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Comparison of the Proportional Integral & Fuzzy Approaches in Power Quality Enhancement in Transmission Systems Using UPFC with Educational Purposes

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ABSTRACT

This paper deals with power quality improvement in power systems. In this research the unified power flow controller (UPFC) is used to compensate the voltage sag which occurred due to short circuit in system. To control the UPFC there are various controlling strategies. This paper focuses on the comparison of the two most desired approach that used by many researchers. In thus research the comparison between PI and fuzzy approach is performed.

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INTRODUCTION

Voltage sags and swells in the low and medium voltage distribution system have been considered to be the most frequent type of power quality problems based on recent power quality researches. Their effect on sensitive loads is severe. Their effects could be ranged from the disruptions of load to influential economic losses up to millions of dollars [1]. Several solutions have been proposed to protect sensitive loads against this kind of disturbances but the dynamic voltage restorer is considered to be the most effective solution. The advantage of this custom power device includes its dynamic response to the disturbance, lower cost and smaller size. As shown in Fig.1 the voltage sags may be occurred at any instant of time, with amplitudes ranging from 10 to 90% and a duration which lasting between a half cycle to one minute [2]. On the other hand, voltage swell, is defined as an increase in rms voltage or current for 110% to 180% under power frequency for duration between 0.5 cycles to 1 minute. Energizing a large capacitor bank or switching off a large inductive load is a typical system event which causes swells [3].

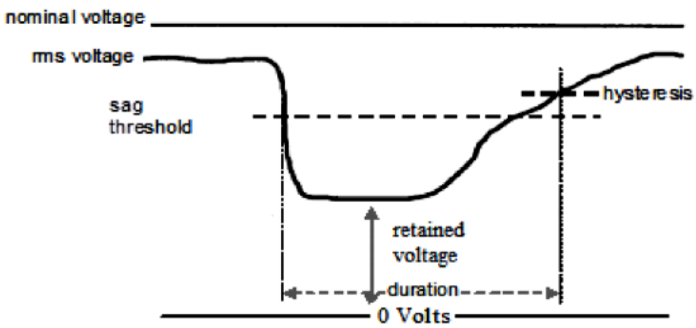

Fig. 1: Voltage sag characteristics

Creating factors of voltage sag due to short circuit faults:

Among symmetrical and unsymmetrical short circuits, the effect of three phase short circuit is more sever on the voltage sag [4- 6]. In order to evaluate the amount of the voltage sag in the radial distribution system, the voltage divider model can be used as illustrated in Fig. 2.

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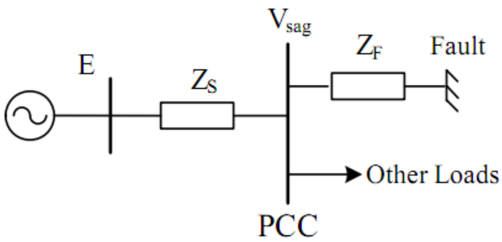

Fig. 2: Voltage divider model for computing voltage sag in a radial distribution system

In this figure, impedance Z_s indicates the source impedance at the point of common coupling (PCC) and Z_F is the impedance between the PCC and fault point. The voltage at PCC bus can be determined as follows [7]:

$$V_{Sag} = \frac{Z_F}{Z_S + Z_F} E$$

In versus of short circuit capacity of system at fault point and PCC, the magnitude of voltage sag can be determined as follows:

$$V_{Sag} = 1 - \frac{S_{FLT}}{S_{PCC}}$$

Single phase or two phases are most short circuits in power systems. In that case, it is needed to take all three phases into account or use the symmetrical component theory. For non-symmetrical faults the voltage divider in Fig.2 can still be employed but it must be split into its three components including a positive-sequence network, a negative sequence network and a zero-sequence network.

For a single-phase fault, the voltage sag in faulted phase is calculated as follows [8]:

$$V_{sag} = \left| \frac{(Z_{F1} + Z_{F2} + Z_{F0})}{(Z_{S1} + Z_{S2} + Z_{S0}) + (Z_{F1} + Z_{F2} + Z_{F0})} \right|$$

Where Z_{S1}, Z_{S2} and Z_{S0} are the source impedance values and Z_{F1}, Z_{F2}, and Z_{F0} the feeder impedance values in the three components.

For a phase to phase fault, the voltage sag in two faulted phases is calculated as follows:

$$V_{sag} = \left| \frac{(Z_{F1} + Z_{F2})}{(Z_{S1} + Z_{S2}) + (Z_{F1} + Z_{F2})} (a^2 - a) \right|$$

The effects of sub transmission loops on voltage sag:

At sub transmission level, the networks often consist of several loops-a typical example is shown in Fig.3. The transmission system is connected to the sub transmission system through two or three transformers. From the busses at the low-voltage side of these transformers a number of substations are fed via a loop. Such a network configuration is also found in industrial power systems. Often the loop only consists of two branches in parallel. The mathematical expressions that will be derived below can also be used to calculate voltage sags due to faults on parallel feeders.

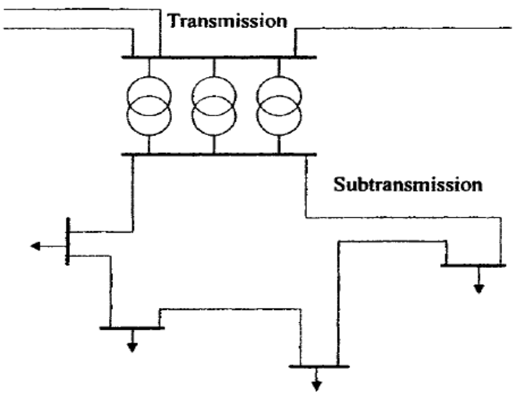

Fig. 3: Example of sub transmission loop

To calculate the sag magnitude we need to identify the load bus, the faulted branch, and the non-faulted branch. Knowing these the equivalent scheme in Fig.4 is obtained, where $\boldsymbol{Z_o}$ is the source impedance at the bus from which the loop is fed; $\boldsymbol{Z_l}$ is the impedance of the faulted branch of the loop; $\boldsymbol{Z_2}$ is the impedance of the non-faulted branch; and $\boldsymbol{p}$ is the position of the fault on the faulted branch ($\boldsymbol{p}$=0 corresponds to a fault at the bus from which the load is fed, ***p***=1 corresponds to a fault at the load bus). The voltage at the load bus can be calculated, resulting in the following expression [9].

$$V_{Sag} = \frac{\rho(1-\rho)Z_1^2}{Z_0(Z_1 + Z_2) + \rho Z_1 Z_2 + \rho(1-\rho)Z_1^2}$$

When a load is fed from a loop, like the ones discussed above, a fault on a branch away from that loop will also cause voltage sag. In that case it is often possible to model the system as shown in Fig.4. The feeder to the fault does not necessarily have to be a single feeder, but could, e.g., represent the effective impedance of another loop.

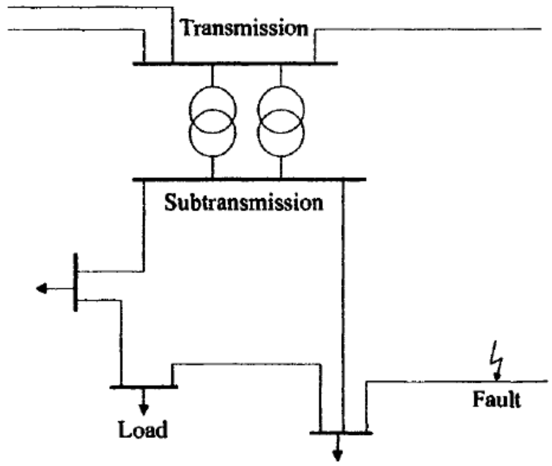

Fig. 4: System with a branch away from a loop

The voltage at the load bus is found from [10]:

$$V_{Sag} = \frac{Z_5 Z_2 + Z_5 Z_3 + Z_5 Z_4 + Z_4 Z_3}{Z_1 Z_2 + Z_1 Z_3 + Z_1 Z_4 + Z_5 Z_2 + Z_5 Z_3 + Z_5 Z_4 + Z_4 Z_2 + Z_4 Z_3}$$

Z_1 is the source impedance at the main sub-transmission bus; Z_2 is the impedance between that bus and the bus from which the load is fed; $Z_3$is the impedance between the bus from which the load is fed and the bus from which the fault is fed; Z_4 and Z_5 are the impedances between the latter bus and the main sub-transmission bus and the fault, respectively.

Unified Power Flow Controller (UPFC):

This FACT device is consisted of two converters. As presented in Fig.5 the converter-1 is to supply or absorb the real power demanded by converter-2 at the common dc link to support the real power exchange resulting from the series voltage injection. Converter-1 can generate or absorb controllable reactive power if desired, and thereby provide independent shunt reactive compensation for the line. The superior operating characteristic of UPFC Converter-2 provides the main function the UPFC by injecting a voltage V_{pq} with controllable magnitude and phase angle ρ in series with the line via an insertion transformer [11-12].

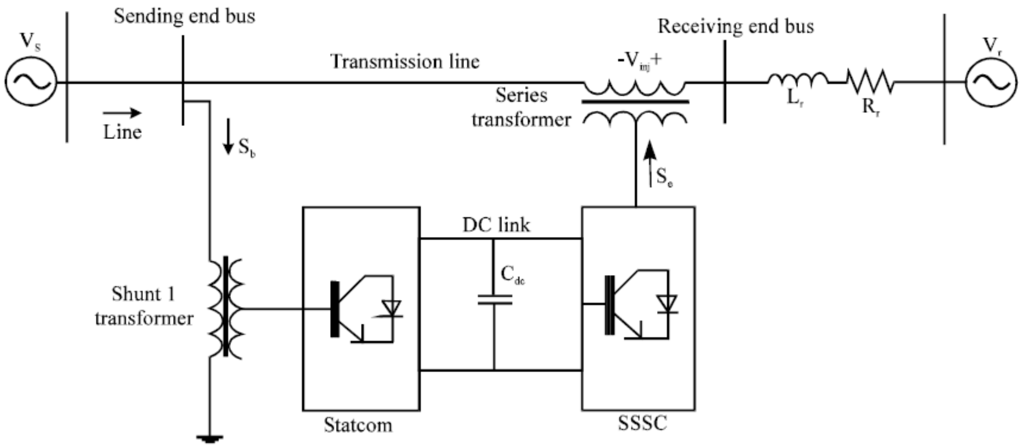

Fig. 5: Basic structure of UPFC

UPFC Startegy Controller:

In this section to find out the effects of UPFC on voltage sag compensation, the unified power flow controller through a PI or Fuzzy controller is applied to transmission level of network. The UPFC configuration and its controller based PI/Fuzzy controller is shown in Figs.6-7 respectively.

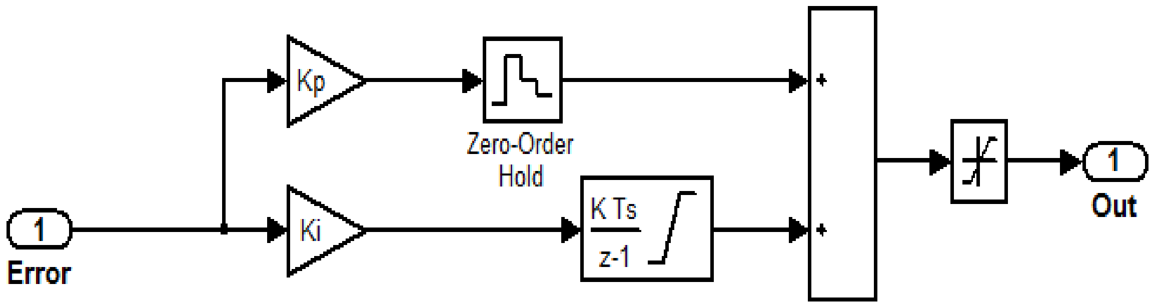

Fig. 6: The PI controller of UPFC

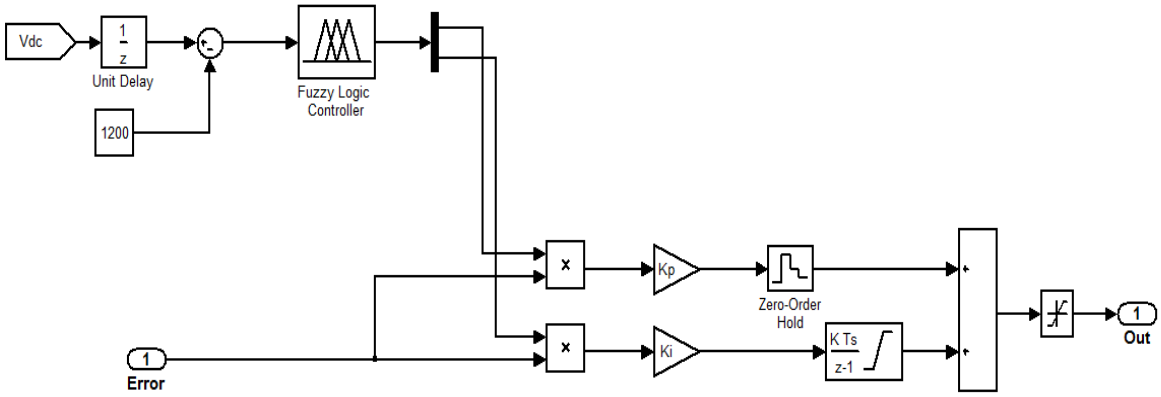

Fig. 7: The fuzzy based controller of UPFC

Educational based simulation and results:

In this section to better teach the power quality course to graduate students a simple simulation is consider to make a comparison between two controlling strategies.at first due to education purpose of this research some questions as follows are presented and tried to answer these questions using the proposed module.

- What is voltage sag?
- What are the main creating factors of voltage sag?
- What are the effects of voltage sag on power system?
- What is method of voltage sag compensation?
- What is the performance of UPFC in voltage sag compensation?
- Which of two controlling strategies PI or fuzzy have the best solution?

To answer these questions at first a simple simulation of test system is without UPFC is presented as shown in Fig.8. To understand the role of UPFC on power system the UPFC is installed to system as shown in Fig.9. As presented in this figure to make a voltage sag in power system a short circuit is occurred.

Advances in Environmental Biology, 8(12) July 2014, Pages: 761-768

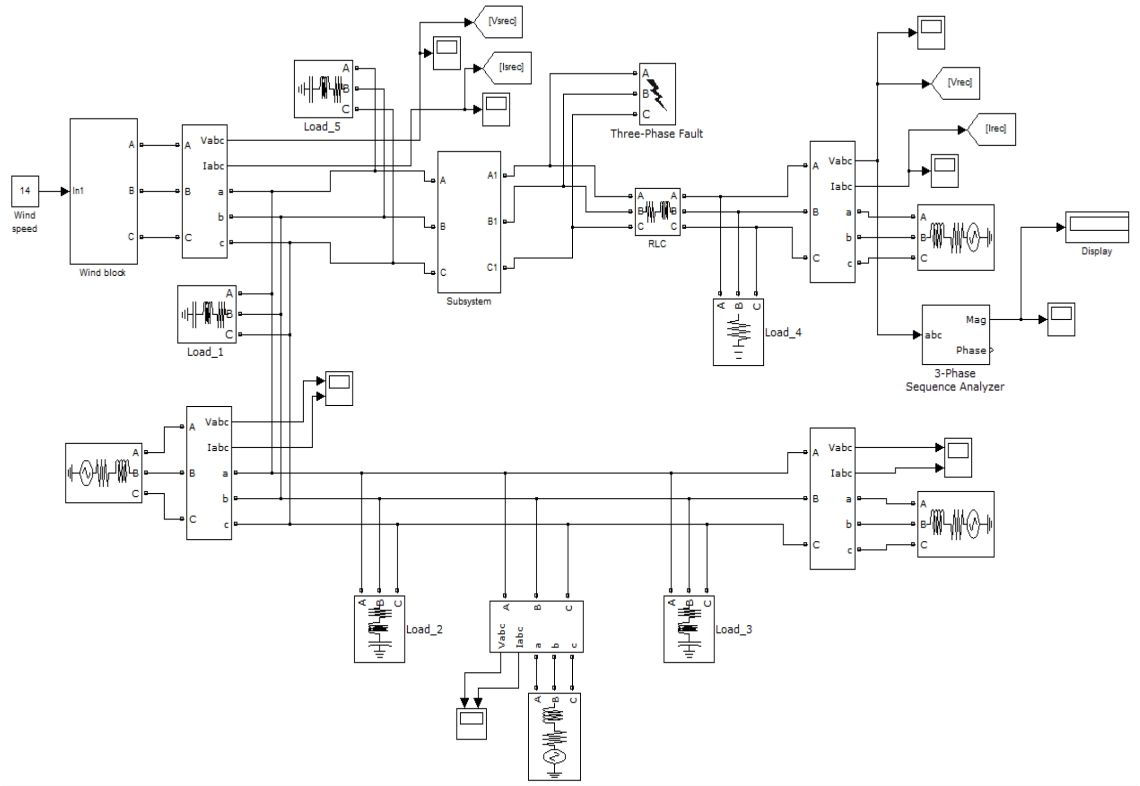

Fig. 8: Test power system without UPFC while fault occurring

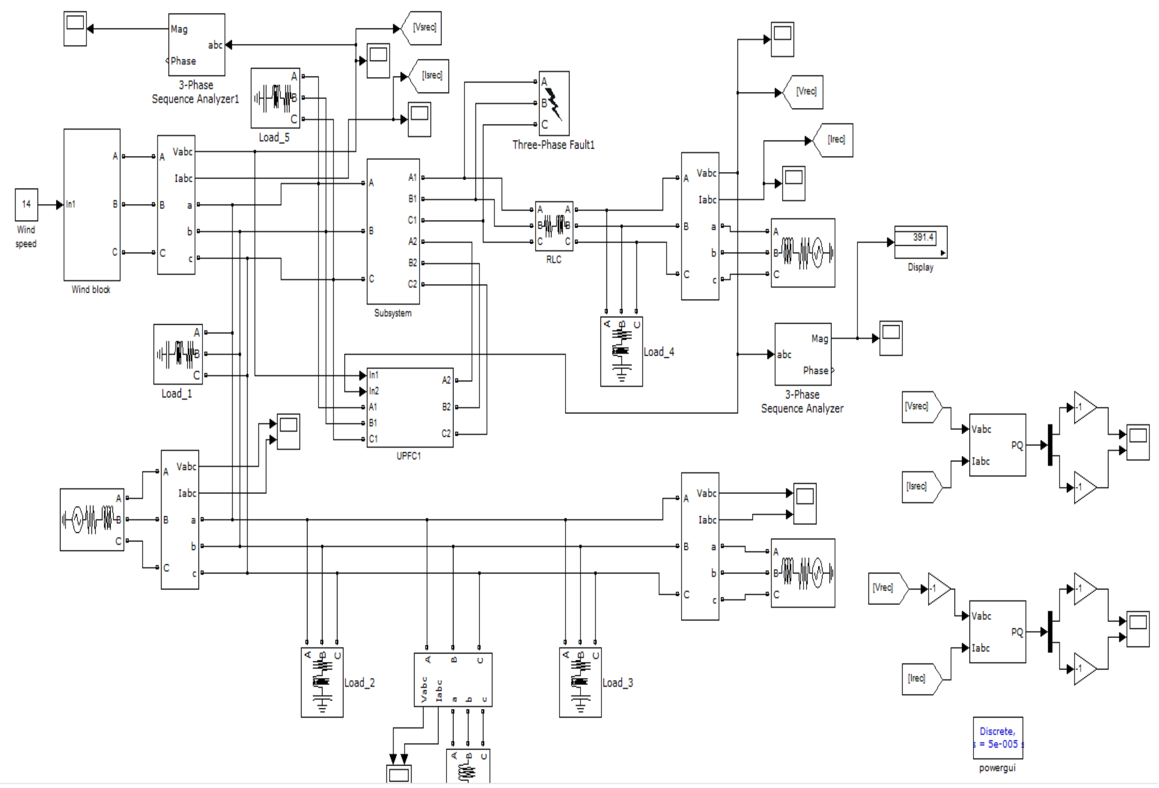

Fig. 9: Test power system with UPFC while fault occurring

At first to investigate the effect of short cicuit as a fault in transmission network, the system without any compensator is simulated.

The voltage and current system are shown in Figs.10-11 respectively. The voltage and current system with PI and Fuzzy based controller of UPFC are shown in Figs.12-16 respectively.

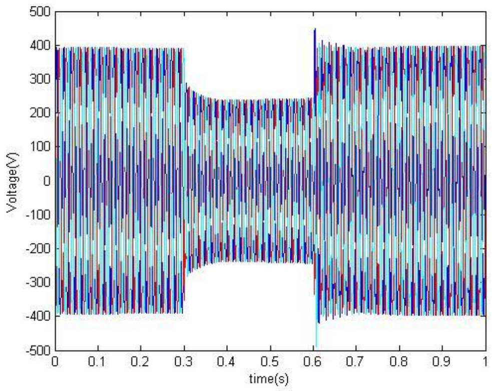

Fig. 10: The voltage of system without UPFC

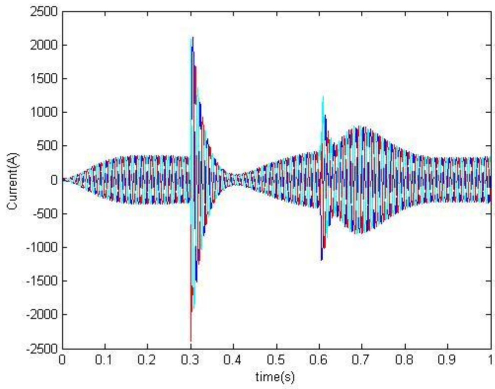

Fig. 11: The current of system without UPFC

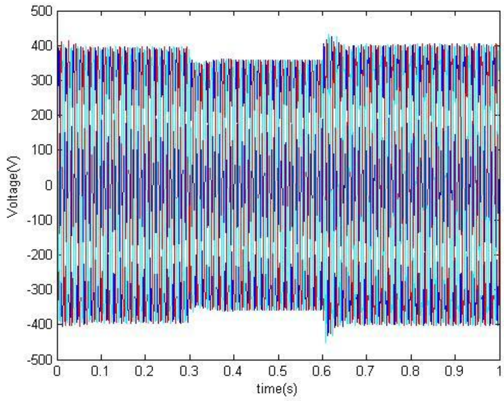

Fig. 12: The voltage of system with PI based controller of UPFC

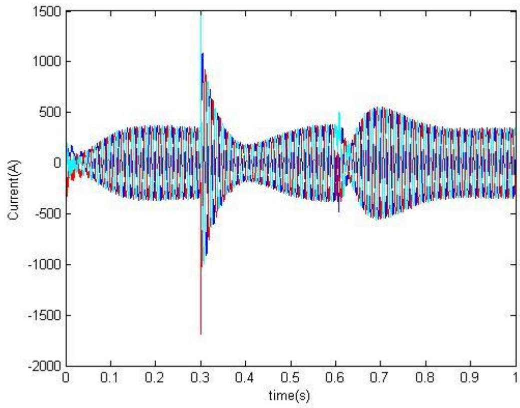

Fig. 13: The current of system with PI based controller of UPFC

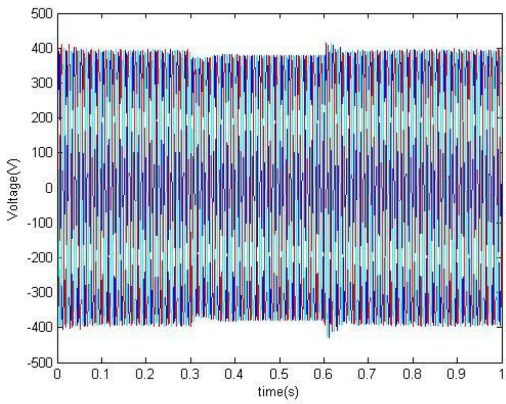

Fig. 14: The voltage of system with Fuzzy based controller of UPFC

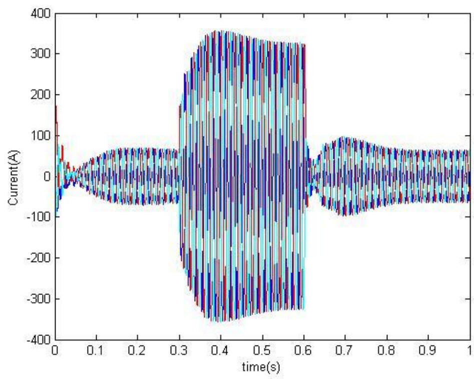

Fig. 15: The voltage of system with Fuzzy based controller of UPFC

To better understand the operation of UPFC in voltage sag compensation under two different control strategies, a comparison is performed between the results of PI and fuzzy controller versus the rms voltage of system. This comparison is shown in Fig.16.

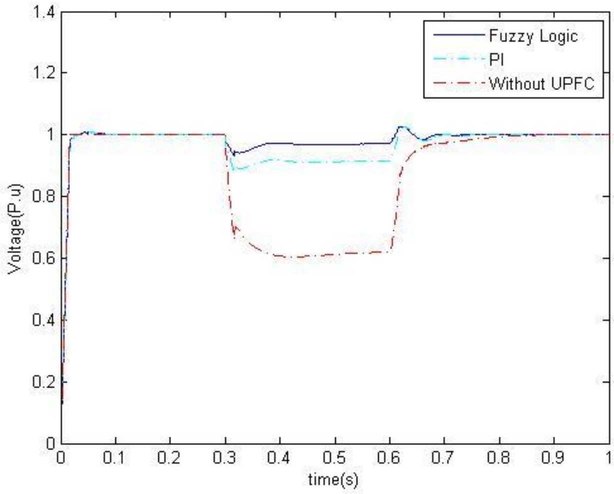

Fig. 16: Comparison between PI and Fuzzy controller operation

The methodology illustrated in this paper has explained for 30 senior graduate students in power system, all of them have passed power quality courses. The students employ the methodology and in the presence of instructor filled a questionnaire form. The questionnaire, comprising six questions, is listed in Table 1.

Table 1: Questionnaire Answered by the Students and Engineers

	Question	Score
1.	The content of this practical is valuable for a student of engineering course	
2.	Are you understanding the concept of voltage sag and its difference with other power quality phenomena	
3.	Are you more familiar with the creating factors of voltage sag in power system	
4.	Are you more familiar with the influence of voltage sag on system	
5.	Are you more familiar with the performance of UPFC in sag/swell compensation	

The students graded them as 1(poor), 2 (medium), 3 (good), and 4 (excellent).

Table 2 gives the average scores for each question out of students' feedback.

Table 2: Average Score Obtained From Students' Answers

	Average Score
Question 1	3.21
Question 2	3.74
Question 3	3.86
Question 4	3.43
Question 5	3.82
Total	3.68

Conclusion:

Present article has outlined and illustrated a MATLAB-SIMULINK model to illustrate the creating factors of voltage sag and investigate the effect of this phenomenon on power system. Also the mitigation of voltage sag using unified power flow controller based two different control strategy including PI and fuzzy approached are simulated, investigated and compared. It is concluded that the improvement of power system condition is proportional to compensation duration by UPFC. Also it is found that the fuzzy controller has the best results with comparison of PI controller. Because of educational purpose of this paper it organized such a way that method considerably to reduce the time and cost needed to teach the subject. Therefore, it is very useful for educational purposes and useful preparatory exercises for student to learn the subject. The evaluation of the project involving more than 30 students indicates benefits of this project in teaching the subject.

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