

Unified Power Flow Controller to Control Reactive Power and Voltage for Power Stations in India by Implementing Fuzzy Logic Controller

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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' as an output are considered. Case studies have been performed for State Electricity System (SES) in the Southern part of India. Simulation has been carried out for four different groups of generations 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 required range with $\pm 5\%$ tolerance and with the UPFC it is demonstrated a constant voltage throughout the day of 24 hours.

Keywords: Reactive Power Control, Voltage, UPFC, FLC, Voltage Source Inverter, Storage Capacitor

1. Introduction

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].

The UPFC has the ability to control three parameters i.e terminal voltage, line impedance, and phase angle between two buses either simultaneously or independently. 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. It is observed that the voltage reactive power control has become particularly important concern for utilities transmitting power over long distances.

2. Reactive Power

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 [1], [3]. 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. If the system voltage deviates from that value, the performance of the device suffers and its life expectancy drops.

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. 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.

3. Fuzzy Logic

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 as shown in the flow chart in Figure 1. 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.

In Power systems many uncertainties arises due to aging of machines, unforeseen load switchings, 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 [3]. Therefore fuzzy set theory based approach, in recent years has emerged as a complement tool to mathematical approach for solving such power system problems. Hence the fuzzy expert system approach is chosen as one of the artificial intelligence approach for solving the power system problems in this paper.

4. Unified Power Flow Controller

Unified Power Flow Controller (UPFC) is used to control the power flow in the transmission systems by controlling the impedance, voltage magnitude and phase angle. 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 [4], [5]. The real power exchange between the converters is affected through the common DC link capacitor. 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. 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 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 [6], [7].

5. Power Quality

Modern power systems are becoming increasingly stressed because of growing demand. The power flow through the line can be regulated by controlling voltage magnitude and angle of series injected voltage [8]. One of the main parameter to judge the quality of power supply is the constant voltage. Due to variation in load parameters there is a wide range of variation in the voltage level. The main focus in this paper is to maintain a constant voltage irrespective of change in load with the implementation of FLC and UPFC. The adequate quantity of reactive power is either injected or absorbed in the required places of the power system to maintain constant voltage. The FLC 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 [9], [10]. 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]. The voltage controllers are connected on line so that we can program the voltage and / or reactive power setting according to daily reactive power dispatch schedules.

Voltage / Var control determines an on-line control strategy for keeping voltage of target power systems considering the load change and reactive power balance in target power system as shown in

the flow chart in Figure 1. The purpose of reactive power/voltage control in a distribution substation is to control the reactive power flow over the main transformer and the voltage on the low voltage bus. The reactive power is either injected or absorbed to maintain a constant voltage on varying load condition. The required reactive power to be injected or absorbed is judged by UPFC. One of the important operative tasks of power utilities is to keep voltage within an allowable range for high quality customer services. 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 [11].

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. A good quality AC power should have constant voltage and frequency. It should be free from harmonics and the power factor should be nearly unity. 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 this, UPFC is used in the system to control the reactive power and to maintain constant voltage profile. The power quality is determined by the comparison with the existing controller, FLC and UPFC.

6. Simulations, Results and Discussions

6.1. Case Study

Case study has been carried out for the practical system of the State Electricity System (SES) in Southern part of India. The different types of generation system have been considered in this proposed work. The case study is carried out for a particular day. Simulations of results are carried out in 'MATLAB' simulation package. 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 requirements 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 shown in Figure 2. The triangular membership function for inputs and output and their 3D views are shown in Figure 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 420 KV, 230 KV and 110 KV for all the 24 hours of the day which is evidenced in Table 1. For this simulation the developed MATLAB software has been used.

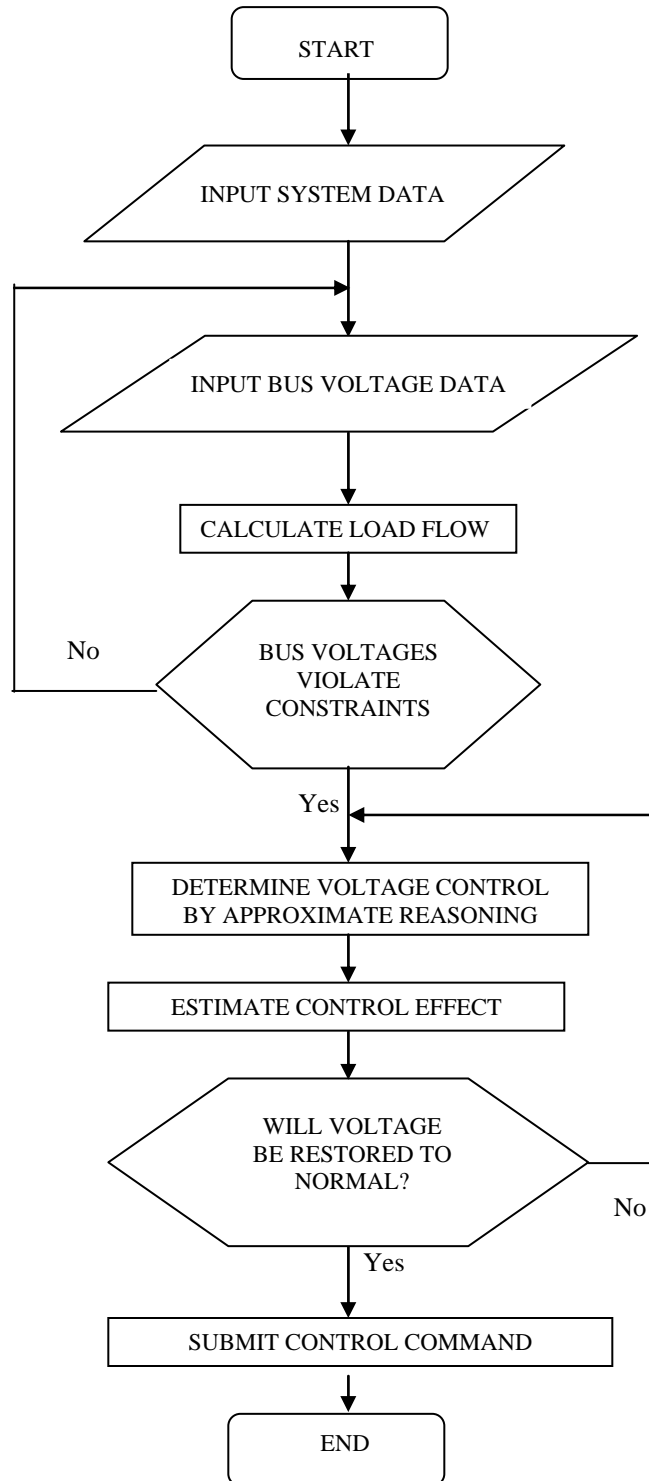
Figure 1: Flow Chart for voltage fuzzy based voltage-reactive power control

Table 1: Table showing the details of Real Power (MW), Reactive Power (MVAR), and Voltage with the Existing Conventional (con) Control, Fuzzy Logic Control (fuz) and UPFC for the four different groups of Generations

Time in Hrs	Unit A				Voltage of A			Unit B				Unit D				Voltage of B & D			Unit C				Voltage of C		
	Real MW	Con MVAR	Fuz MV AR	UP FC MV AR	Con 420 KV	Fuz 420 KV	UPFC 420 KV	Real MW	Con MV AR	Fuz MV AR	UP FC MV AR	Real MW	Con MV AR	Fuz MV AR	UP FC MV AR	Con 110 KV	Fuz 110 KV	UPFC 110 KV	Real MW	Con MV AR	Fuz MVAR	UPFC MVAR	Con 230 KV	Fuz 230 KV	UPFC 230 KV
1	635	55	49.6	37	430	426	420	15	12	9.96	8.73	2	44	42	40	114	111	110	30	12	10.9	8.9	233	231	230
2	640	65	58.6	41	428	424	420	15	12	9.96	8.73	2	50	42	40	114	111	110	30	12	10.9	8.9	233	231	230
3	610	50	48	39	429	425	420	15	12	9.96	8.73	2	48	42	40	114	111	110	30	12	10.8	10.8	229	230	230
4	640	65	58.6	39	428	424	420	15	12	10.5	10.5	2	50	42	42	112	110	110	30	12	10.8	10.8	229	230	230
5	640	80	62.5	43	427	423	420	46	22	16.3	16.3	2	48	42	42	112	110	110	30	12	10.8	10.8	229	230	230
6	640	80	62.2	52	424	420	420	90	44	40.5	40.5	2	48	42	42	110	110	110	105	40	37.4	37.4	229	230	230
7	645	90	79.7	52	416	418	420	90	44	41	42.5	2	56	42	45	107	109	110	105	40	37.4	39.4	225	227	230
8	645	125	81.8	57	414	416	420	90	44	40.5	40.5	2	52	42	42	112	110	110	105	40	37.1	39.4	225	227	230
9	645	110	81.5	57	415	417	420	90	44	41	42.5	2	48	42	45	107	109	110	105	40	37.4	38.7	227	229	230
10	645	90	79.7	52	416	418	420	90	44	41	42.5	2	44	42	45	108	109	110	105	40	37.4	37.4	229	230	230
11	645	90	81.8	57	414	416	420	90	44	41	42.5	2	56	42	45	107	109	110	105	40	37.1	37.4	229	230	230
12	645	50	48	48	418	420	420	90	44	41	42.5	2	52	42	45	106	109	110	105	40	37.1	34.6	235	232	230
13	640	85	76.9	52	416	418	420	85	44	40.5	40.5	2	48	42	42	110	110	110	105	40	37.1	35.8	233	231	230
14	640	85	76.2	55	415	417	420	85	44	40.9	38.2	2	46	42	40	113	111	110	105	40	37.1	34.6	235	232	230
15	640	80	62.2	52	418	420	420	85	44	40.9	37.4	2	52	42	38	115	112	110	105	40	37.1	35.8	233	231	230
16	640	85	76.9	52	416	418	420	85	44	40.9	38.2	2	52	42	40	114	111	110	105	40	37.1	35.8	233	231	230
17	640	90	71	50	417	419	420	85	44	40.5	40.5	2	42	42	42	110	110	110	105	40	37.1	38.7	227	229	230
18	640	90	71	50	417	419	420	85	44	40.5	40.5	2	43	42	42	110	110	110	105	40	37.4	37.4	229	230	230
19	640	120	76.2	55	415	417	420	85	44	40.5	40.5	2	44	42	42	111	110	110	105	40	37.4	37.4	229	230	230
20	640	85	76.9	52	416	418	420	85	44	40.5	40.5	2	44	42	42	111	110	110	105	40	37.4	37.4	229	230	230
21	640	80	62.2	45	425	421	420	85	44	40.5	40.5	2	48	42	42	112	110	110	105	40	37.4	31.9	236	233	230
22	640	80	62.5	43	427	423	420	15	12	9.96	8.73	2	50	42	40	114	111	110	105	40	37.1	35.8	233	231	230
23	640	70	62.5	43	427	423	420	15	12	9.96	8.73	2	46	42	40	113	111	110	15	12	10.9	6.8	235	232	230
24	640	70	62.2	45	425	421	420	15	12	9.96	8.73	2	45	42	40	113	111	110	15	12	10.9	6.8	235	232	230

Real - Real Power; Con – Conventional Controller; Fuz – Fuzzy Logic Controller

In this proposed work, there are four different types of generating stations (Station A,B,C & D). Station A consists of few thermal power generating stations which are connected to 420 KV load bus. Station B has some hydro irrigation stations which are connected to 110 KV load system. The station C has few hydro non-irrigation stations which are connected to 230 KV system. And the station D has some diesel generators which are connected to 110 KV load system. The real powers generated, the reactive power requirements and the voltage maintained in all these four stations by the conventional controllers are shown as detailed in Table 1. Now for the case study the existing conventional controllers are replaced by FLC and UPFC and the reactive power values and the voltage values are simulated and noted as recorded in Table 1.

Figure 2: Fuzzy Logic Controller

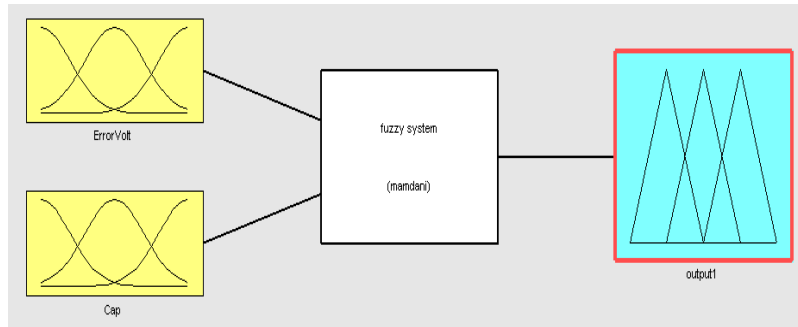


Figure 3: One Sample of Triangular Membership for Inputs and Output

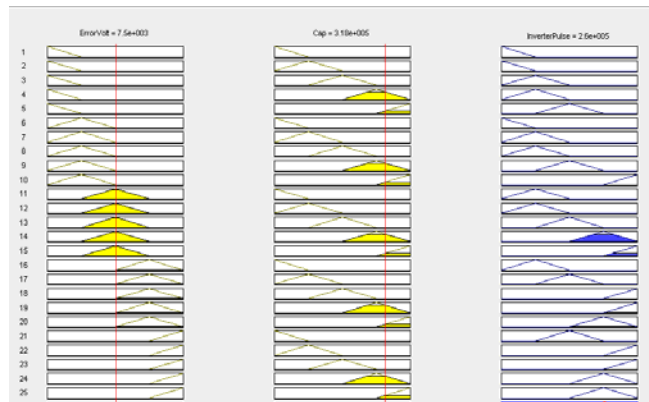
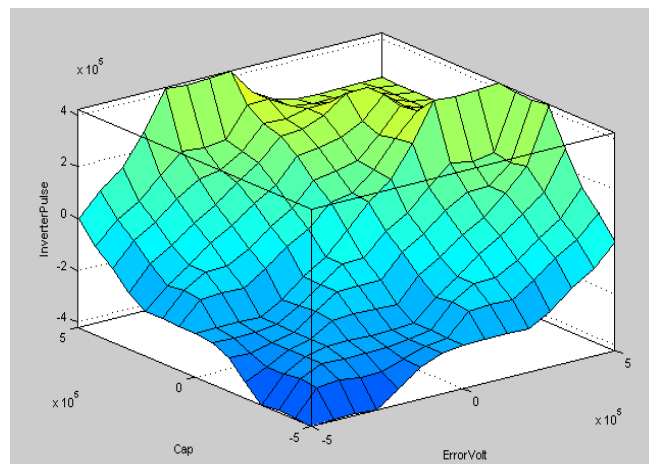


Figure 4: One Sample of 3D View of Inputs and Output.



6.2. Simulations

Simulation work has been carried out for the practical SES in Southern part of India. There are four groups of generating stations (Station A, B, C & D). The real power generated (MW) are shown in Table 1 for all the four units for 24 hours of a day. The reactive power values (MVAR) and the voltage value (KV) with the existing conventional controller of SES for a particular day are taken and shown in the Table 1. The existing 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 shown in Table 1.

6.3. Results and Discussions

From the results which are demonstrated in Table 1, it is observed from the Figures 5, 6, 7 and 8 that the reactive power requirement by Fuzzy controller is lower than the existing conventional controllers. Also, it is noticed from figures 9, 10 and 11, that the voltage level is much closer to the required voltage of levels with the tolerance of $\pm 5\%$. By implementing the UPFC controller it is evidenced from the same Figures 5, 6, 7 and 8 that the reactive power requirements is still lower than the Fuzzy controller as well as the conventional controllers. It is also much appreciably noticed that with the implementation of UPFC the voltages are maintained constant of 420 KV, 210 KV and 110 KV irrespective of changes in the load throughout the 24 hours as shown in Fig. 9, 10 and 11. 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 in turn 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 throughout the day of 24 hours which is demonstrated very clearly in Figures 9, 10 and 11.

Figure 5: Reactive Power for 24 hours in Unit A

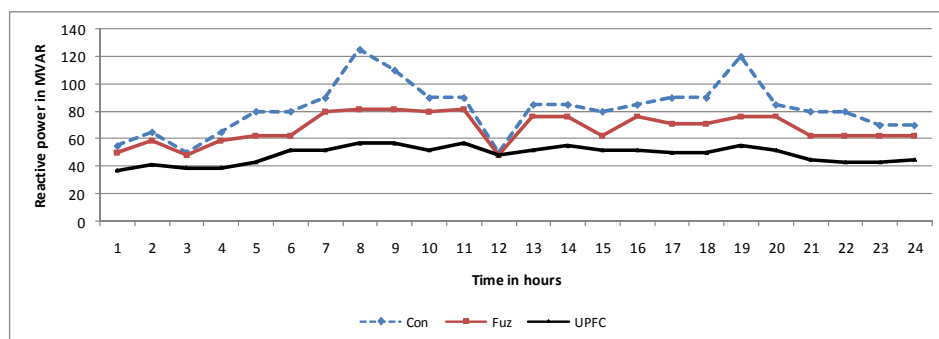


Figure 6: Reactive Power for 24 hours in Unit B

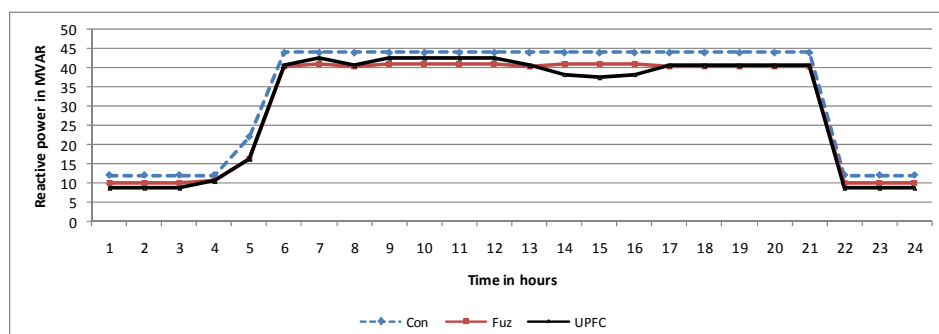


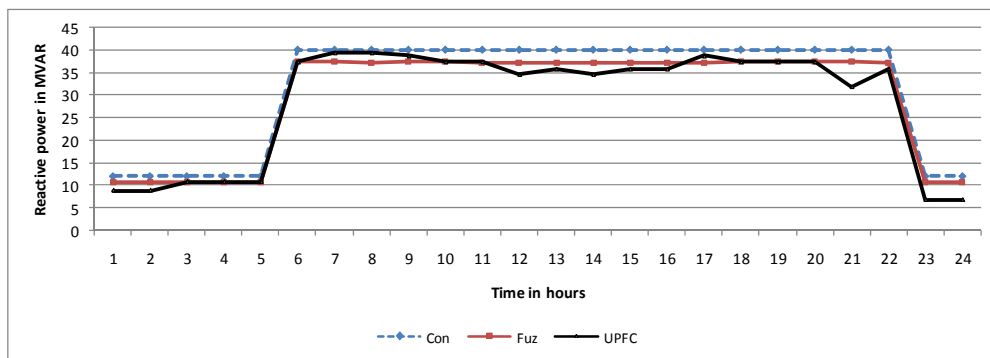
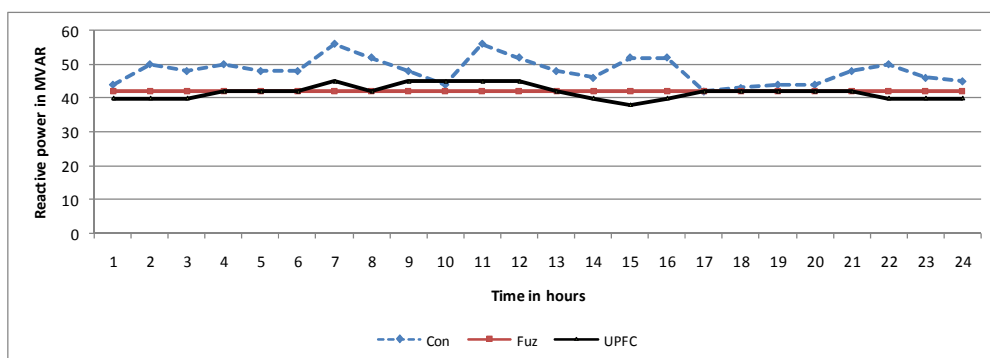
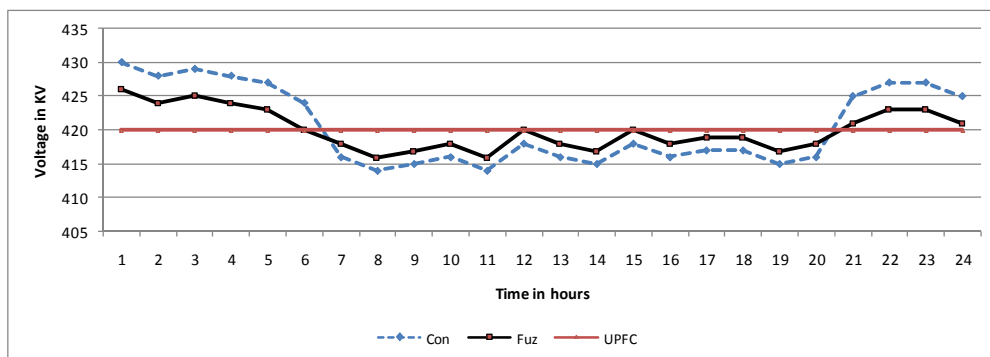
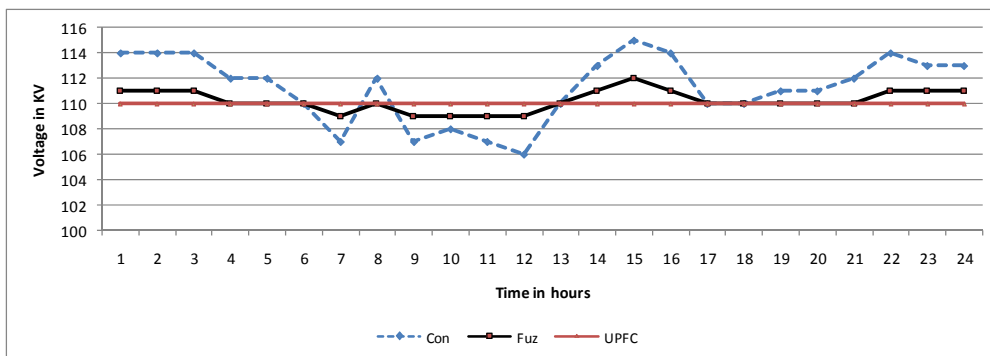
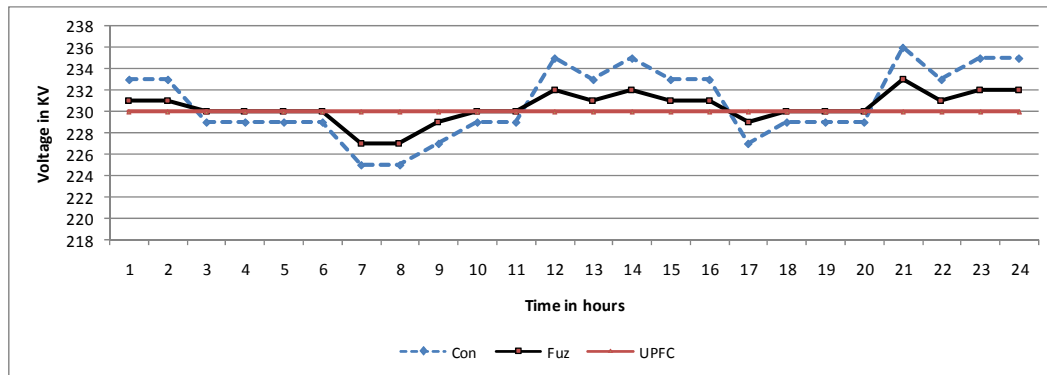
Figure 7: Reactive Power for 24 hours in Unit C**Figure 8:** Reactive Power for 24 hours in Unit D**Figure 9:** Voltage level in the Load Bus for 24 hours in Unit A**Figure 10:** Voltage level in the Load Bus for 24 hours in Unit B & D

Figure 11: Voltage level in the Load Bus for 24 hours in Unit C



7. Conclusion

The objective of reactive power control in a power station is to minimize the real power loss which will reduce the operative cost and improve the voltage profile. In this work, 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 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. It has been observed 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. Another important conclusion is that with the introduction of UPFC it is evidenced that the voltages are maintained constant (420 KV, 230 KV and 110 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 very economically throughout the day with less requirements of reactive power.

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