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Stability Monitoring & Control On The Grid Prototype

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ABSTRACT

This paper discusses about the studies made on the 3-Phase Grid Prototype to simulate disturbances and regain stability. Few experiments are analyzed to understand the difficulties faced while achieving stability. A hardware model was constructed "3-Phase Grid Prototype" with provision for simulating generator, trans-mission Lines and loads for Dynamic stability studies.

Key words: *FACTS, UPFC, SCADA, Stability, Dynamic, Prototype, Simulation*

INTRODUCTION

This research paper presents the study and analysis made on the hardware model: "3-Phase Grid Prototype".

This model simulates 400 kV transmission line system to study the dynamic stability and difficulties arising in achieving the stability during power flow and fault conditions in a interconnected grid system.
This model has capacity of 3 generators, 3 transmission lines, 3 loads, SCADA automation and FACTS device – UPFC.
[1] Saurabh Jain, Dr Anand Khare et.al, (2016) in their paper have described about the construction of 3-Phase Grid Prototype hardware model on which stability studies can be analyzed while simulating conditions of disturbances during power flow and fault analysis in an interconnected grid system and regain stability with external devices to control and monitor the system with use of SCADA and UPFC.

CONFIGURATION OF 3 PHASE GRID PROTOTYPE

a. Generators (G)

The generator panel has two 3-Phase generators of 2 KVA capacity each and one 2 KVA Solar Renewable energy source 415 Volts, three phase motor-generator sets are provided with motor drives, reverse power relay, short circuit relay with circuit breakers for their protection. Three phase digital Multi Function Meters (MFM) displays voltage, current, power factor, frequency, active and reactive power. The multifunction meters also have RS285 port for data communication with computer software. The generator alternator output is stepped down by transformer to100 volts

The Motor-Alternator Control Panel

The two 3 Phase / 2 KVA motor alternator sets (Generator supply 1 and 2) have a separate Control Panel with digital meters and variac arrangement to control speed and excitation of motor-generator and another variac for varying the voltage.

Solar Renewable Energy Source: 3-Phase 2kVA with sinusoidal output.

b. Loads (L)

The passive load comprises of Resistive / Inductive / Capacitive banks and protection devices.

c. Transmission Lines (TL)

The TL has pi section divided in three sections of 200 km each giving a total length of 600 km (see table no 1). TL also has the necessary protection devices - MCB / over current relay. The TL is provided with the digital MFM with RS285 Port. The TL configuration is in the form of a pi-section with RLC values. One MFM is provided at the Sending end of the TL and another at the Receiving end of each section.

d. SCADA Automation

Supervisory Control and Data Acquisition monitors and controls various components on the hardware model – 3-Phase Grid Prototype.

e. UPFC device

The shunt and series transformer with the AC to DC and DC to AC arrangement allows better utilization of existing transmission system, increases transmission system reliability & also increases grid stability.

REVIEW OF LITERATURE

[2] Soheil Ganjefar, et.al, (2009) have discussed about stability of power system which includes 4 major parts, permanent stability, transient stability, voltage stability and dynamic stability (small signal). They state that one of the most important parts of power system stability is dynamic stability. Controlling devices to improve dynamic

stability of power systems are called power system stabilizers (PSS). Changes and expansions of the network may cause movement of stabilizers. In this paper internet has been used for a fast and easy-accessible network. Simulation in this paper has been done by MATLAB software. They have concluded the advantages of their method which includes: reduction of number of network stabilizers, controlling dynamic stability of the whole system in one point, increasing flexibility of network which resulted in efficiency by this method.

[3] Abdul Ghani Abro, et.al, (2012) in their paper have discussed about the deregulation and growth of the power industry, power systems elements which are forced to operate very near to their maximum capacity and how the system becomes vulnerable. They have elaborated about controlled operations in power systems which is very critical and important in order to achieve stable power system. Therefore, implementing fast, efficient and reliable control algorithms, robust and efficient power system controllers with intelligent systems; neural networks, fuzzy logic and bio-inspired optimization algorithms is necessary. Their paper reviews intelligent controllers at the generator end of power systems and discussed further about the performance of power system enhancement by using local-agents and wide area control simultaneously. They concluded that Wide-area-control alone does not enhance power system performance. Their results state that neuro-controller has performed better than conventional controller as it reduces computational burden and has simpler control loop.

[4] Byung Ha Lee, et.al, (1993) in their paper have discussed about the static voltage stability and the dynamic voltage stability. For an accurate analysis of the dynamic voltage stability, they have built a model which includes excitation systems, tap-changers, capacitors and power system stabilizers in addition to network equations. This model is developed to determine optimal control parameters for dynamic voltage stability enhancement, control of static voltage stability, for which shunt capacitor and tap-changer were used. Their results and findings show that the control of the shunt capacitor and the tap-changer can increase the stability margin for static voltage stability and the increase of the stability margin improves the overall voltage of the power system, preventing a severe voltage decline.

[5] Kiran R, et.al, (2103) in their paper have discussed about optimal location for PMUs and FACTS devices, to have an efficient monetary and control system. This paper presents a simple and effective method for optimal placement of PMUs and FACTS devices. A voltage stability based weak bus screening method has been utilized to select critical buses for determining power system stability. An algorithm is proposed for the PMU placement to determine optimal locations for the system observability. This

paper deals with simulation of IEEE 14-bus power system using STATCOM & UPFC to improve the power quality. They state that UPFC is capable of improving transient stability in a power system; the real and reactive powers can be easily controlled. The simulation results of eight bus system with and without STATCOM & UPFC have been analyzed. Their simulation studies indicate the usefulness of STATCOM & UPFC to mitigate the voltage sag. Transmission capability of the existing transmission line has improved with the presence of UPFC.

[6] Nagasubbaiah V, et.al, (2015) in their paper have proposed PSO based PSS. The authors conclude that construction and implementation of proposed controller is fairly easy and economical, which can be useful in real world power system. The proposed controller has been tested on a 3 machine 9 bus power system in comparison with the GA based PSS controllers under different fault conditions.

[7] Galina Antonova, et.al, in their paper describe the latest developments in the wide area monitoring of power grids IEEEC37 118.1-2011 synchrophasor measurement. They have outlined fundamentals of synchro-phasor systems, and focused on the latest techno advances and applications utilized in the existing and emerging power grids. They state that introduction of synchro-phasor measurements as well as advances in communications and processing power makes it technically feasible to monitor the stability of the power system on-line in real system.

[8] Yuyao Chen, et.al, (2013) in their paper have discussed about the dynamic stability and to practically analyze the stability of voltage. Time-domain simulation is opted as it is an important measure in research of complex power grid. In their paper they have used full dynamic simulation program based on time-domain simulation in dynamic voltage stability research, raise methods and steps to figure out dynamic voltage stability in both with and without consideration of over-excitation limitation. Their results conclude that the effect and influence of generator over-excitation limitation in full dynamic voltage stability research.

[9] Garng M, et.al, in their paper have proposed a method for online monitoring of a power system, which aims at detection of the voltage instability. They state the advantages of the method: Kirchhoff-Law by which simple numerical calculation and strong adaptation in steady state and transient process the instability can be predicted through the indicators it would be easy to find the vulnerable area in a system. A real time measurement based voltage stability indicator for monitoring of the power systems is presented in their paper. They have concluded that:

- The indicator can predict the voltage stability problem correctly and properly by using both steady-state data as well as dynamic data.

- The indicator can be used for both static and dynamic voltage problems.
- It is very easy to locate the vulnerable locations of the system.
- The indicator can correctly predict the collapse point of the system.

[10] Lee Cheun, et.al, (2013) in their paper have discussed about smart grid which provides bi-directional flow of electricity and information, with improving the power grid reliability, security, and efficiency of electrical system from generation to transmission and distribution. Their paper reviews the current state-of-art technology and focuses on the system reliability analysis and failure in protection mechanism.

[11] Alok Kumar, et.al, in their paper have discussed about the benefits of utilizing FACTS devices with the purpose of improving the operation of an electrical power system. Performance of different FACTS controllers has also been discussed. The essential features of FACTS controllers and their potential to improve system stability for effective & economic operation of the power system has been highlighted.

[12] Mudassir A Maniar, et.al, (2013) in their paper have presented analytical method to find optimal location of PMU to make power system observable. This Optimal PMU Placement (OPP) is optimization problem which has been solved using BILP (Binary Integer Linear Programming). The analytical method has been coded in the MATLAB and applied to different IEEE test systems up to 118 buses.

[13] J Wadhawan, et.al, (2012) in their paper have proposed a model of unified power flow controller (UPFC) in a single machine six bus system.
The solution is the use of FACTS. Their model consists of a simple voltage source whose magnitude and angle depends on the UPFC control parameter. They have concluded with their results and observations that in case of power flow control mode for first three faults i.e. LG, LL, LLG, active power is increased with same reactive power with the use of UPFC.
For voltage injection mode:
i. Bypass breaker closed P=584.2MW, Q = 27 MVAR ii. Bypass breaker opened, the magnitude of the injected series voltage is increased. Their simulation results show the effectiveness of UPFC to control the real and reactive power.

[14] Ankita Pail, et.al, (2015) in their paper have discussed about the architecture of power system automation and its usage in the industry along with its future scope and technologies. They state that the use of Ethernet will involve communications within substations and control room. In future the control systems will supervise the systems, rather than controlling it. Computers will be at the power plant but the operator will be somewhere else. Data will be available through portals to the outside world with the aim to optimize process and operation costs to reduce.

[15] Manoj Chaudhry, et.al, (2014) in their paper have highlighted the advantages of using FACTS devices for the purpose of improving the operation of an electrical power system. Comparison on the basis of performance of different FACTS controllers has been discussed. Voltage profile improvement and stability enhancement of power system using UPFC is presented in the paper. SIMULINK models of five bus test system and UPFC were developed. The test system has been analyzed with & without incorporating UPFC. Two case studies were taken up, where faults occurred at two buses i.e. 4th and 5th. For both cases the faults were created at 1 second and cleared at 1.5 second. It has been observed that the oscillations of rotor angle in generator, which is near to fault, increased and lost synchronism. In other generator rotor angle sustained for 30 seconds. Further, UPFC has been incorporated in test system at line 1- 4 and analyzed for the fault conditions.

[16] Neha Gaur, et.al, (2012) in their paper have discussed about the present and past status of the research and development activities in the area of electric power distribution automation both in developed as well as in developing countries. The information given in this paper is useful to electric power distribution utilities and academicians involved in research and development activities in the area of power distribution automation.

[17] Akwukwaegbu, et.al, (2013) in their paper have presented an analysis of reactive power control and voltage stability in power systems. They describe a new model used to enhance voltage stability and expose several key issues that had remained as research challenges in this area. The steady state voltage and reactive power control in distribution systems can be properly controlled by coordinating the available voltage and reactive power control equipment, such as on-load tap-changers, substation shunt capacitors and feeder shunt capacitors. In their paper, several representative techniques of reactive power and voltage, VAR control are reviewed. Their advantages and disadvantages are analyzed.

[18] B. Vijay Kumar, et.al, (2016) in their paper have proposed a hybrid method for improving the dynamic stability of the power system using UPFC. Their proposed method is implemented in the MATLAB/SIMULINK platform with IEEE 30 and IEEE 14 standard bench mark system.

Their paper describes about the hybrid technique based improvement on the dynamic stability of the power system. In their technique, the maximum power loss bus is referred as the optimum location of the UPFC, which has been obtained by the bat inspired algorithm. They concluded with a comparison result which is effective technique to maintain the dynamic stability of the power system.

[19] Neil Higgins, et.al, in their paper presents a new approach to power system automation, which investigates the interplay between two international standards, IEC 61850 and IEC 61499, and proposes a way of combining of the application functions of IEC 61850-compliant devices with IEC 61499 compliant "glue logic," using the communication services of IEC 61850-7-2. They discuss about a pathway to flexible power system automation. This involves the use of IEC 61499 as an integration, extension, and verification mechanism for IEC61850-based systems. In order to enhance the benefits of this approach, devices like protective relays, bay controllers and substation controllers could be implemented on IEC 61499-compliant platforms, which would add new value to IEC 61850 compliance—the ability to customize protection, monitoring, control, and automation functions. IEC 61499 could also be extended toward power system equipment—CBs, transformers, merging units.

[20] Bashar .S. A, et.al, (2016) in their paper have presented an overview on power system stability. Definition of frequency stability is presented together with its principles and criteria. The literature discusses major frequency disturbances in various countries, highlighting power system balance, frequency grid relation and power frequency control.

[21] Rajib Roy, et.al, (2012) in their paper have discussed about automation system, the remote operation, control and monitoring are necessary for any modern system. Their study is about the application of SCADA in overall operation, control and monitoring of transmission and distribution electrical power system network of Dhaka city, Bangladesh. DPDC (Dhaka Power Distribution Company Limited) is the authority which is managing the transmission and distribution network of Dhaka city, Bangladesh. The 132 and 33KV circuit breakers of power system network of Dhaka city are generally operated through the SCADA system for uninterrupted power supply to the consumers. The RTU is placed in every substation of the electrical power system network of Dhaka city. The SPIDER software is used for SCADA system of DPDC. The SPIDER uses UNIX based platform. The SCADA system helps in managing the overall system of DPDC with minimum supervision and manpower. Moreover it improves the system efficiency.
The SCADA system helps in monitoring and controlling of the overall electricity network of Dhaka city which provides uninterrupted electricity supply to the consumer. The application of SCADA has simplified the managing of the electricity network of Dhaka city with minimum human interference. From their study they concluded that in order to improve the overall system performance, reliability and stability it is necessary to implement the SCADA system for controlling the whole electricity network of Bangladesh. The

manual operation of power system in Bangladesh requires huge manpower which increases the overall system cost. Moreover quick decision making becomes difficult in manual system during system failure or unbalanced situation.

EXPERIMENTS, RESULTS AND CONCLUSIONS

The *dynamic instability* causing the unbalance in the generator and load shutdown can be *controlled* by implement-ting SCADA automation along with UPFC and PSS.

Experiments performed outline the efficient and effective control and monitoring system to take appropriate action on different conditions of grid operation. The SCADA automation has proved to be an efficient and economic tool to manage the complex power system grid. The UPFC device has shown a 10% to 15% improvement and optimized the power flow in the existing system.

The annexure comprises of the data in the form of figures and experiments. Figure no 1 shows the UPFC device used for the experiment. Figure no 2 gives the circuit of the grid network comprising generators 3nos, loads 3nos and Transmission lines 3nos for experimental setup on the 3-Phase Grid Prototype shown in figure no 4 where as figure no 3 gives the front end design of the software used to monitor & control the 3-Phase Grid Prototype through the computer.

Experiments were conducted on monitoring and control of voltage, speed and frequency of generator through SCADA automation in various steps given in the table no 1, in this table the last column gives the observations made in the experiment. Table no 2 studies the synchronization between G3 and grid “G1 & G2” along with the observations. Table no 3 lists out the voltage drop of the generator bus bar and loads with percentage % change in the ratio of the generator capacity. Table no 5 describes various conditions which were observed during the process of generator failure i.e. G1 switched off whereas in G2 and G3 there was a drop in the voltage and increment in the current. In L1, L2 & L3 there was a drop in the supply of power and in TL1, TL2 and TL3 a reduction in power transmission. Here the function of SCADA operated through the computer is also listed in column 2 and related observation in column 3 of the table.

Experiment no 2 was conducted on supervising the status of circuit breakers, (increased power to trip circuit breaker). Table no 6 gives the monitoring status of MCB and Over Current Relay under the fault condition of LLL-G.

Experiment no 3 deals with the active and reactive power control which had varied shunt and series transformer output from the UPFC. Here the table no 7 shows power flow without UPFC device and table no 8 gives the power flow with UPFC device. Here it can be seen that with the presence of the UPFC device power factor has increased and consequently active power (W) where as the reactive power (VARS) changed accordingly.

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ANNEXURE:

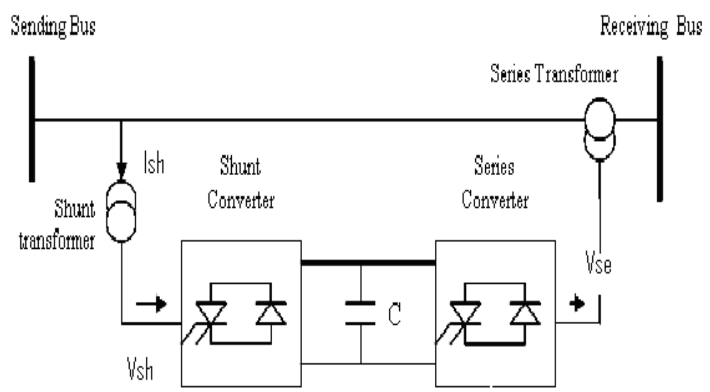

Figure 1: Connection diagram of FACTS device – UPFC

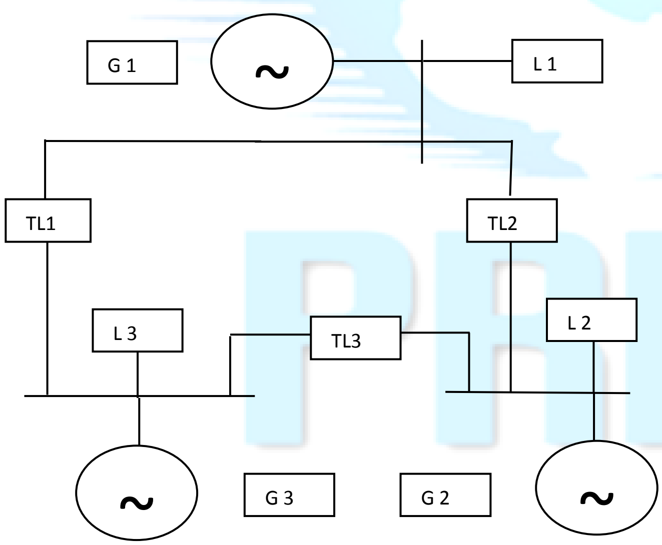

Fig 2: Grid comprising 3 Generators, 3 Transmission lines and 3 Loads

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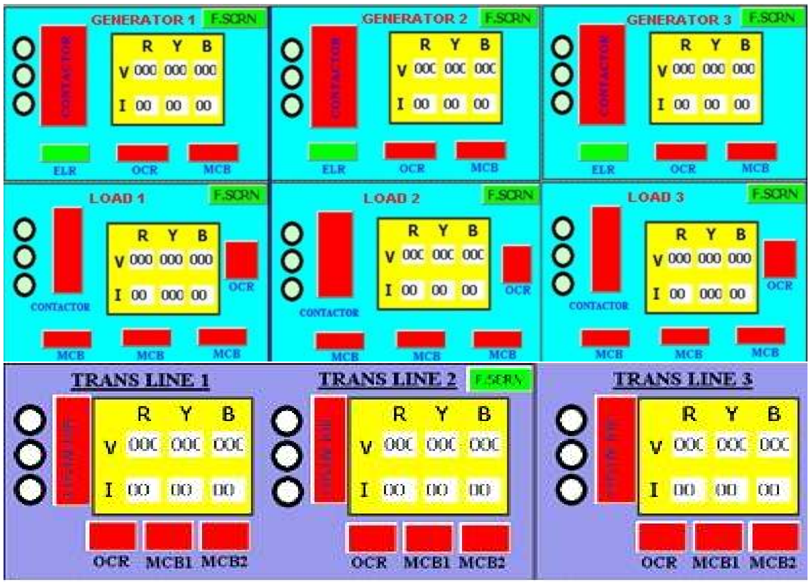

Figure 3: Front end design of software

Figure 4: 3-Phase Grid Prototype

EXPERIMENTS

Experiment no 1. Monitoring and Control of Voltage, Speed and Frequency through SCADA Automation

Synchronization between G1 & G2				
STEP 1 Voltage, Speed Frequency	STEP 2 Synchroscope	STEP 3 Coupling	STEP 4 Process	OBSERVATIONS
a. The values of voltage, speed and frequency are set of both G1 & G2 to read same values.	a. Meter was reading the status, "Not Tuned". b. After iteration, the status read "Tuned"	a. The Transmission Line 2 was connected between G1 & G2	a. After coupling the Synchroscope, it indicated that the G1 & G2 out of tune. b. There was a voltage drop at G1 and increase at G2. c. There was a change in Frequency. d. The Reverse Power Relay triggered and disconnected the G1.	a. The Protection system i.e. Reverse Power Relay triggered and disconnected the G1 from the circuit, this indicates that power was flowing from G2 to G1. b. After iteration Synchronism was achieved.

Table no.1: Synchronization between G1 & G2

Synchronization between G3 and Grid "G1 - G2"				
STEP 1 Voltage Speed Frequency	STEP 2 Synchroscope	STEP 3 Coupling	STEP 4 Process	OBSERVATIONS
a. The values of voltage, speed and frequency were set of both G3 to read same values that of Grid "G1-G2".	a. Meter was reading the status, "Not Tuned". b. After iteration, the status read "Tuned"	a. The Transmission Line 1 & 3 was connected between G1 & G2	a. After coupling the Synchroscope, it indicated that the G1 & G2 went out of tune. b. There was a voltage drop at G1 and increase at G2 & G3. c. There was a change in Frequency. d. The Reverse Power Relay triggered & disconnected the G1 & G2	a. The Protection system i.e. Reverse Power Relay triggered and disconnected the G1 and G2 from the circuit, this indicates that power was flowing from G3 to G1 & G2. b. After iteration Synchronism was achieved.

Table no.2: Synchronization between G3 and Grid "G1 - G2".

G1	*G2*	*G3*	*loads with percentage % change in ratio of the Generator rating*	*Observations*
Voltage drop in percentage				
Negligible change	*Negligible change*	*Negligible change*	*10 %*	There was continuous voltage drop as the loads were increased. This was monitored and controlled by SCADA and accordingly the voltages were increased to maintain the voltage at 100 volts.
Negligible change	*Negligible change*	*Negligible change*	*20%*	
0.5%	*0.5%*	*Negligible change*	*30%*	
0.9%	*0.7%*	*0.4%*	*40%*	
1%	*0.9%*	*0.6%*	*50%*	
2%	*1.5%*	*2%*	*60%*	
4%	*3%*	*4%*	*70%*	
5%	*5%*	*5%*	*80%*	
8%	*7.8%*	*7.9%*	*90%*	

Table no.3: ***Voltage drop in percentage***

Grid System Capacity Configuration	
G1	200 MVA
G2	500 MVA
G3	800 MVA
L1	500 MVA
L2	400 MVA
L3	600 MVA
TL1	150 MVA
TL2	150 MVA
TL3	50 MVA

Table no 4: The above table gives the power capacity value of Generator, Transmission Lines & Loads.

Simulating Generator Failure			
	Conditions	SCADA through computer	Observations
G1	Switched off	Switched off	Generator Failure
G2	Drop in voltage and increase in current.	a. voltage regulation and excitation accelerated.	Change in Synchroscope due to disturbance, but achieved stability after iteration.
G3	Drop in voltage and increase in current	a. voltage regulation and excitation accelerated.	
L1	Drop in supply of power	Load shedding: Load reduced to maintain balance.	The variable load bank was reduced
L2	Drop in supply of power	Maintaining Voltage	Voltage magnitude regulated
L3	Drop in supply of power	Maintaining Voltage	Voltage magnitude regulated
TL1	Redistribution in Power Transmission	No action	-
TL2	Redistribution in Power Transmission	No action	-
TL3	Redistribution in Power Transmission	No action	-

Table no 5: Simulating Generator Failure

Experiment no 2: Supervising the status of circuit breakers, increased power to trip Circuit Breaker

Fault Simulated to test status of MCB & Over Current Relay		
	Condition	SCADA monitoring
G1	Fault LLL-G	TRIP
G2		ON
G3		ON
L1		ON
L2		ON
L3		ON
TL1		ON
TL2		ON
TL3		ON

Table no 6: Monitoring the status of MCB & OCR

Experiment no 3: Active and reactive power control, varied shunt and series transformer output of UPFC

Bus Bar	Voltage(v)	Active power (W) VI Cos ø	Reactive power (VAR) VI Sine ø	Power factor Cos ø
	Model - V	Model - W	Model - VAR	
G1	100	1.04	0.84	0.8
G2	100	0.32	0.2	0.80
G3	100	0.80	0.6	0.80
T1	100	0.24	0.2	0.69
T2	100	0.24	0.2	0.69
T3	100	0.30	0.28	0.69
L1	100	0.3	0.3	0.69
L2	100	0.7	0.7	0.69
L3	100	0.5	0.5	0.69

Table no 7: Power Flow without UPFC Devices

Bus Bar	Voltage(v)	Active power (W) VI Cos ø	Reactive power (VAR) VI Sin ø	Power Factor Cos ø
	Model - V	Model - W	Model - VAR	
G1	100	1.4	0	1
G2	100	0.36	0.16	0.90
G3	100	0.9	0.40	0.90
T1	100	0.32	0.24	0.80
T2	100	0.32	0.24	0.80
T3	100	0.32	0.24	0.80
L1	100	0.48	0.36	0.80
L2	100	0.96	0.72	0.80
L3	100	0.80	0.60	0.80

Table no 8: Power Flow with UPFC