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Fuzzy Based Unified Power Flow Controller to Control Reactive Power and Voltage for a Utility System 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. Fuzzy set theory is a marvelous tool for modeling the kind of uncertainty associated with vagueness with imprecision, and / or with a lack of information regarding a particular element of the problem at hand. In this proposed work the Fuzzy Logic Controller (FLC) is implemented with two inputs as 'error voltage' and 'capacitor values' and the 'inverter pulse' is taken as an output. Case studies have been performed for National Thermal Power Station (NTPS) of a utility system in India. In this three generators each of 210 MW are connected to a load bus of 230 KV system. Simulation has been carried out with FLC and UPFC in MATLAB. These proposed approaches are compared with the existing one and concluded that the reactive power requirement by FLC is lower than the existing conventional controller which is further less with UPFC. Also there is a vast deviation in the voltage with the existing controller and with FLC the voltage is within the range of 230 KV + 5% and with the UPFC it is demonstrated a constant voltage of 230 KV throughout the day of 24 hours.

Keywords: Reactive Power Control, Voltage, UPFC, FLC, STATCOM, SSSC

Introduction

The reactive power is the latest soul of a power transmission system. It is very precious in keeping the system voltage stable. It is evident that sufficient reactive power reserve is required to maintain terminal voltage at the load bus. The voltage control should be carried out on line against a possible disturbance, particularly in a heavily loaded system. Such control should be fast for on line applications, flexible for changing system conditions and easy to comply with operators decision making logic. As the voltage profile of electric power system could be constantly affected, either by the variations of load or by the change of network configuration, a real time control taken by the utility is required to fast alleviate the problem. 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. To control the reactive power flow over the main transformer shunt capacitors (SC) are usually installed at the low voltage bus of the sub station. The secondary bus voltage of a main transformer at the distribution sub-station is usually regulated by an Automatic Voltage Regulator (AVR) through the action of Load Tap Changing (LTC), transformers. It is observed that the voltage reactive power control has become particularly important concern for utilities transmitting power over long distances.

Reactive Power Control

One of the important operative tasks of power utilities is to keep voltage within an allowable range for high quality customer services. The purpose of reactive power / voltage control in a generating station is to control the reactive power flow to control the voltage on the low voltage bus [1]. 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[2]. If the system voltage deviates from that value, the performance of the device suffers and its life expectancy drops.

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. To maintain the voltage level at various buses either the reactive power is injected or absorbed. Electric power load varies from hour to hour and voltage can be varied by change of the power load. To maintain constant voltage profile, the reactive power control is needed. If the voltage of the bus is more than the specified level then the reactive power from that bus is to absorbed. On the other hand, if the voltage level is lower than the required level than the reactive power has to be injected to that bus. This is known as the reactive power control. Power utility operators in control centres handle various equipments such as generators, transformers. static condenser, shunt reactor, UPFC etc., so that they can inject / observe reactive power and control the voltage directly in target power system in order to follow the load change.

Fuzzy Fundamentals

The mathematical formulations of real-world problems are derived under certain restrictive assumptions and even with these assumptions, the solutions of large-scale power system problems are not trivial. 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. 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[3]. The fuzzy rule approach is designed to closely describe the input, output relationship of the actual problem by using linguistic terms. Fuzzy logic membership functions and fuzzy rules are designed to provide a simple technique to directly implement experience and intuition into a computer program. This approach is much closer to people’s decision making process in real life.

The relationship can have significant interactions and non-linearities. Fuzzy logic membership functions and fuzzy rules are designed to provide a simple technique to directly implement experience and intuition into a computer program. In the fuzzy logic approach, the preference calculation is based on the entire profile of the membership functions rather than base on point values. This approach is much closer to people’s decision making process in real life. 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.

Unified Power Flow Controller

The introduction of UPFC in power system improves the stability and it is one of the crucial factors for effective modern power systems. Effective means for controlling and improving power flow is done by installing fast reacting devices such as UPFC [4]. The optimal power flow problem is used to minimize the overall cost functions, which include the total active and reactive production cost function of the generators and installation cost of UPFCs. The main advantages of UPFC are the ability in enhancing system and increasing the loadability and will treat the solution in modern and deregulated power systems issues. The UPFC is a FACTS device which can control power-system parameters such as terminal voltage, line impedance and phase angle. The primary function of the UPFRC is to control power flow on a given line and voltage at the UPFC bus. This is achieved by regulating the controllable parameters of the system: line impedance, phase angle and voltage magnitude [5].

UPFC is a well-known Flexible AC Transmission System (FACTS) device that can control power-system parameters such as terminal voltage, line impedance 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. 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 uses solid state devices, which provide functional flexibility, generally not attainable by conventional thyristor controlled systems [6], [7]. It uses a pair of three-phase controllable bridges to produce current that is injected into a transmission line using a series transformer. The controller can control active and reactive power flows in a transmission line.

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. The UPFC is a device which can control simultaneously all three parameters of line power flow (line impedance, voltage and phase angle) [8], [9].

Power System Model

The power systems are equipped with a number of voltage controlling devices such as capacitors, Tap setting in transforms and compensations like UPFC etc. 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. The operation of an ac power transmission line, are generally constrained by limitation of one or more network parameters and operating variables [10]. This configuration facilitates free flow of real power between ac terminals of two converters in either direction while enabling each converter to independently generate or absorb reactive power at its own ac terminals.

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. The proposed power system model of a Thermal Power Station is shown as detailed in Figure 1. At present in one of the national thermal power station the practical data are collected and analyzed. In this work, it is proposed to add the Fuzzy logic controller, UPFC by replacing the existing conventional controller. In this practical power system there are three 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 three generators. All the three generators are connected to the load with 230 KV system. For a particular day of 24 hours the real power (MW) and reactive power (MVAR), the voltage (KV) values are taken from the practical thermal station for all the three generators (Unit 1, Unit 2, and Unit 3) as detailed in Table 1. The reactive power (MVAR) and the Voltage (KV) values are taken with FLC and UPFC respectively are recorded as shown in Table 1.

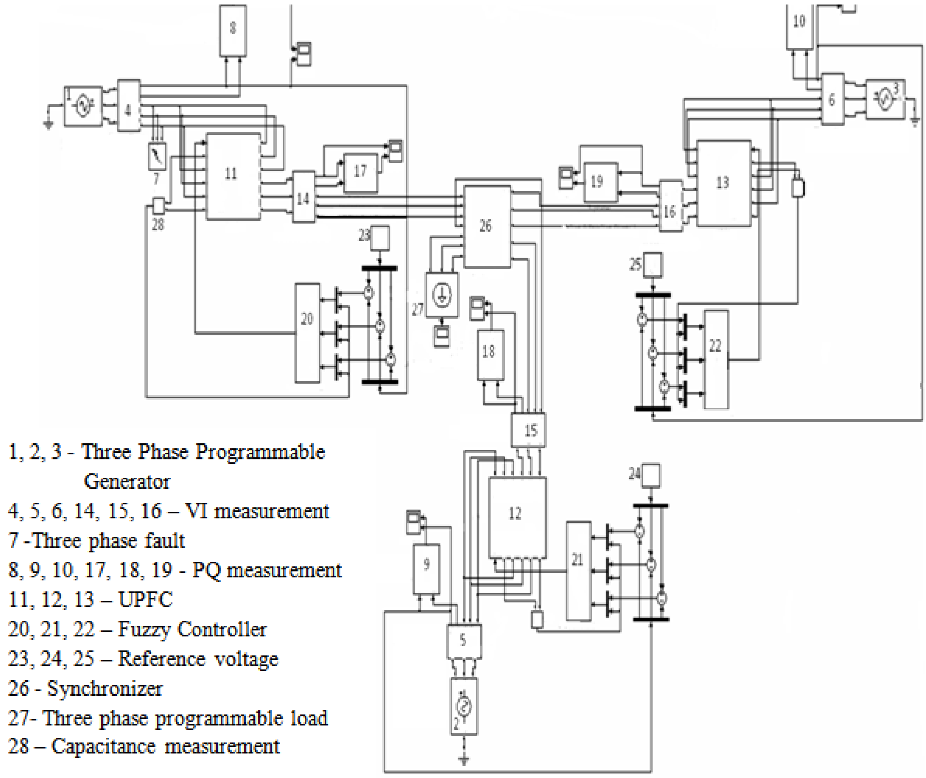


Figure 1: Proposed Thermal Power Station Model

Case Study, Results and Discussions

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 three generators each of 210 MW capacity. The existing reactive power controllers used to maintain a constant voltage of around 230 KV are considered as conventional controllers. The reactive power values (MVAR) and the output voltage (KV) are taken as a base value in this paper as shown in Table 1. The FLC is implemented in the case study for simulation work. 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 to maintain a constant voltage profile. These two inputs are feed into the FLC and the output which is the generation of Inverter pulse is achieved as represented in Figure 2. The triangular membership function for input and output and their 3D views are shown in Fig. 3 and 4. 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 of 230 KV for all the 24 hours of the day as demonstrated in Table 1. For this simulation the developed MATLAB software has been used.

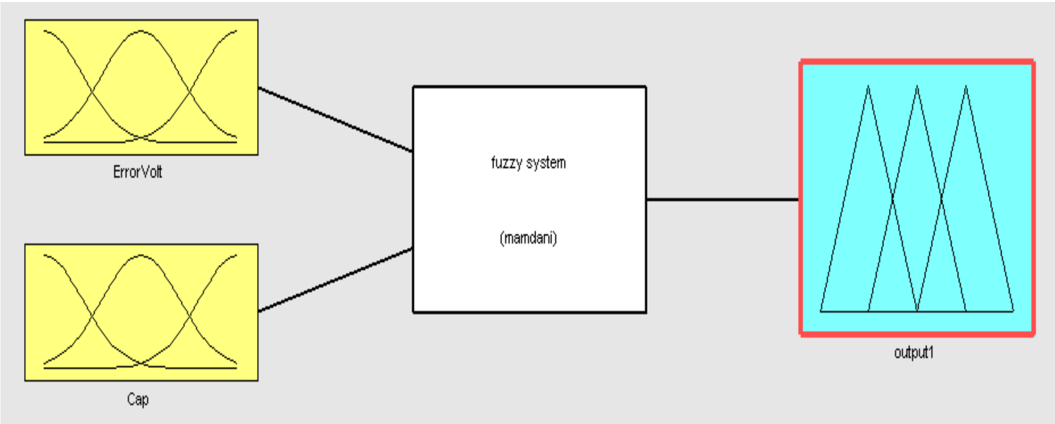
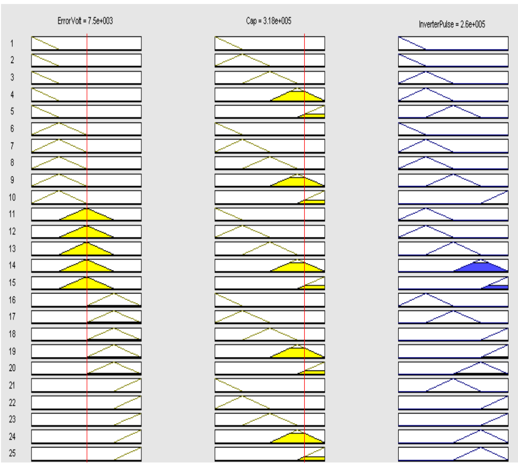


Figure 2: Fuzzy Logic Controller



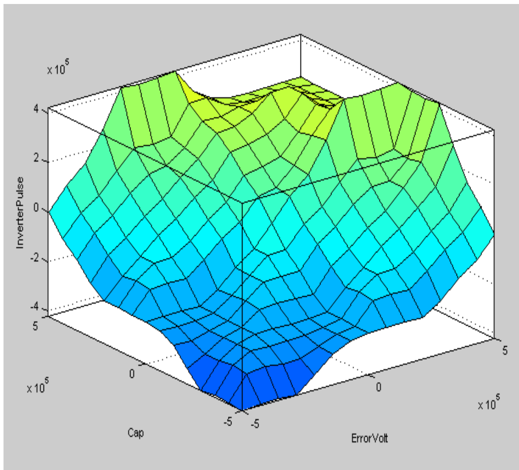


Figure 3: One of the triangular membership input and output

Figure 4: One sample of 3D View of for input and output.

Simulations

Simulation work has been carried out for the practical National Thermal Power Station (NTPS) in India. There are three generators each of 210 MW (unit 1, 2, and 3). The real power generated (MW) are shown in Table 1 for all the three units for 24 hours of a day. The reactive power values (MVAR) and the voltage value (KV) with the existing conventional controller of NTPS which is considered as a utility system for a particular day are taken and recorded in Table 1.

The conventional controllers are replaced by the FLC for simulation work. With this FLC, the readings are taken for the reactive power requirement and the voltage level as recorded in Table 1. After this, the UPFC has been introduced and simulation has been carried out. The reactive power requirement and the voltage levels are noted and recorded as demonstrated in Table 1.

Table 1: showing the details of Real Power (MW), Reactive Power (MVAR) and Voltage (KV) with the existing Conventional Controller (Con), Fuzzy Logic Controller (Fuz) and UPFC for the three generators of Utility system in India

Time in Hrs	Unit 1				Unit 2				Unit 3				Voltage		
	Real MW	Con - MVAR	Fuz - MVAR	UPFC MVAR	Real MW	Con - MVAR	Fuz - MVAR	UPFC MVAR	Real MW	Con - MVAR	Fuz - MVAR	UPFC MVAR	Con 230 KV	Fuz 230 KV	UPFC 230 KV
1	192	33	28.7	26	191	16	14.5	14	193	19	18.2	19	237	232	230
2	186	28	26	28	185	16	14.3	16	191	19	18.1	21	228	230	230
3	192	28	26	28	191	16	14.8	16	194	18	17.6	21	228	230	230
4	192	28	26	28	189	15	13.7	16	195	20	19.4	21	231	230	230
5	189	29	26	31	188	12	11.3	19	198	22	19.9	24	225	227	230
6	179	29	26	31	180	16	14.5	19	195	22	20.5	24	223	227	230
7	184	28	26	29	184	10	9.98	17	195	22	19.4	22	237	229	230
8	190	29	26	28	189	15	13.7	16	196	22	20.4	21	232	230	230
9	189	29	26	28	192	17	16.9	16	196	21	20.4	21	228	230	230
10	189	29	27.2	26	189	16	14.4	14	199	24	22.8	19	234	232	230
11	189	28	26	27	193	16	15.2	15	194	18	17.7	20	232	231	230
12	189	29	27.2	26	192	16	14.5	14	192	20	18.2	19	235	232	230
13	189	27	26	27	191	16	14.8	15	196	22	20.4	20	229	231	230
14	189	27	26	27	192	17	15.1	15	198	22	21.6	20	230	231	230
15	186	28	26	29	191	16	14.8	17	190	20	18.6	22	227	229	230
16	193	28	26	28	191	16	14.8	16	197	22	20.6	21	232	230	230
17	192	28	26	28	192	17	15.2	16	198	23	21.6	21	229	230	230
18	193	34	31.3	25	192	16	14.5	13	196	22	20.5	18	231	233	230
19	192	30	26	27	191	16	14.8	15	198	23	21.6	20	234	231	230
20	195	32	26.1	27	192	17	15.1	15	196	22	20.4	20	233	231	230
21	195	34	28.8	26	192	16	14.5	14	193	21	18.2	19	234	232	230
22	209	28	26	26	197	24	16.9	14	194	21	18.2	19	235	232	230
23	186	30	26	27	196	22	15.7	15	189	22	20.5	20	228	231	230
24	187	28	26	26	192	17	14.5	13	192	20	18.2	19	225	232	230

Real – Real Power, Con – Conventional Controller, Fuz – Fuzzy Controller

Results and Discussion

From the results as shown in Table 1, it is observed from the Figure 5, 6 and 7that the reactive power requirement by Fuzzy controller is lower than the existing conventional controllers. Also, it is noticed that the voltage level is much closer to the required voltage of 230 KV + 5 % as evidenced in Figure 8. By implementing the UPFC controller it is evidenced from the same Figures 5, 6, and 7 that the reactive power requirements are still much lower than the Fuzzy controller as well as the conventional controllers. It is also much appreciably noticed that the voltage is maintained constant at 230 KV irrespective of changes in the load throughout the 24 hours as evidenced in Figure 8. Hence, it is concluded that the reactive power requirement is much reduced with the introduction of UPFC, which will automatically reduce the real power and reactive power generation. Hence, the cost of production will be reduced. Also, it is concluded that with the introduction of UPFC, it is possible to maintain a constant voltage of 230 KV throughout the day of 24 hours which is evidenced clearly from figure 8.

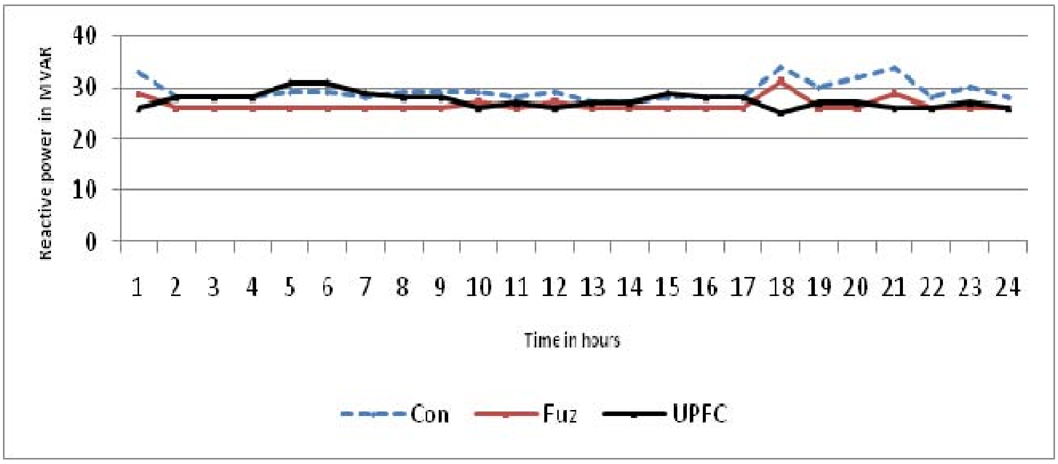


Figure 5: Reactive Power for 24 hours in Unit 1

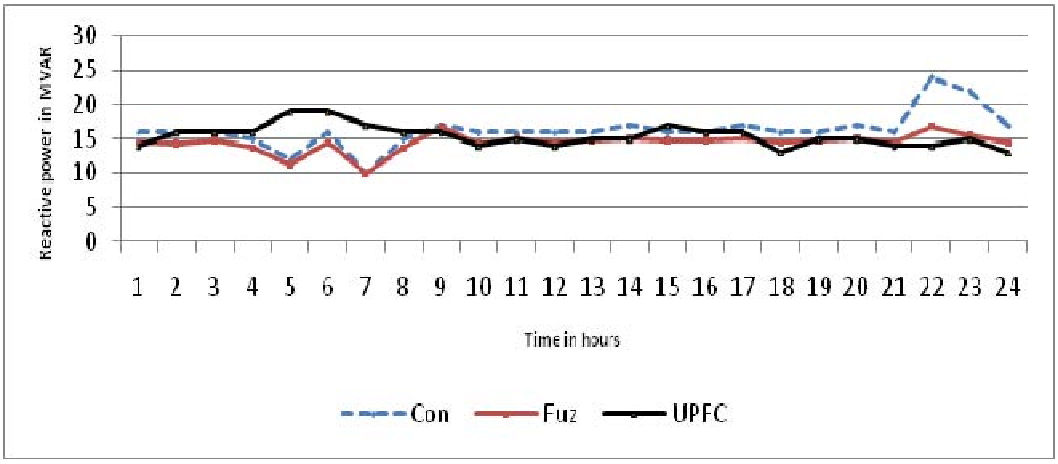


Figure 6: Reactive Power for 24 hours in Unit 2

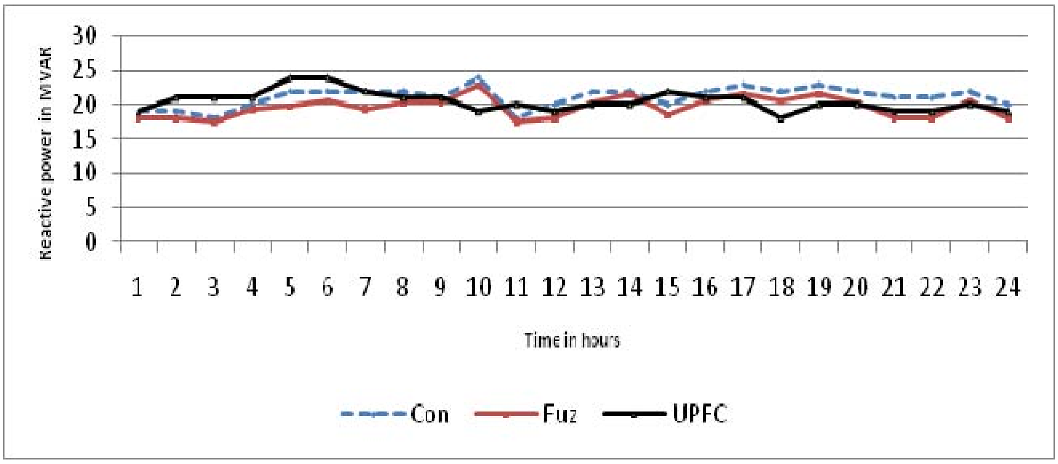


Figure 7: Reactive Power for 24 hours in Unit 3

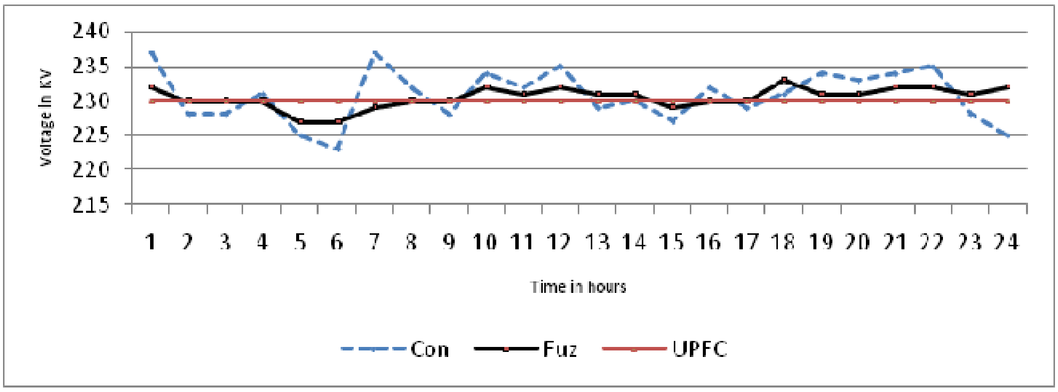


Figure 8: Voltage Level in the Load Bus for 24 hours

Conclusion

In this paper, the FLC 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 practical power system of national thermal power station in India with the conventional controller has been taken for case study with the implementation of FLC and UPFC. The simulation work has been carried out with the help of developed MATLab software and the results were analyzed with the conventional controller. 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 FLC as well as conventional controller. Hence, UPFC is a better choice to reduce the reactive power requirement and cost effective in a power system. Another important conclusion is that with the introduction of UPFC it is evidenced that the voltage is maintained constant of 230 KV throughout the day of 24 hours. It is observed that there is a vast change in voltage level in the existing conventional controller method which is much reduced by the FLC. But the UPFC is much suited to maintain a constant voltage economically throughout the day with less reactive power requirements.

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