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# Power Flow Control by Unified Power Flow Controller

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## ABSTRACT

**The demand of energy usage is increasing rapidly and to meet the energy requirements, best possible transmission systems should be adopted to avoid energy losses in our transmission systems. In Pakistan's WAPDA (Water & Power Development Authority) system, the rapid increase in load and less generation capacity has increased load shedding thought the country. The government has planned to increase the generation capacity but the supply companies are facing line load-ability, environmental constraints, power limitations problems etc. Most of the supply companies prefer to extend the existing electrical networks instead of building new network to reduce financial burdens.**

**In this paper the implementation of the FACTS (Flexible AC Transmission Systems) Devices in an electrical network is described. The FACTS devices enhance power transfer capacity of the line without adding new transmission line. These devices also protect the system from overloading in case of any contingency in the electrical network. The control of power flow, reactive power compensation and voltage control are the main capabilities of FACTS devices. This paper describes the impacts of FACTS devices on improving the voltage stability and power handling capability of a transmission line. The proposed methods for the controllable flow of active and reactive power in a transmission line are also elaborated. A simple electrical system is examined to explain the improvement in the constraints of power system using FACTS devices.**

**Key Words:** **Flexible AC Transmission Systems, Genetic Algorithm, Phase Shifting Transformer, Static VAR Compensator, Static Compensator**

## 1. INTRODUCTION

The modern-day power systems are heavily stressed because of the growing demand of electricity and competition in the electricity market [1]. In the past few years, a huge difference between the supply and demand of electricity has been observed in Pakistan. These power shortages are just because of the increasing population and improved living standard. The solution of these problems is to increase the power generation and decrease the power losses. Any increase in the generation demands new transmission lines which require high capital investment. Although the existing transmission networks are being operated near to their rated capacity yet there is some flexibility in increasing the power handling capacity of the existing transmissions lines. The FACTS are power electronic based semiconductor devices used to enhance the power

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handling capability of the transmission lines [2]. The main capabilities of FACTS devices are to control the flow of power, reactive power compensation and voltage control. The installation of a new electrical network or extending the existing electrical network requires a high capital cost. The FACTS controllers save this capital by improving the constraints of the power system [3]. The FACTS controllers utilize the existing electrical network to its maximum capacity. In past VAR generators were connected to improve the voltage profiles of the electrical networks. Thus these VAR generators actually improve the performance of the electrical network. In different contingency conditions, the FACTS devices can be used to improve the static voltage stability margin of the system. The loading margin of the transmission line can be increased to its maximum capacity by the use of UPFC (Unified Power Flow Controller) [4]. The SVC (Static Var Compensator) and STATCOM (Static Compensator) show better performance in terms of improving the voltage profile and reduction of losses of the transmission line [5]. Although the shunt capacitors serve the same purpose and is less expensive but has rare use because of its operating time. A substation is used to transport the electric energy from a producer A to load Centre-B located at a specific distance. The consumer can be supplied through a number of transmission lines. The problem of uncontrolled power flows between the transmission lines occurs in these types of systems. Moreover, the transmission lines are loaded unevenly under these conditions. The active power can be regulated in the power system through PSTs (Phase Shifting Transformers) [6].

The voltage instability in a power system is caused by the imbalance of reactive power. When an electrical system tends to approach its operating limits the loss of real and reactive power increases rapidly. Thus in order to obtain the voltage stability, the reactive power must have to be supplied locally and adequately. The applications of FACTS controllers enhance the voltage stability and loading margin of the system. The addition of UPFC at a weakest bus of the power system improves the voltage stability and loading margin [7]. The FACTS controllers have a strong effect on static voltage stability in power systems. The voltage stability and loading margin of an electrical network can be increased by the application of FACTS controllers [8].

The selection of the most suitable FACTS device to control the flow of active and reactive power depends upon the performance analysis of different FACTS devices. The application of FACTS controllers for congestion management and voltage support improves the stable operation of the power system. The voltage level can be maintained at its reference value (1 pu) by the use of devices like STATCOM and UPFC [9].

The installation of FACTS controllers solves the problems of uneven power flow and transient and dynamic voltage instability. The application of these devices locally is limited by their systematic control and capital cost. The above-mentioned problems can be solved locally and economically by using the combination of ESS (Energy Storage Systems) and FACTS devices [10].

The transient stability control ensures the stable operation of the power system in the event of large disturbances. The transient stability of the power system can be improved by applying FACTS controllers [11]. The advancements in the field of

FACTS technology had introduced many different configurations to control the power flow.

The UPFC can improve the power quality of the system [12]. In order to improve the power quality performance of UPFC with PI controller and with conventional system is investigated. The UPFC with PI controller improves the power quality of the power system. The active and reactive power can be controlled effectively by the use of UPFC. The benefits of applying FACTS controllers in AC networks are power flow control, stability and loading margin. The power system performance characteristics can be improved by using several FACTS controllers [13].

The high initial costs of FACTS controllers limit their applications locally. However, FACTS devices had provided the most reliable and efficient solution keeping in view the limits of the power system [14]. The benefits of FACTS controllers in the electrical utilities is of much importance. The problems of high losses by using advanced FACTS controllers must also be considered.

The flexible and dynamic control of electrical networks is made possible through FACTS devices [15]. The effectiveness of FACTS devices can be examined by applying them to the system with different scenarios. The semiconductor technology can be summarized in the development of these devices. In addition, major real-world installations and utility experiences with and without FACTS controllers can be also examined to know the importance of these devices. The power flow in electrical systems can also be optimized through FACTS controllers.

The FACTS Devices improve the transient stability by reducing the reactance of lines and also increases the power flow capacity of transmission lines [16]. They provide the reactive power support to the system. In future, the IGBT (Insulated-Gate Bipolar Transistor) controlled devices will be used in practical applications in high voltage power networks.

The UPFC combines the functions of several FACTS devices and is capable of implementing voltage regulation, series compensation, and phase angle regulation at the same time, thus realizing the separate control of the active power and reactive power transmitted simultaneously over the line [17].

FACTSs and voltage-source converters, with smart dynamic controllers, are emerging as a stabilization and power filtering equipment to improve the power quality. Also, distributed FACTSs play an important role in improving the power factor, energy utilization, enhancing the power quality, and ensuring efficient energy utilization and energy management in smart grids with renewable energy sources [18].

A novel HEUPFC (Hybrid Electromagnetic Unified Power Flow Controller) is composed of a larger capacity ST and a smaller capacity UPFC is discussed. This HEUPFC can control the bulk ST power flow with coarse step changes and precise UPFC control, and precisely control the active and reactive power flow [19]. A novel structure of the UPFC (Unified Power Flow Controller) proposes a load flow method for power systems with this kind of UPFCs. The equivalent model of the novel UPFC is analyzed and then a load flow method is proposed based on the power injection model and Newton-Raphson algorithm. This method can deal with the UPFC of both the novel structure and the conventional structure [20]. The cascaded control scheme for MMC-UPFC based on voltage limit control and symmetric component decoupling to balance the ac current of transmission line is proposed. An appropriate transformer connection for MMC-UPFC, the negative- and zero-sequence currents are suppressed by the corresponding inner current loops [21]. The impact of UPFC's various control strategies on the convergence of power flow calculations and propose a control strategy for converting constant power control to constant variable control during the iterative process [22].

## 2. PROPOSED MODEL

The most of loads of power system are inductive in nature and they draw reactive power along with active power from the supply source. In order to obtain better system results we have to maintain the adequate supply of both active and reactive power. The modern electrical power system comprises of number of generators, transmission lines, transformers and loads. Some transmission systems are more loaded than their rated capacity because of the increase in power demand. The power transmission lines operate at different voltage levels varying from 110-800 KV (66-500 KV in Pakistan). The voltages of the power transmission lines are kept high to reduce the losses in transmission lines. While the distribution systems operate below 100 KV because of security and convenience associated with the supply of electric power to domestic and industrial loads. The power transmission lines are highly interconnected because of the following economic advantages:

- A tie line control is used to share the generating reserves for interconnected electric power transmission lines.
- The transformers increase or decrease the voltage levels according to required conditions and power transmission lines can be operated at different voltages.
- The AC lines have inherent power flow control as the power flow is determined by the power at the sending end or receiving end. Let us assume a lossless transmission line and the line charging as negligible. The transmission line Equation (1) can be given as

$$P = \frac{V_1 V_2}{X}\sin(\theta_1 - \theta_2) \qquad (1)$$

In Equation (1), "$V_1$" and "$V_2$" are the sending end and receiving end voltages,"$\theta_1$" and "$\theta_2$" are the voltage angles while "X" is the reactance of the line. In case of disturbances such as line outage, line trip, generator outage or sudden increase in load, we have to change the flow of power to ensure system reliability and security under these dynamic conditions. The flow of power is changed by the FACTS devices used in the system. Moreover, the flow of power in AC transmission line is controlled to enhance power system transmission capacity.

As the load increases bus voltage drops and cross the minimum allowable limit, as a result the buses which are operating closer to the limits have a tendency to drop their voltage below 0.95 pu. which is their limiting value. We have to cope with this problem by using FACTS devices. The FACTS devices can set a reference voltage level and maintain it throughout the system. Moreover, in case of the contingency of one line, other lines can become overloaded.

The voltage at the buses changes and line currents are redistributed throughout the network when a transmission line is switched onto or off the system through circuit breakers. In order to predict new steady-state bus voltages and line currents, a technique of contingency analysis is used. The system planners and operators are more concerned about overloads and under voltages rather than finding the exact values of voltage and current. Due to this reason, large-scale network models used for contingency evaluation are not required to be exactly like the models used for fault calculations. In this case, we have checked various contingency conditions and their effect on bus voltages and currents and the application of our devices to improve them.

We can maintain power flow across lines by fixing these devices. They will only allow the reference power to flow, diverting the remaining power to flow from under-loaded lines. The proposed model shows that when these problems come in our selected network and then the FACTS devices help us to solve these problems.

The UPFC can be used to control the flow of active and reactive power in transmission system connected to the high voltage side of the network and control the amount of reactive power supplied to the line at the point of installation. When a line is switched onto or off the system through the action of circuit breakers, the line currents are redistributed throughout the network and bus voltages is changed. The new steady-state bus voltages and line currents can be predicted by the contingency analysis program.

The large-scale network models used for contingency evaluation, like used for fault calculations, are not very precise. The system planners and operators who get huge amount of data in a short time period are more concerned in knowing if overload levels of current and out-of-limit voltages exist instead of finding the exact values of these parameters. The simulation of the whole electrical network is carried out in MATLAB, but in MATLAB the load flow analysis does not work with FACTS devices, so to cope with this problem we have to develop our own load flow tool in MATLAB for more accuracy.

We have implemented UPFC from FACTS technology on a 4-bus network. The data obtained from Network including line impedances, transformer parameters, load demand and generation is shown in Fig. 1. The UPFC can provide reactive power to the system because it consists of STATCOM which has the ability to generate reactive power according to the demand of network. The power grid consists of two power generation substations and one major load centre at bus B3. The first power generation substation (M1) has a rating of 2100 MVA (L3). UPFC is connected between bus number 1 and 2. Without UPFC, Active Power of bus number two was 663 MW and reactive power was -122.3 MVAR. The generation substation M2 is also connected to the load by a 50-km line by setting the reference of the Active and Reactive power of M1 connected to this load by two transmission lines L1 and L2. L1 is 280-km long and L2 is split into two segments of 150 km where the active and reactive power is absorbed by the load which is a function of the system voltage. The total length of the line L1 is 280 Km, line L2 is 300 Km and line L3 is 50 Km. The UPFC measurement block has set the parameters of Active power, reactive power and the phase and magnitudes of the voltage. Both the generators are also connected with the transformers. This system is implemented on 4-bus system and it was concluded that the power transfer capacity of the lines has been increased because of installing FACTS devices. This can also be implemented on whole NTDCL (National Transmission & Dispatch Company Limited) network throughout the Pakistan.

## 3. RESULTS AND DISCUSSIONS

The generating substation M1with the rating 2100 MVA, and the generating station M2 has a rating of 1400 MVA. The load centre of approximately 2200 MW is modelled using a dynamic load. The UPFC transfers active power from one line to the other line according to the reference which is set for active power per kilometre. It is noted that UPFC does not produce active power in bus 2. The UPFC sets Active power of bus 2-763MW and maintains Reactive Power to -122.3 MVAR. However, the shunt compensation devices in the UPFC supply the reactive power to the system. The UPFC basically controls the flow of active power. In overload conditions, it allows the flow of active power according to a reference power thereby minimizing the contingency which is set for a line and the network diagram. The results without using UPFC and with using UPFC is shown in Tables 1 and Table-2.

The active power is being set to 763 MW, however the other parameters are changed simultaneously as shown in Table 3.

The active power has a relationship with the voltage angles and the reactive power is changed by changing the voltages of the lines. It is shown in Table 3 that the active power of the bus 1 was 1337 MW without UPFC and it is changed to 1331 MW by incorporating the UPFC between the lines. The reactive power of the bus 1 without UPFC was -233 MVAR which was changed to -294 MW simultaneously. The changes in the bus voltages without using UPFC and with using UPFC is shown in Figs. 2-3 respectively. The increase in the active power of the Bus 2 from 663 MW to 763 MW is shown in Table 3. It is also observed that the reactive power at bus 2 is the same with UPFC and without UPFC as shown in Table 4.

TABLE 1. SIMULATION RESULTS WITHOUT UPFC

| Bus | Active Power (MW) | Reactive Power (MVAR) | Voltages (V) |
|---|---|---|---|
| 1 | 1337 | -233 | 1.006 |
| 2 | 663.5 | -122.3 | 1.006 |
| 3 | 988.9 | -29.25 | 1.002 |
| 4 | 563.2 | -40.67 | 1.014 |

TABLE 2. SIMULATION RESULTS WITH UPFC

| Bus | Active Power (MW) | Reactive Power (MVAR) | Voltages (V) |
|---|---|---|---|
| 1 | 1331 | -294.2 | 1.01 |
| 2 | 762.4 | -122 | 0.9925 |
| 3 | 987 | --10.71 | 0.9988 |
| 4 | 460.3 | -15.92 | 1.017 |

TABLE 3. COMPARSION OF RESULTS OF ACTIVE POWERS

| Bus | Active Power(MW) without UPFC | Active Powers (MW) with UPFC |
|---|---|---|
| 1 | 1337 | 1331 |
| 2 | 663.5 | 762.4 |
| 3 | 988.9 | 987 |
| 4 | 563.2 | 460.3 |

TABLE 4. COMAPRISON OF RESULTS OF REACTIVE POWER

| Bus | Reactive Power(MVAR) without UPFC | Reactive Power (MVAR) with UPFC |
|---|---|---|
| 1 | -233 | -294.2 |
| 2 | -122.3 | -122 |
| 3 | -29.25 | --10.71 |
| 4 | -40.67 | -15.92 |

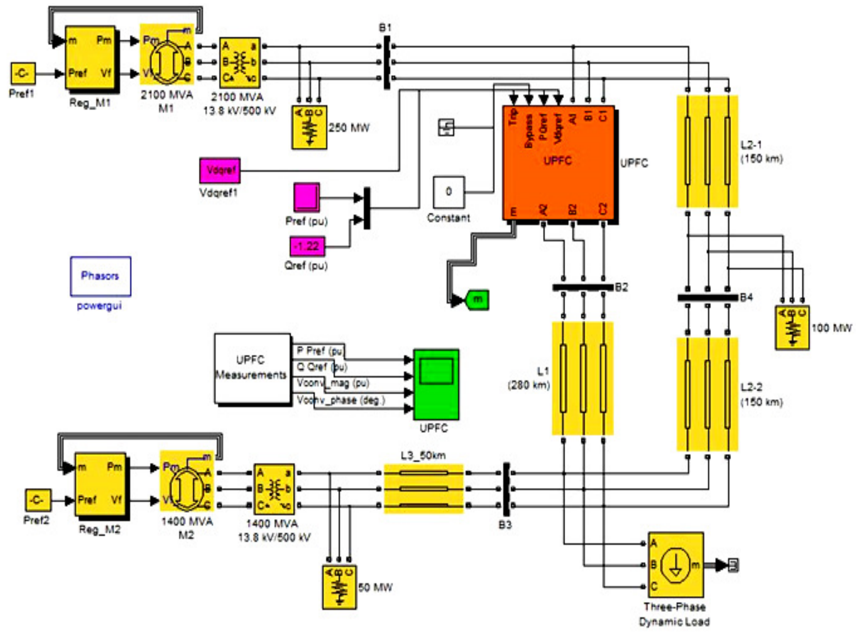


FIG. 1. NETWORK DIAGRAM ON SIMULINK

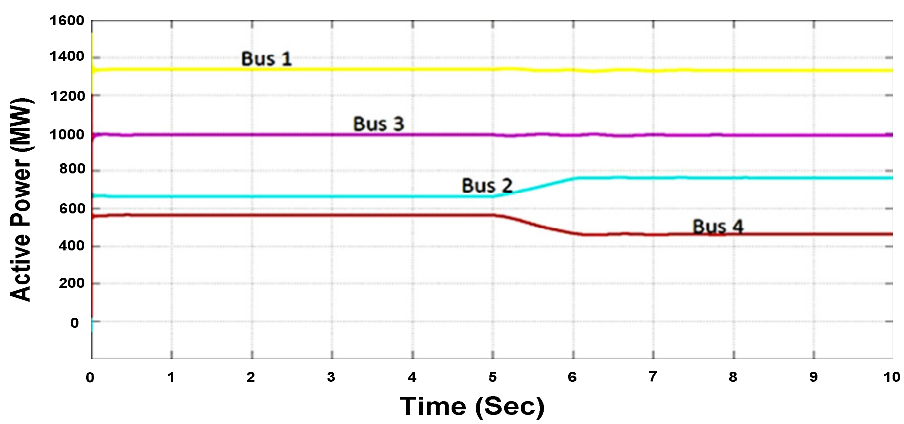


FIG. 2. ACTIVE POWER WITHOUT UPFC

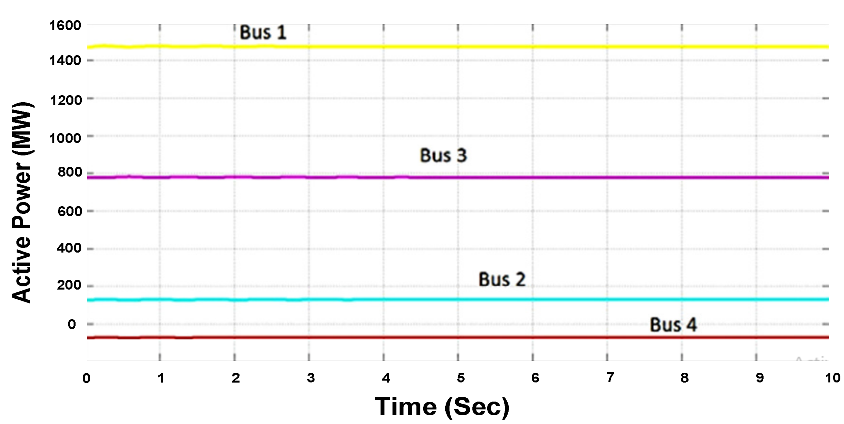


FIG. 3. ACTIVE POWERS WITH UPFC

| TABLE 4. COMAPRISON OF RESULTS OF REACTIVE POWER | | |
|---|---|---|
| Bus | Reactive Power(MVAR) without UPFC | Reactive Power (MVAR) with UPFC |
| 1 | -233 | -294.2 |
| 2 | -122.3 | -122 |
| 3 | -29.25 | --10.71 |
| 4 | -40.67 | -15.92 |

This shows that employing the UPFC doesn't change the reactive power of the concerned bus. However, reactive power is transformed into another bus to change the active powers of the buses.

The Bus voltages in the system have a dynamic range of 10%. If the voltage drops below 0.90 pu or increase above 1.10 pu the system operation will be disturbed. The shunt compensating FACTS devices maintains the voltage range by supplying or absorbing the reactive power. The results of reactive power without UPFC and with UPFC are shown in Figs. 4-5 respectively. Moreover, the active powers are changed at the expense of voltage angles. The controlling of voltage angles at sending end and receiving end of the transmission lines serves this purpose.

## 4. CONCLUSION

The flow of power can be controlled in a network through FACTS devices. The basic quantities of power system like Active Power, Reactive Power and voltages etc. can be controlled by using UPFC. The power and voltages of the system can be also adjusted simultaneously according to network demand by using UPFC. The Incorporation of FACTS devices improve the stability of the power system. In Pakistan's WAPDA system, the rapid increase in load and less generation is increasing demand and supply problems thought the country. The government has planned to increase the generation capacity but the supply companies are facing the problems of line load-ability, environmental constraints, power limits etc.

The series controlled compensation provided by FACTS can provide an efficient solution to this problem. With the use of conventional compensation devices, we can enhance the power transfer capability of the existing lines and hence we can overcome with the problem of line load-ability issues. With the application of FACTS, we can also provide an additional feature of stability even in post contingency conditions for both transient and steady-state stability issues. The need of the time for Pakistan transmission companies is to install FACTS devices because it will be beneficial in terms of cost as well as lesser environmental issues.

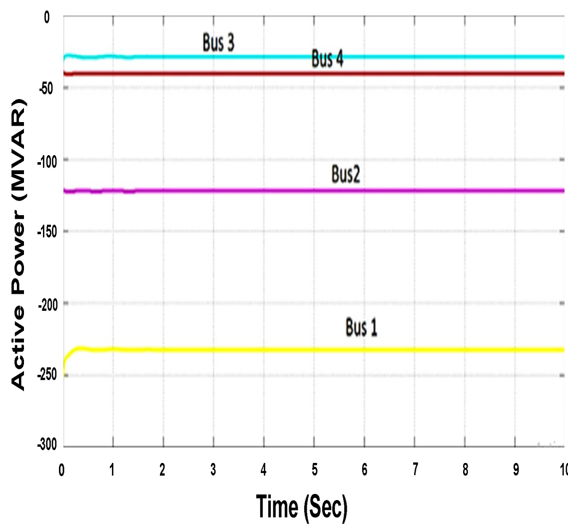


FIG. 4. REACTIVE POWERS WITHOUT UPFC

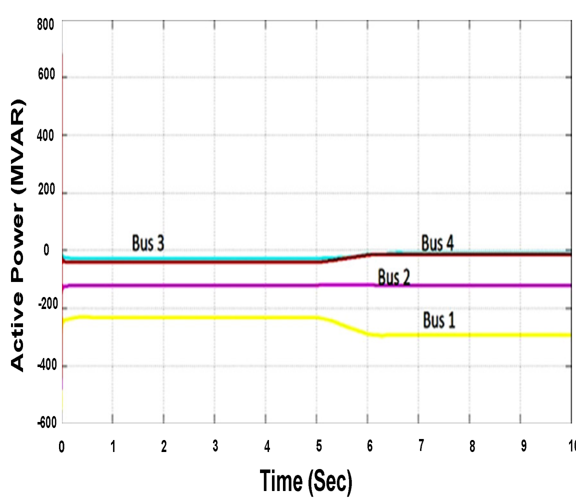


FIG. 5. REACTIVE POWERS WITH UPFC

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