-THROUGH-INDUCTORS

3.*S*HUNT-ADMITTANCE-Y/2

Provision of connecting Y/2 shunt at both

Shunt compensation by placement of inductors on each line to reduce the effect of shunt susceptances of HV line. Shunt inductors have been introduced when the loads are removed or the system is lightly loaded. Adjustable shunt inductors have been provided and these can be connected at both ends of the transmission line.

5. REGULATION THROUGH PARALLEL TRANSFORMERS

Provision of regulating transformer in parallel is provided to study the control of magnitude and phase angle which would control the flow of active and reactive power on transmission line.

SCADA ARCHITECTURE FOR THE POWER SYSTEM MONITOR

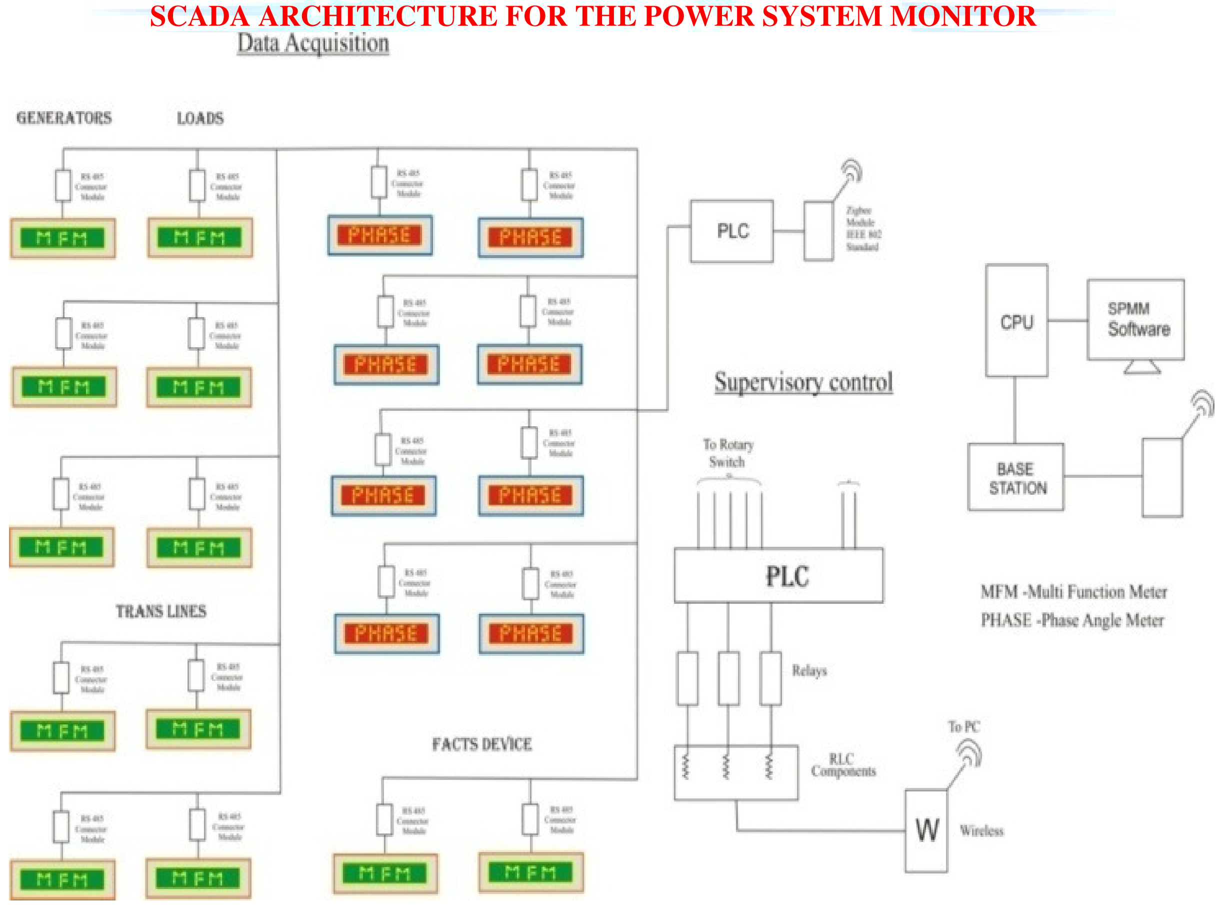

Figure. 3 SCADA Architecture with FACTS Devices

6. *P*ARALLEL TRANSMISSION LINES

one of the features is a quadrature booster provided on the Power System Monitor for sharing power.

7. *U*PFC (Unified Power Flow Control)

It is provided on the Power System Monitor to Control: Voltage Magnitude, Phase angle, Impedance, Active and Reactive Power. Fig. 5

shows that the UPFC consists of a series and shunt converter and it is connected back-to-back through a common dc link.

8. *C*ONTROL OF REACTIVE POWER IN TRANSMISSION LINES

It is necessary to tackle Under-Voltage at the Load Bus and prevent collapse of voltage that caused blackout in USA in 2003. To control Reactive Power (Q) in the transmission lines Series and Shunt Transformers are provided in each Transmission line to change the voltage magnitude by changing Tap Positions. Change in the voltage magnitude at the transmission line bus controls flow of the reactive power in the transmission line which was applied and variations were studied in experiment fig no: 4 & and Table 1.

EXPERIMENTS

BASE VALUES OF POWER SYSTEM

Base Power – 20 MVA
Base Voltage – 200 KV
Base Current – 100 Amps
Base Impedance – 2000 Ohms

BASE VALUES ON THE MODEL

Base Power – 200 mVA
Base Voltage -- 20 V
Base Current – 10 mA
Base Impedance – 2000 Ohms
Frequency – 50 Hz

EXPERIMENT 1:- LOAD FORECASTING

This logic was used to test the actual data of jul 2011 and jul 2012. The Results are as follows:-

The avg incremented % came to be 7.07 % which was used to increment the 2011 peak loads. It was found that 16 out of 24 predicted peak loads satisfied the 2012 Load scenario. Remaining 8 cases were satisfied partially varying from 50.1% to 80%.

Accuracy of predicting the loads in 9 cases was 70%-99%, for 7 cases –it was from 50.1% -70%. This becomes more clear if we compare the electricity consumption growth % trend in India which is 1.34% less then what we have obtained from the algorithm in july month. See [8],[9],[10]

YEAR	ELECTRICITY CONSUMPTION(IN BILLION KWH)	GROWTH RATE
2007	587.9	
2008	517.2	-12.02%
2009	523.35	1.19%
2010	568	+9.82%
2011	568	0%
2012	600.6	5.73%

EXPERIMENT -2 POWER FLOW

This illustrates study of Power Flow in an interconnected power system network comprising of 3 Generators, 3 Loads and 3 Transmission Lines. Figure 4 shows the circuit

Generating Station: Medellin: Rating: 140 MVA (use G1)

Load =60 MVA at Gen bus G1 (use L1) Medellin

Generating Station BBC: Rating 40MVA (use G2)

Load = 120 MVA at Gen bus G2 (use L2) BBC

Generating Station Termopaipa reading 100 MVA (use G3)

Load = 100 MVA at Generator Bus Station G3 (use L3) Termopaipa

Interconnect the circuit as per the figure 4.

Note: Voltages at all Generators, Loads and Transmission Lines have to be maintained at 20 Volts

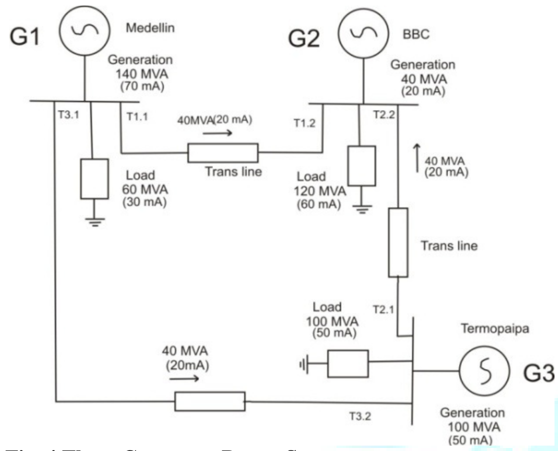

Fig. 4 Three Generator Power System

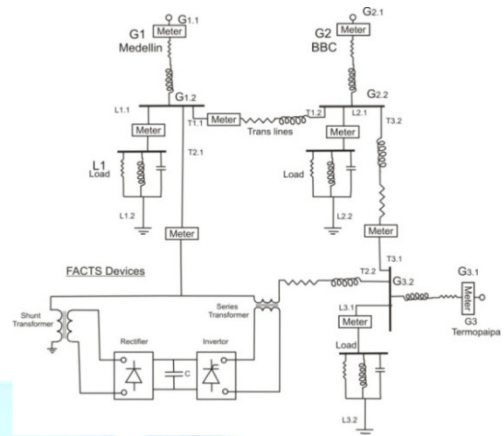

Fig. 5 Simulated on Power Monitor for Power Flow with FACTS Devices

TABLE I:- For Fig. 4

Bus Bar	Voltage(v)		Current		Power(VI)		Active power(W) VI Cos ø		Reactive power(VAR) VI Sine ø		Powe r factor VI Cos ø
	Model V	Actual KV	Model Ma	Actual A	Model VI (mVA)	Actual MVI (MVA)	Model W	Actual MW	Model VAR	Actual MVAR	
G1	20	200	70	700	140	140	112	112	84	84	0.8
G2	20	200	50	500	100	100	80	80	60	60	0.8
G3	20	200	20	200	40	40	32	32	24	24	0.8
T1	20	200	50	500	100	100	80	80	60	60	0.8
T2	20	200	30	300	60	60	48	48	36	36	0.8
T3	20	200	60	600	120	120	96	96	72	72	0.8
L1	20	200	20	200	40	40	32	32	24	24	0.8
L2	20	200	20	200	40	40	32	32	24	24	0.8
L3	20	200	20	200	40	40	32	32	24	24	0.8

The Phase Angle (with reference to slack bus) at each Generator, Load bus and also Active and reactive power in all transmission lines can be measured.

EXPERIMENT 3:- LOAD FLOW WITH & WITHOUT UPFC DEVICES.

Interconnect the circuit as per the Fig. 2

TABLE II for Fig. 5:-

Bus Bar	Voltage(v)		Current		Power(VI)		Active power(W) VI Cos ø		Reactive power(VAR) VI Sin ø		Power factor Cos ø
	Mode l V	Actual KV	Mode l mA	Actual A	Model VI	Actua l MVI	Model W	Actual MW	Model VAR	Actual MVAR	
G1	20	200	220	2200	4.4	440	4.4	440	0	0	1
G1(wit hout UPFC)	20	200	180	1800	3.6	360	2.52	252	2.54	254	0.7

: Power Boosting through Transmission Line with UPFC is = (220-180) / 220 = 18.18 %

CONCLUSIONS

The requirement for efficient and economic management of electrical system has promoted research in implementing innovative technologies in power generation and transmission. Flexible Alternate Current Transmission System uses electronic devices for controlling power flow in transmission network, enabling transmission lines system to be loaded to its full capacity. The device enhances utilization and reliability of transmission lines resulting into financial benefit of additional sales of power. Purpose of making the model was to realize a firsthand detailed study of various aspects related to economic management of power transmission. The experimental model developed here uses SCADA architecture for remote supervisory control and data acquisition using wireless methods and computer-software.

Practical experiments were conducted by simulating a real power system on the model by scaling down voltage, power through the base values and after the study the result of the model are converted back to the real quantity of practical system.

Experiments were conducted on Power System Monitor. FACTS Device – UPFC provided dynamic control of voltage, phase angle, impedance, active and reactive power flow in reserve calculation, and VAR, voltage control. **Real-time data like, outside temperature and** transmission lines. Division of power was achieved in parallel lines to their optimized capacities; enhanced transfer of power in lines by 20% while maintaining reliability of system operation.

Energy Management System (EMS) includes applications such as automatic generation control, can all be studied on this monitor. Planning and forecasting studies can be made for modernization of the electrical network. Also power flow studies, short circuit calculations (positive, negative and zero sequence networks) and power factor studies. **historical data is used to predict load forecasting--the load-hours or days in advance.** Economic dispatch is concerned with determining which generators should be operated based on system load and fuel cost.

Loss of power in transmission line was obtained by taking the difference of the reading displayed by the multifunction meter at the sending and receiving end of the transmission line, the loss was reduced as the impedance of the transmission line was reduced due to series capacitance compensation and the control exerted by the UPFC Device.

The spare stored energy in the capacitor of the UPFC Inverter (as a result of higher generation and lesser utilization at the load end) was diverted through a DC transmission line connected at the junction of the charged capacitor.

The spare power was transferred to another load located distantly where at the other end of the DC transmission line an inverter was placed to obtain the AC supply for the local load. The capacitance was also varied in steps from 5,000 to 80,000 MFD. This resulted into reservoir for excess energy. This saves power which otherwise would have been wasted had it not been stored in the capacitor. This results in to economic utilization of power and helping out consumers who otherwise would sit in the dark.

Development of real time Power System Monitor enabled FACTS devices simulation and application of SCADA for economic and efficient management-studies.

System reliability in terms of interconnections, control, fault rectification, protection, pf correction and overall performance It will introduce efficiency due to automatic control to a predetermined optimization limits set for its operation. There by contributing to the economic factors related to the operation, control and transmission of power.

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