IMPLEMENTATION OF FUZZY LOGIC WITH UNIFIED POWER FLOW CONTROLLER FOR THERMAL POWER STATION IN INDIA

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Abstract: *A Unified Power Flow Controller (UPFC) is an electrical device for providing fast-acting reactive power compensation on high-voltage electricity transmission networks. The UPFC is a combination of a static synchronous compensator (STATCOM) and a static synchronous series compensator (SSSC) coupled via a common DC voltage link. UPFC is used to control the power flow in the transmission systems by controlling the impedance, voltage magnitude and phase angle. The objective in this paper is to maintain a constant voltage profile irrespective of changes in the load. This is achieved either by injecting or absorbing the reactive power. In this paper for implementing fuzzy logic approach two inputs (error voltage and capacitor value) are taken and the "Inverter Pulse" which is used for UPFC power electronic device to control the voltage is taken as an output. Case studies have been performed for National Thermal Power Station (NTPS) of a practical system in India. Simulation work in MATLab has been carried out with fuzzy controller and UPFC. It is observed that with Fuzzy and UPFC the reactive power requirement is less and a constant voltage of 420 KV has been achieved throughout the day.*

Key Words: *Power System, UPFC, FACTS, Fuzzy Controller, Reactive power Control.*

1. Introduction

Modern power systems are becoming increasingly stressed because of growing demand. It is well known that the power flow through transmission line is a function of line impedance, magnitude and phase angle of bus voltage. A UPFC is a member of FACTS devices. The most common FACTS devices are the STATCOM and the SSSC. STATCOM can either generate or absorb reactive power to provide voltage regulation. SSSC injects in series with the transmission line a voltage with controllable magnitude and phase angle controlling the reactive power flow.

UPFC consists of one STATCOM, connected in shunt with the transmission line, and one SSSC connected in series with the transmission line, connected to each other by a common DC link. The series converter injects a voltage in series with the system voltage through a series transformer. The power flow through the line can be regulated by controlling voltage magnitude and angle of series injected voltage [1]. The shunt converter also has a capability of independently supplying or absorbing reactive power to regulate the voltage of the AC system. However, both the series and shunt converters can independently exchange reactive power [1-2]. The fuzzy logic controllers are used to generate the required inverter pulses which are used to control the UPFC power electronic based devices which can control independently both real and reactive power flows on a transmission corridor [3].

The first voltage source converter known as STATCOM injects an almost sinusoidal current of variable magnitude at the Point of connection. The second voltage source converter known as SSSC injects a sinusoidal voltage of variable magnitude in series with the transmission line. The real power exchange between the converters is affected through the common DC link capacitor [4-5]. UPFC is the most versatile and powerful device. It has the ability to control three parameters, i.e. terminal voltages, line impedance, and phase angle between two buses, either simultaneously or independently. It is able to efficiently control the plant over a wide range of operation conditions [6-8]. The use of fuzzy logic is very attractive for this case where a non linear system has to be controlled and several uncertainties are present [3]. In this paper, comparison has been made with the conventional controller and fuzzy controller. Also, it has been compared with and without UPFC.

The organization of this paper is that the introduction is presented in section 1. Fuzzy fundamentals are explained in section 2. The reactive power control is dealt in section 3. UPFC is described in section 4. The power system model is developed in section 5 with the required diagram. In section 6, the case study, simulation and results are dealt. Finally, in section 7, the conclusion is presented.

2. Fuzzy Fundamentals

Fuzzy systems are quite like the conventional systems but the main difference is that the fuzzy systems contain fuzzifiers which convert input into their fuzzy representations and defuzzifiers which convert the output of the fuzzy process logic into the crisp solution variables. The underlying power of fuzzy set theory is that it uses linguistic variables rather than quantitative variables to represent imprecise concepts. IF-THEN rules are the fuzzy rules. These rules can be extracted from common sense, intuitive knowledge, survey results, general principles and laws and other means that reflect the real world situations [9].

In the fuzzy logic approach, the preference calculation is based on the entire profile of the membership functions rather than base on point values. Therefore fuzzy expert system approach is chosen as one of its area of artificial intelligence approach for solving the power system problems in this paper. The proposed fuzzy approach uses voltage-stability indexes at the load buses as the post-contingent quantities, in addition to real power loadings and bus-voltage violations to evaluate the network contingency ranking. In Power systems many uncertainties arises due to aging of machines, unforeseen load switching, fluctuations, losses in transmission lines, voltage and frequency instability, change of weather conditions. These uncertainties arise in power system problems because power systems are large, complex, geographically widely distributed and influenced by unexpected events. These facts make it difficult to effectively deal with many power systems problems through strict mathematical formulations alone. Fuzzy logic technology has achieved impressive success in diverse engineering applications ranging from mass market consumer product to sophisticated decision and control problems.

3. Reactive Power Control

A substantial increase in loads have taken place without a corresponding increase in transmission capability, it is becoming more and more difficult for the operator to determine the most economical and secure scheduling of reactive power control variables. The objective of reactive power control in a power station is to minimize the real power loss which will reduce the operating cost and improve the voltage profile.

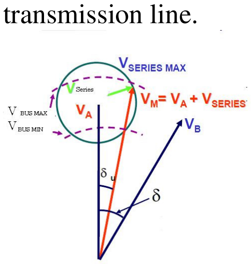
In order to maintain constant voltage profiles on various conditions of load and system configuration changes, power system are equipped with a lot of voltage controlling devices such as capacitor, UPFC for supplying reactive power [10].

If the system voltage deviates from that value, the performance of the device suffers and its life expectancy drops. Thus the controlling of the voltage level on power systems is a basic requirement. The reactive power planning is one of the more complex problems as it requires the simultaneous minimization of two objective functions. The first objective deals with the minimization real power in reducing the operating cost and improving the voltage profile. The second objective minimizes the allocation cost of additional reactive power sources. The reactive power is either injected or absorbed to maintain a constant voltage on varying load condition [11]. The required reactive power to be injected or absorbed is judged by UPFC.

4. Unified Power Flow Controller

The UPFC consists of two solid-state voltage source inverters (VSIs) connected by a common DC link that includes a storage capacitor. The first one is a STATCOM and the second one is a SSSC. The UPFC can be used to control the flow of active and reactive power through the line and to control the amount of reactive power supplied to the line at the point of installation [12].

The shunt inverter is used for voltage regulation at the point of connection injecting an opportune reactive power flow into the line and to balance the real power flow exchanged between the series inverter and the transmission line. The series inverter can be used to control the real and reactive line power flow inserting an opportune voltage with controllable magnitude and phase in series with the transmission line.



Without UPFC

$$P_s = \frac{V_A \, V_B \sin(\delta)}{X}$$

With UPFC

$$P_s = \frac{(V_A + V_{SERIE}) \, V_B \sin(\delta - \delta_u)}{X}$$

X = Line Reactance

Fig. 1. Vector diagram for with and without UPFC

The shunt inverter is operated in such a way as to draw a controlled current from the AC bus. The current reference is chosen to satisfy the shunt reactive power reference and to provide any real power needed to balance the real power of the series inverter (please refer Figure 1). The series inverter controls the magnitude and angle of the voltage injected in series with the line. This voltage injection is always intended to influence the flow of power on the line. The voltage levels without UPFC and with UPFC can be calculated by using the formulae given in Figure 1. The series voltage can be determined in different ways. In general, the shunt inverter will be operated in automatic voltage control mode and the series inverter in automatic power flow control mode [13].

5. Power System Model

The objective of this paper is to minimize real power losses, reactive power requirements and to improve the voltage profile of the given system which will reduce the operating cost. To achieve

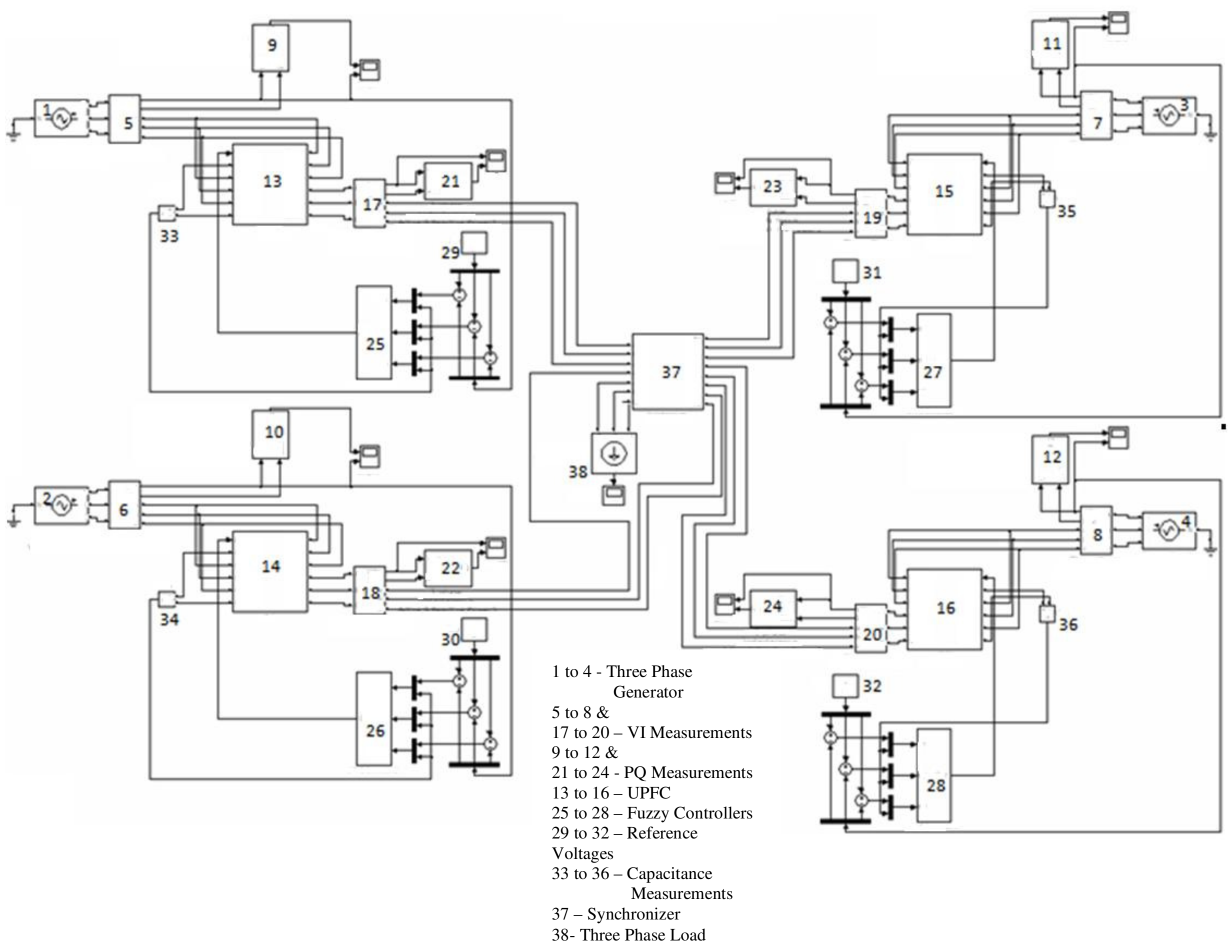


Fig.2. Power System Model for a Thermal PowerStation with Four Generators

this, UPFC is used in the system to control the reactive power and to maintain constant voltage profile [14]. As the power systems are becoming more complex, it requires careful design of the new devices for the operation of controlling the power flow in transmission system, which should be flexible enough to adapt to any momentary systems conditions. Modern power systems are becoming increasingly stressed because of growing demand. It is very precious in keeping the system voltage stable [15]. The proposed power system model of a Thermal Power Station is shown in detail in Figure 2. At present in one of the national thermal power station the practical data are collected and analyzed. In this paper, it is proposed to add the Fuzzy logic controller, UPFC by replacing the conventional controller.

In this practical power system there are four generators with the necessary V, I measuring devices. It has the required PQ and capacitance measuring devices. A synchronizer is connected for parallel running all the four generators. All the four generators are connected to the load. For a particular day of 24 hours the real power (MW) and reactive power (MVAR) values are taken from the practical thermal station for all the four generators (Unit 1, Unit 2, Unit 3 & Unit 4) (Please refer Table 1). The voltage level for the 24 hours is taken. The practical system values which are shown in Table 1 are without UPFC. In this paper, the simulation is carried out with UPFC and comparison is done with and without UPFC model. These values are shown in Table 1.

Table 1: Table showing the details of Real Power (MW), Reactive Power (MVAR), and voltage without and with UPFC for the four Generators of Thermal Power Station.

Time In Hrs.	**Unit 1**			**Unit 2**			**Unit 3**			**Unit 4**			**420 KV**	**420 KV**
	MW	**MVAR**		**MW**	**MVAR**		**MW**	**MVAR**			**MVAR**			
		Without UPFC	**With UPFC**		**Without UPFC**	**With UPFC**		**Without UPFC**	**With UPFC**	**MW**	**Without UPFC**	**With UPFC**	**Without UPFC**	**With UPFC**
1	201	19	6	195	16	5	202	18	7	207	30	10	418	420
2	195	16	-6	190	3	-5	193	8	-7	201	30	-10	422	420
3	200	14	-14	196	8	-13	202	14	-15	208	26	-18	426	420
4	204	6	-14	196	7	-13	201	14	-15	204	26	-18	426	420
5	199	14	-10	193	12	-9	199	16	-11	202	26	-14	424	420
6	195	16	-8	194	15	-7	199	18	-9	200	26	-12	423	420
7	196	15	-12	191	19	-11	195	26	-13	200	33	-16	425	420
8	202	23	0	195	23	0	201	27	0	204	37	0	420	420
9	197	23	6	202	22	5	202	26	7	204	35	10	418	420
10	197	21	10	203	16	9	202	20	11	205	29	14	416	420
11	195	21	10	203	20	9	203	24	11	204	33	14	416	420
12	195	15	10	205	14	9	208	22	11	204	27	14	416	420
13	195	16	6	207	16	5	206	20	7	203	28	10	418	420
14	196	18	8	206	14	7	207	20	9	205	28	12	417	420
15	196	19	8	205	17	7	207	22	9	204	30	12	417	420
16	196	21	0	205	20	0	207	24	0	203	33	0	420	420
17	195	23	6	206	21	5	207	26	7	205	34	10	418	420
18	194	16	4	194	16	3	201	19	6	196	28	8	419	420
19	199	16	4	201	19	3	203	23	6	204	32	8	419	420
20	202	21	8	205	14	7	204	20	9	202	27	12	417	420
21	203	16	8	206	16	7	203	20	9	203	27	12	417	420
22	202	16	6	206	14	5	203	18	7	201	26	10	418	420
23	201	21	-4	206	19	-3	202	23	-5	200	31	-8	421	420
24	199	19	-4	197	20	-3	202	23	-5	195	33	-8	421	420

6. Case Study, Simulation and Results

6.1 Case Study

Case study has been carried out for the practical system of the National Thermal Power Station in India. In this power generating station, there are four generators each of 210 MW capacity. The reactive power controllers used to maintain a constant voltage of around 420 KV are considered as conventional controllers. Presently, the PID controllers are used to control the reactive power requirements. These PID controllers are costly and inaccurate. It is observed from this that the reactive power requirements are very high and there is a fluctuation in the voltage level.

In this research work, the fuzzy logic with UPFC has been considered as a main controller to replace the existing PID controller. The simulation work in the MATLAB software package with this proposed controller has been carried out and the values are recorded. The reactive power values (MVAR) and the output voltage (KV) is taken as a base value in this paper (Please refer Table 1). In the FLC there are two inputs. Input 1 is the error voltage which is difference between the desired value and the actual value and input 2 is capacitor value which is required to inject or absorb the reactive power requirement. These two inputs are feed into the FLC and the output which is the generation of Inverter pulse is achieved (please refer fig. 3). One of the triangular membership functions for input and output and their 3D views are shown in Fig. 4 and 5. This inverter pulse is used to turn on the power electronic devices used in STATCOM, SSSC of the UPFC. The UPFC is FACT device used to control the reactive power injection or absorbsion by which the bus bar voltage is maintained as constant (420 KV) for all the 24 hours of the day (Please refer Table 1).

6.2 Simulation and Results

In this table 1, there are four generators each 210 MW (unit 1, 2, 3, 4). The real power generated (MW) are shown for all the four units for 24 hours of a day. The reactive power values (MVAR) and the voltage value (KV) without UPFC are also shown in this table. These values are obtained for the practical thermal power station for a particular day with the conventional controller. The results of proposed controller and the existing controller values are shown in the Table 1.

From the Figures 6, 7, 8 & 9, it is evidenced that the reactive power requirement without UPFC is higher and with the implementation of UPFC the reactive power requirement is much less. It is also noticed that the voltage is maintained constant (420 KV) throughout the day of 24 hours as evidenced in figure 10. Also, it can be clearly seen that there is a slight deviations in the voltage levels without UPFC. Hence, with the introduction of UPFC in the power system model the voltage is maintained as 420 KV for the whole day of 24 hours.

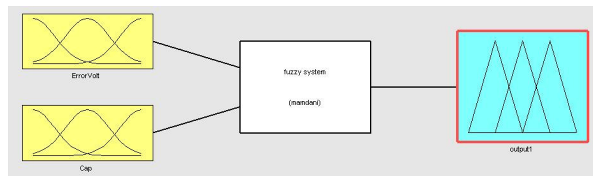


Fig. 3. Fuzzy Logic Controller

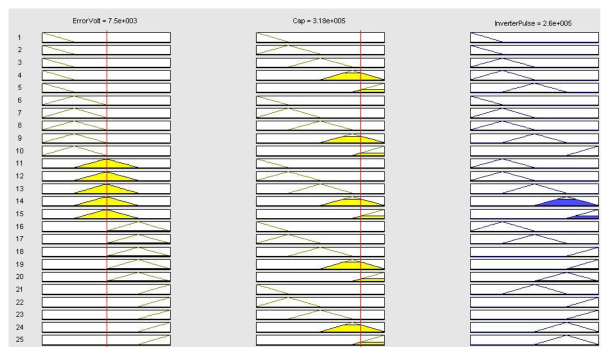


Fig. 4. One sample of Triangular Membership for input and output

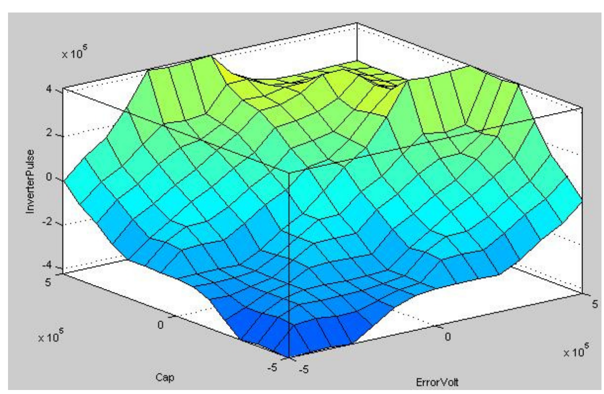


Fig. 5. One sample of 3D View of input and output.

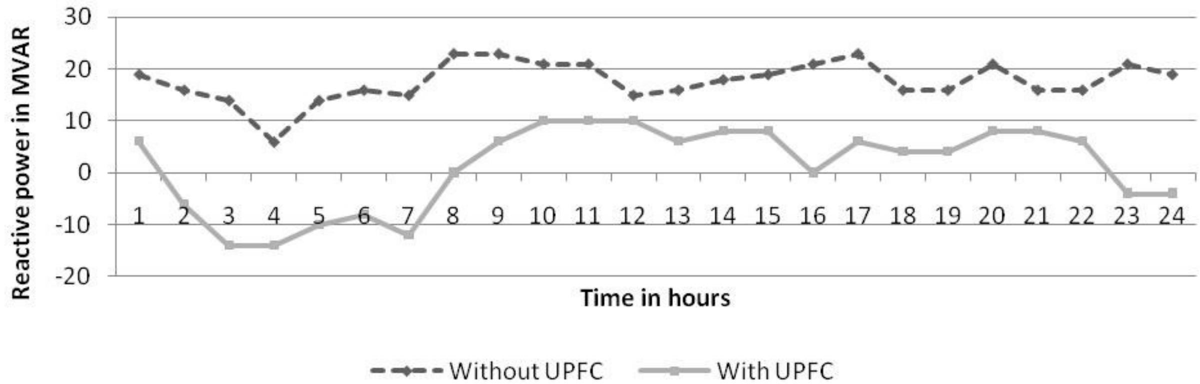


Fig. 6. Reactive Power for 24 hours in Unit 1.

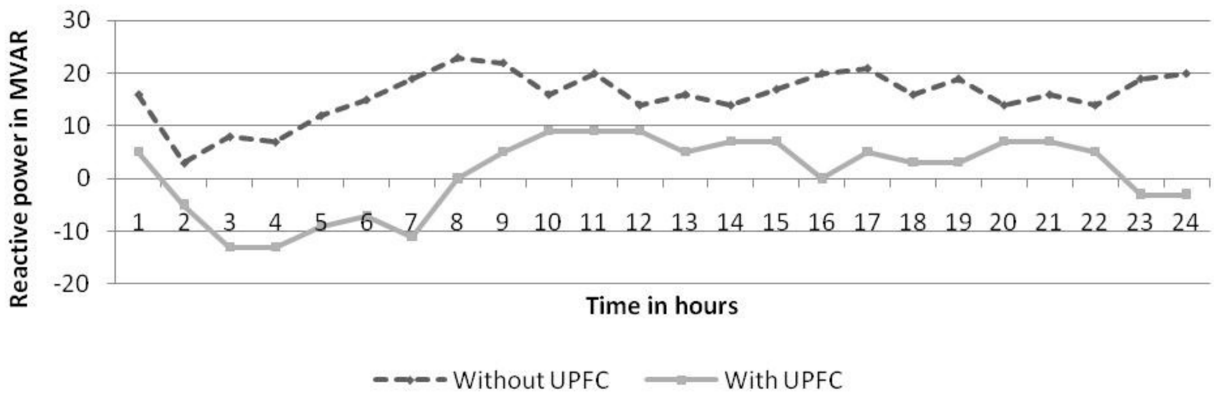


Fig. 7. Reactive Power for 24 hours in Unit II

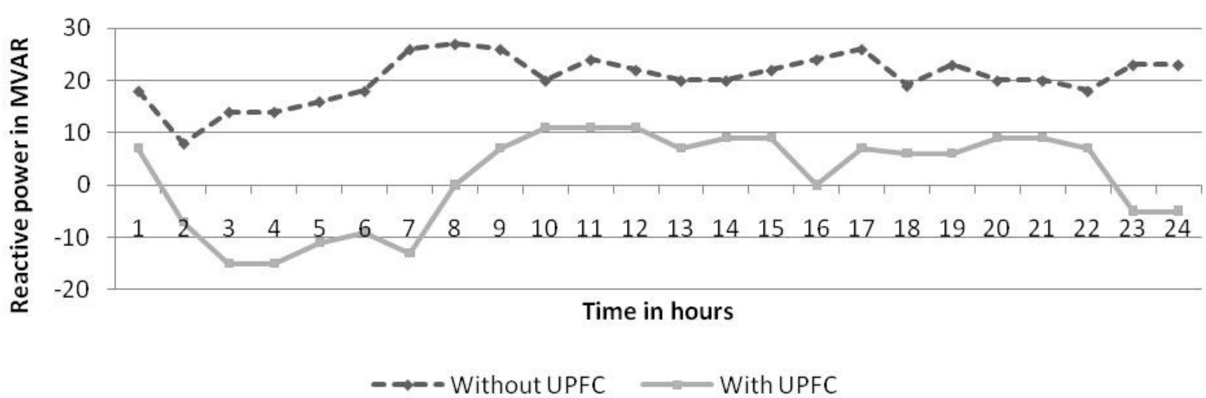


Fig. 8. Reactive Power for 24 hours in Unit III

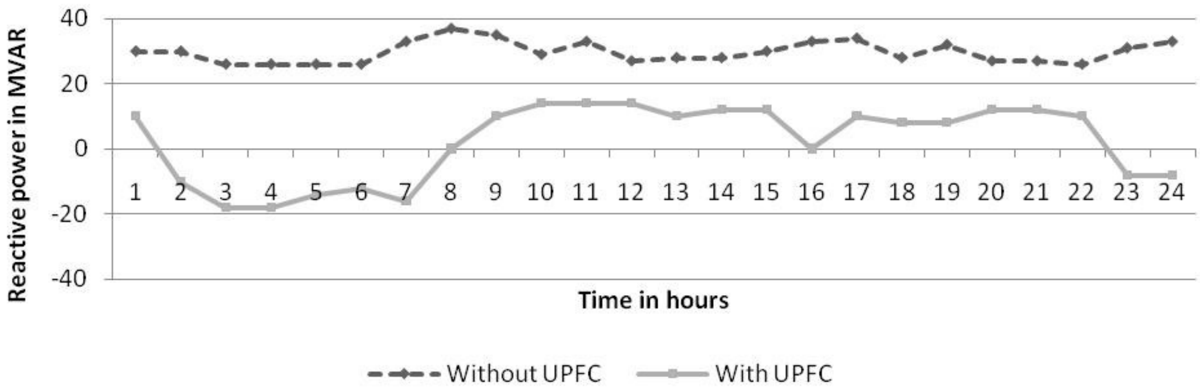


Fig. 9. Reactive Power for 24 hours in Unit IV

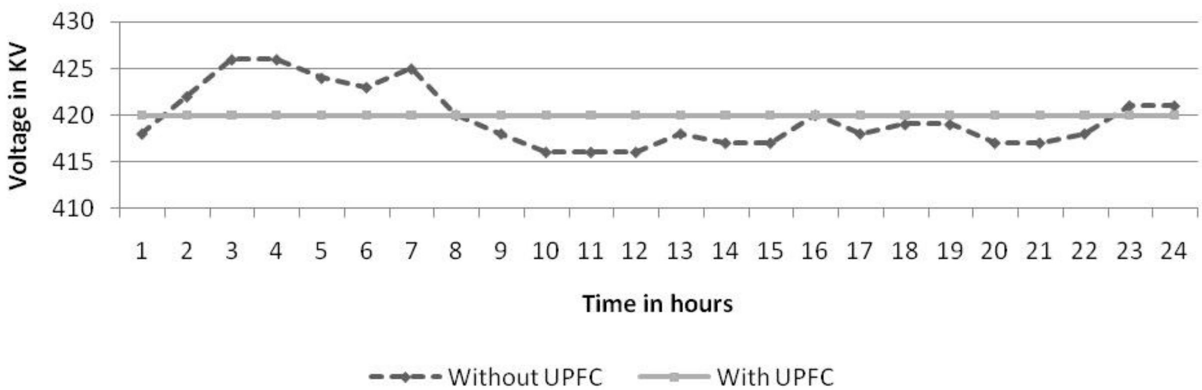


Fig. 10. Voltage level for 24 hours in KV

7. Conclusion

The fuzzy controller and UPFC are used for controlling the reactive power requirement as well as to maintain a constant bus bar voltage at the load bus irrespective of the load changes. The existing conventional controller has been replaced with FLC and UPFC for the simulation work. It has been noticed that the reactive power requirement to maintain a constant voltage in the load bus with UPFC is much lower than without UPFC. With this the reactive power generation is reduced with UPFC which also reduces the cost as well as the power loss. It is also observed that with the implementation of UPFC the voltage is maintained constant as 420 KV throughout the day. In this way, the objective of maintaining a constant voltage of 420 kv for the whole day is achieved.

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