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Mitigation of Voltage Imbalance in A Two Feeder Distribution System Using Iupqc

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ABSTRACT: *Proliferation of electronic equipment in commercial and industrial processes has resulted in increasingly sensitive electrical loads to be fed from power distribution system which introduce contamination to voltage and current waveforms at the point of common coupling of industrial loads. The unified power quality conditioner (UPQC) is connected between two different feeders (lines), hence this method of connection of the UPQC is called as Interline UPQC (IUPQC).This paper proposes a new connection for a UPQC to improve the power quality of two feeders in a distribution system. Interline Unified Power Quality Conditioner (IUPQC), specifically aims at the integration of series VSC and Shunt VSC to provide high quality power supply by means of voltage sag/swell compensation, harmonic elimination in a power distribution network, so that improved power quality can be made available at the point of common coupling. The structure, control and capability of the IUPQC are discussed in this paper. The efficiency of the proposed configuration has been verified through simulation using MATLAB/ SIMULINK.*
Keywords: *Power quality, UPQC, PQ disturbances, fuzzy controller.*

I. INTRODUCTION

Power quality determines the fitness of electric power to consumer devices. Synchronization of the voltage frequency and phase allows electrical systems to function in their intended manner without significant loss of performance or life[1]. Without the proper power, an electrical device (or load) may malfunction, fail prematurely or not operate at all. There are many ways in which electric power can be of poor quality and many more causes of such poor quality power. Poor power quality may result into increased power losses, and other remarkable abnormalities in the distribution side. The problems became more serious with the high usage of non-linear loads. The main reason for this is that the nonlinear loads, as a rule, draw non sinusoidal currents from the supply and lead to voltage distortion and related system problems.

For Power Quality improvement, the developments of power electronics devices such as FACTS and Custom Power Devices have introduced an emerging branch of technology providing the power system with versatile new control capabilities. Like Flexible AC Transmission Systems (FACTS) for transmission systems, the new technology known as Custom Power pertains to the use of power electronics controllers in a distribution systems. Just as FACTS improves the power transfer capability and stability margins, custom power makes sure consumers get pre-specified quality and reliability of supply. Voltage sags and swells in the medium and low voltage grid are considered to be the most frequent type of Power Quality problems. Their impact on sensitive loads is severe. Different solutions have been developed to protect sensitive loads against such disturbances. Among these IUPQC is most effective device. Unified Power Quality Conditioner (UPQC) consists of two IGBT based Voltage source converters (VSC), one shunt and one series cascaded by a common DC bus. Whenever the supply voltage undergoes sag then series converter injects suitable voltage with supply. Thus UPQC improves the power quality by preventing load current harmonics and by correcting the input power factor. Voltage-Source Converter based Custom power devices are increasingly being used in custom power applications for improving the power quality (PQ) of power distribution systems. Devices such as distribution static compensator (DSTATCOM) and dynamic voltage restorer (DVR) are extensively being used in power quality improvement. A DSTATCOM can compensate for distortion and unbalance in a load such that a balanced sinusoidal current flows through the feeder [3,4].]. It can also regulate the voltage of a distribution bus. A DVR can compensate for voltage sag/swell and distortion in the supply side voltage such that the voltage across a sensitive/critical load terminal is perfectly regulated. A unified power-quality conditioner (UPQC) can perform the functions of both DSTATCOM and DVR. The UPQC consists of two voltage-source converters (VSCs) that are connected to a common dc bus. One of the VSCs is connected in series with a distribution feeder, while the other one is connected in shunt with the same feeder. The dc links of both VSCs are supplied through a common dc capacitor. This paper presents the new connection for UPQC. Interline Unified Power Quality Conditioner (IUPQC) which is the most sophisticated mitigating device for the power quality disturbances. The main aim of the IUPQC is to hold the voltages Vt1 and Vt2 constant against voltage sag/swell/any power disturbances in either of the feeders. Many contributions were introduced to modify the configurations and the control algorithms to enhance its performance.

II. CONTROL SCHEME

Sinusoidal PWM-Based Control Scheme:

In order to mitigate the simulated voltage sags in the test system of each mitigation technique, also to mitigate voltage sags in practical application, a sinusoidal PWM-based control scheme is implemented, with reference to IUPQC. The aim of the control scheme is to maintain a constant voltage magnitude at the point where sensitive load is connected, under the system disturbance. The control system only measures the rms voltage at load point, in example, no reactive power measurements is required. The VSC switching strategy is based on a sinusoidal PWM technique which offers simplicity and good response. Since custom power is a relatively low-power application, PWM methods offer a more flexible option than the fundamental frequency switching (FFS) methods favoured in FACTS applications. Besides, high switching frequencies can be used to improve the efficiency of the converter, without incurring significant switching losses.

The IUPQC control system exerts voltage angle control as follows:

An error signal is obtained by comparing the reference voltage with the rms voltage measured at the load point. The fuzzy controller processes the error signal and generates the required angle δ to drive the error to zero, in example, the load rms voltage is brought back to the reference voltage. In the PWM generators, the sinusoidal signal, vcontrol, is phase modulated by means of the angle δ or delta as nominated in the Fig.1. The modulated signal, v control is compared against a triangular signal (carrier) in order to generate the switching signals of the VSC valves. The main parameters of the sinusoidal PWM scheme are the amplitude modulation index, ma , of signal v control, and the frequency modulation index, mf, of the triangular signal. The v control in the Fig.1 are nominated as CtrlA, CtrlB and CtrlC. The amplitude index ma is kept fixed at 1 p.u, in order to obtain the highest fundamental voltage component at the controller output. The switching frequency if is set at 450 Hz,

mf = 9. It should be noted that, an assumption of balanced network and operating conditions are made.

The modulating angle δ or delta is applied to the PWM generators in phase A, whereas the angles for phase B and C are shifted by 240° or -120° and 120° respectively. It can be seen in Fig.1 that the control implementation is kept very simple by using only voltage measurements as feedback variable in the control scheme. The speed of response and robustness of the control scheme are clearly shown in the test results. The PWM control scheme shown in Fig. 1 is implemented in MATLAB/SIMULINK to carry out the IUPQC test simulations. The gain of the fuzzy controller used in this scheme is 700.With a view to have a self regulated dc bus, the voltage across the capacitor is sensed at regular intervals and controlled by employing a suitable closed loop control. The DC link voltage, Vdc is sensed at a regular interval and is compared with its reference counterpart Vdc*. The error signal is processed in a fuzzy controller. A limit is put on the output of controller this ensures that the source supplies active power of the load and dc bus of the UPQC.

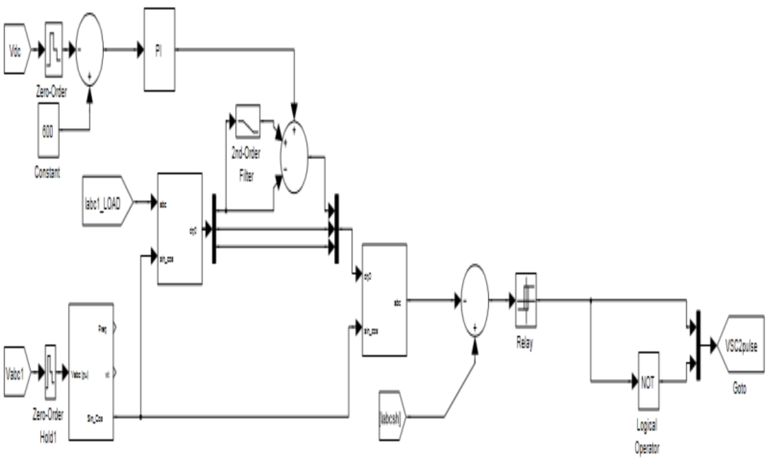


Figure: 1 PWM based control scheme

Later part of active power supplied by source is used to provide a self supported DC link of the UPQC. Thus, the DC bus voltage of the UPQC is maintained to have a proper current control. Subtraction of load currents from the reference supply currents results in three phase reference currents for the shunt inverter. These reference currents are compared with actual shunt compensating currents and the error signals are then converted into (or processed to give) switching pulses using PWM technique which are further used to drive shunt inverter. In response to the PWM gating signals the shunt inverter supplies harmonic currents required by load. In addition to this it also supplies the reactive power demand of the load. In effect, the shunt bi-directional converter that is connected through an inductor in parallel with the load terminals accomplishes three functions simultaneously. It injects reactive current to compensate current harmonics of the load. It provides reactive power for the load and thereby improve power factor of the system. It also draws the fundamental current to compensate the power loss of the system and make the voltage of DC capacitor constant.

III. INTERLINE UNIFIED POWER QUALITY CONDITIONER (IUPQC)

The IUPQC shown in Fig.2 consists of two VSCs (VSC-1 and VSC-2) that are connected back to back through a common energy storage dc capacitor. Let us assume that the VSC-1 is connected in shunt to Feeder-1 while the VSC-2 is connected in series with Feeder-2. Each of the two VSCs is realized by three H-bridge inverters. In this structure, each switch represents a power semiconductor device (e.g., IGBT) and an anti-parallel diode. All the inverters are supplied from a common single dc capacitor Cdc and each inverter has a transformer connected at its output. The complete structure of a three-phase IUPQC with two such VSCs is shown in Fig. 2. The secondary (distribution) sides of the shunt-connected transformers (VSC-1) are connected in star with the neutral point being connected to the load neutral. The secondary winding of the series-connected transformers (VSC-2) are directly connected in series with the bus B-2 and load L-2. The ac filter capacitors Cf and Ck are also connected in each phase to prevent the flow of the harmonic currents generated due to switching. The six inverters of the IUPQC are controlled independently. The switching action is obtained using output feedback control. In this figure, the feeder impedances are denoted by the pairs (Rs1, L s1) and (R s2, L s2). It can be seen that the two feeders supply the loads L-1 and L-2. The load L-1 is assumed to have two separate components—an unbalanced part (L-11) and a non-linear part (L-12). The currents drawn by these two loads are denoted by i_{l1} and i_{l2}, respectively. We further assume that the load L-2 is a sensitive load that requires uninterrupted and regulated voltage. The shunt VSC (VSC-1) is connected to bus B-1 at the end of Feeder-1, while the series VSC (VSC-2) is connected at bus B-2 at the end of Feeder-2. The voltages of buses B-1 and B-2 and across the sensitive load terminal are denoted by Vt1, V t2 , and Vl2, respectively.

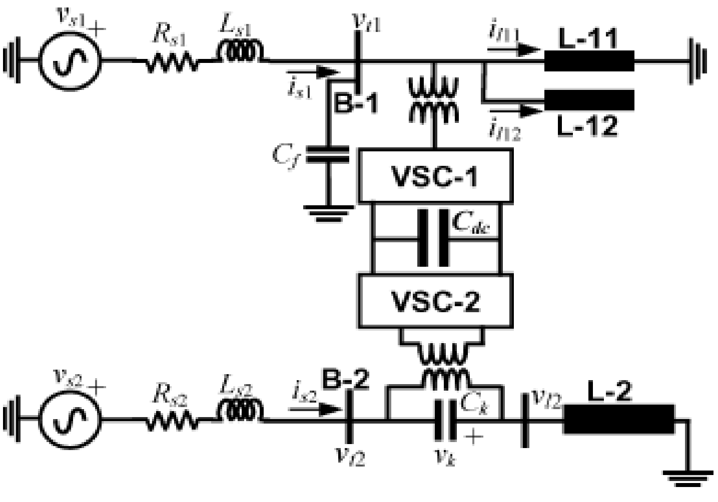


Figure:2 Typical IUPQC connected in a distribution system

An IUPQC connected to a distribution system is shown in Fig.2. In this figure, the feeder impedances are denoted by the Pairs (R_{s1},L_{s1}) and(R_{s2} ,L_{s2}) . It can be seen that the two feeders supply the loads L-1 and L-2. The load L-1 is assumed to have two separate components—an unbalanced part (L-11) and a non-linear part (L-12). The currents drawn by these two loads are denoted by i_{l11} and i_{l12}, respectively. We further assume that the load L-2 is a sensitive load that requires uninterrupted and regulated voltage. The shunt VSC (VSC-1) is connected to bus B-1 at the end of Feeder-1, while the series VSC (VSC-2) is connected at bus B-2 at the end of

Feeder-2. The voltages of buses B-1 and B-2 and across the sensitive load terminal are denoted by v_{t1},v_{t2} , and v_{l2} , respectively. The aim of the IUPQC is two-fold:

• to protect the sensitive load L-2 from the disturbances occurring in the system by regulating the voltage v_{l2};

• to regulate the bus B-1 voltage v_{t1} against sag/swell and or disturbances in the system. In order to attain these aims, the shunt VSC-1 is operated as a voltage controller while the series VSC-2 regulates the voltage v_{l2} across the sensitive load.

A 3-phase supply voltage of 11kv line to line, 50Hz with sag of 81% at source end, non-linear and unbalanced load at load end is considered. Non-linear load (Diode Rectifier feeding an RL load) injects current harmonics into the system. IUPQC is able to reduce the harmonics from entering into the system using shunt control. IUPQC with its series voltage control calculates the required voltage to be injected in series with the line to compensate the voltage sag in the insertion transformer produces the series injected (compensated) voltage by drawing the required power from the DC link. IUPQC with shunt PI controller estimates the required current to be injected in shunt with the line to compensate the disturbances.

Fuzzy Logic controller

Fuzzy logic is a form of multi valued logic that can be taken from a fuzzy set theory. Fuzzy logic variables can have truth logic between 0 and 1.Fuzzy logic is a good mean to control a system where there is no specific relation between input and output Quantities. It has a simple rule based if-then approach to solve a control problem rather than modeling total system. This logic depends on operator’s experience not on modeling of the system. Because of its usefulness in reducing complexity in mathematical Models it is gaining more attention. In power system area fuzzy logic is used in stability studies, unit commitment, and reactive power Control in distribution systems etc. fuzzy logic is made from fuzzification, knowledge rule base and de fuzzification. Steps to Choose the inputs to FLC: two inputs generator speed variation and speed derivative deviation used. Defining knowledge rule base and Choose membership functions for inputs in fuzzy set notation. Triangular membership functions are used.

Fuzzy control is a control method based on fuzzy logic. Just as fuzzy logic can be described as “computing with words rather than numbers. Fuzzy control can be simply described as “control with sentence rather than equations”. Controllers based on fuzzy logic give the linguistic strategies control conversion from expert knowledge in automatic control strategies. The development of control system based on fuzzy logic involves the following steps:

a. Fuzzification strategy
b. Data base building
c. Rule base elaboration
d. Interface machine elaboration
e. De fuzziffication strategy.

In addition, design of fuzzy logic controller can provide desirable both small signal and large signal dynamic performance at same time, which is not possible with linear control technique. The development of fuzzy logic approach here is limited to the design and structure of the controller. Here the input is voltage and its variations; the output constrain as the ref I .The inputs of FLC are defined as the voltage error, and change of error. The fuzzy controller ran with the input and output normalized universe (-1,1). Fuzzy sets are defined for each input and output variable. There are seven fuzzy levels (NB-negative big, NM-negative medium, NS-negative small Z-zero, PS-positive small, PM-positive medium, PB-positive big) the membership functions for input and output variables are triangular. The min-max method interface engine is used. The fuzzy method used in this FLC is center of area. The complete set of control rules is shown in Table.1. Each of the 49 control rules represents the desired controller respons particular situation. The block diagram presented in Fig.2 shows a FLC controller in the MATLAB simulation.

By using the fuzzy controller instead of PI controller the transient response of the IUPQC is very fast. In this paper we have taken fuzzy logic controller. From the conventional PI dc-link voltage controller PI controller is replaced by fuzzy logic controller and is taken as conventional fuzzy logic controller and from the fast acting dc-link voltage controller the PI controller is replaced by fuzzy controller and is taken as fast acting fuzzy logic controller. The fuzzy logic dc-link voltage controller gives fast transient response than that of PI dc-link voltage controllers. The transient response of the conventional and fast acting fuzzy logic dc-link controllers in figs

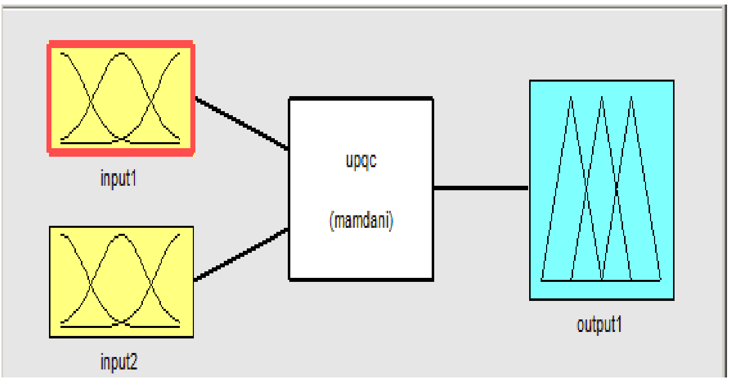


Fig .FLC controller in MATLAB simulation

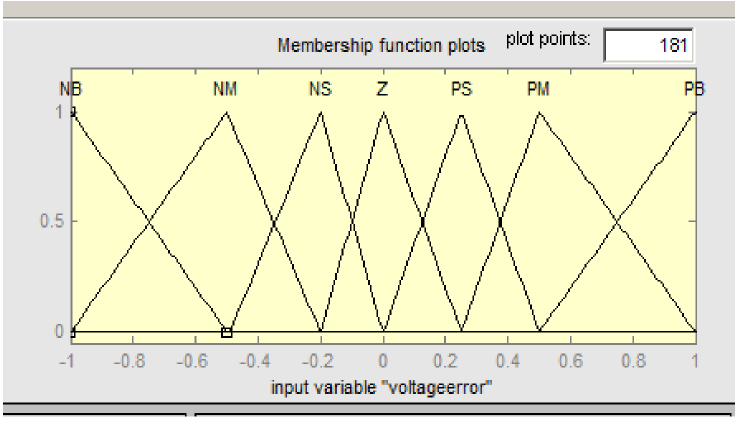


Fig: Input Variable Volatagerror

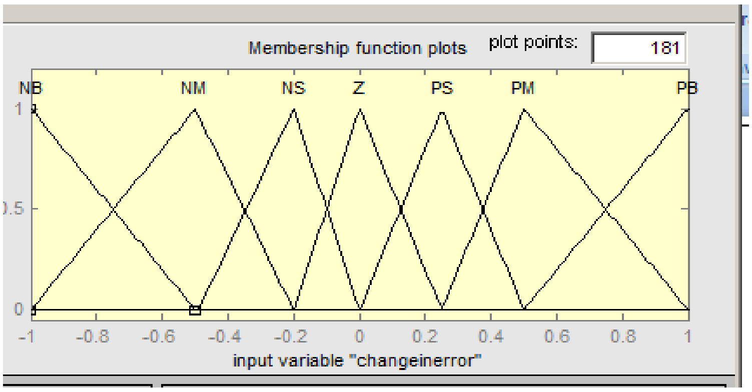


Fig: Input Variable Volatag change inerror

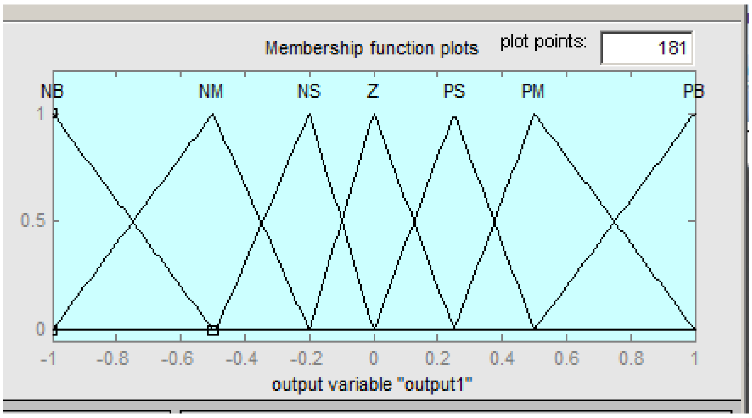
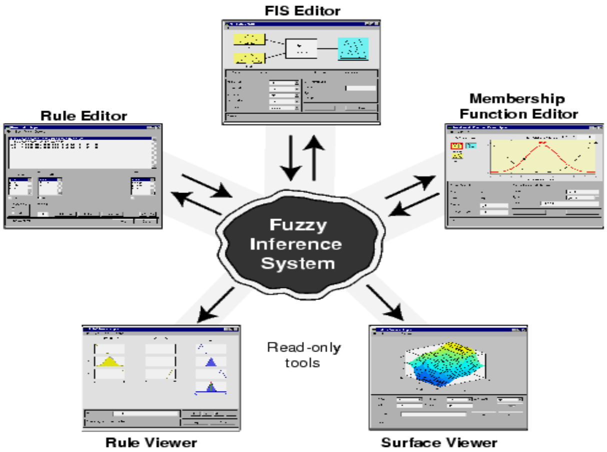


Fig: output Variable current

Fuzzy Logic Toolbox

The Fuzzy Logic Toolbox provides GUIs to let we perform classical fuzzy system development and pattern recognition Using the toolbox, we can:
- Develop and analyze fuzzy inference systems
- Develop adaptive neuro-fuzzy inference systems
- Perform fuzzy clustering

Fuzzy inference is a method that interprets the values in the input vector and, based on user defined rules, assigns values to the output vector. Using the GUI editors and viewers in the Fuzzy Logic Toolbox, you can build the rules set, define the membership functions, and analyze the behavior of a fuzzy inference system (FIS). The process of fuzzy inference involves all of the pieces that are described in Membership Functions, Logical Operations, and if-then rules.



There are five primary GUI tools for building, editing, and observing fuzzy inference systems in the Fuzzy Logic Toolbox. The Fuzzy Inference System or FIS Editor, the Membership Function Editor, the Rule Editor, the Rule Viewer, and the Surface Viewer:

FIS Editor - Displays general information about a fuzzy inference system.

Membership Function Editor-The Membership Function Editor is used to define the shapes of all the membership functions associated with each variable. The Rule Editor is for editing the list of rules that defines the behavior of the system.

Rule Editor - The Rule Editor is for editing the list of rules that defines the behaviour of the system.

Rule Viewer - Lets us to view detailed behaviour of a FIS to help diagnose the behaviour of specific rules or study the effect of changing input variables

Surface Viewer - Generates a 3-D surface from two input variables and the output of an FIS.

Power quality improvement using iupqc:

There are three ways to solve the problems of power quality and provide quality power customized to meet user's requirement:
- System improvement
- Use mitigation equipment based on power electronics
- Improvement of equipment immunity

Of these, the best way to handle power quality problems is to mitigate the effects of distorted voltage or current at the point of common coupling. This would ensure that the harmonics are restricted from entering the distribution system and contaminating the system power as a whole. Thereby, the other loads connected to the system are provided with clean power. This paper illustrates how various power quality disturbances are mitigated using equipment called IUPQC.

1) Mitigation of Voltage Sag

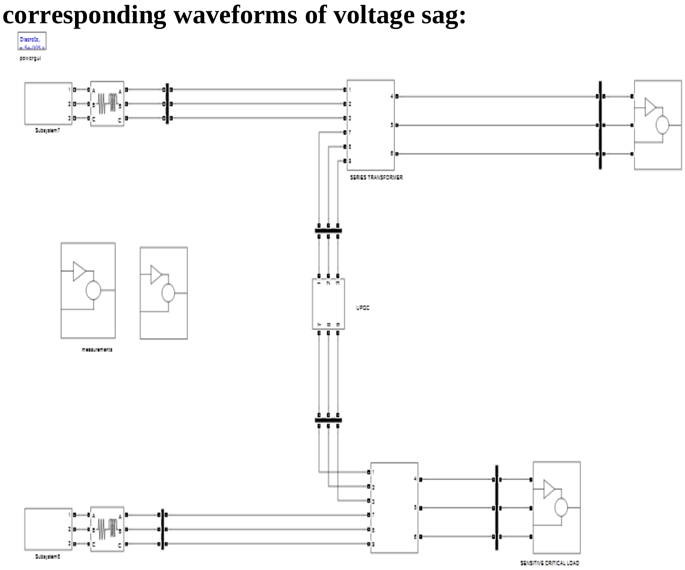
A 3-phase supply voltage (11kv, 50Hz) with impulsive sag of 0.5 p.u magnitude and the duration about 0.5 to 30 cycles is taken. With the system operating in the steadys tate, 15 cycle impulsive voltage sag of 0.5 p.u magnitude is occurring at 0.3msec for which the peak of the supply voltage reduces from its nominal value of 10kv to 5kv. The simulation results are shown in Fig.4. The Total Harmonic Distortion (THD) at load side is found to be 0.45%. The source voltage THD is effectively found to be 0.04%. In order to supply the balanced power required to the load, the DC capacitor voltage drops as soon as the sag occurs. As the sag is removed, the capacitor voltage returns to the steady state. The voltage injected by UPQC in kV is shown in Fig. 4(d). Active and reactive powers both on source and load sides are shown in Fig. 4 (e) and Fig. 4(f).

2) Mitigation of Voltage Swell

A 3-phase supply voltage (11kv, 50Hz) with momentary swell of 0.26 p.u magnitude and the duration about 0.5 to 30 cycles is taken. With the system operating in the steady state, a 21 cycle momentary voltage swell of 0.26 p.u magnitude is occurring at 0.3 m sec for which the peak of the supply voltage raises from its nominal value of 10kv to 12.6kV. In order to supply the balanced power required to the load, the DC capacitor voltage raises as soon as the swell occurs. As the swell is removed the capacitor voltage returns to the steady state. The Total Harmonic Distortion (THD) at load side is found to be 0.90%. The source voltage THD is effectively found to be 0.04%.

V. SIMULATION RESULTS

Simulation model and corresponding waveforms of voltage sag:



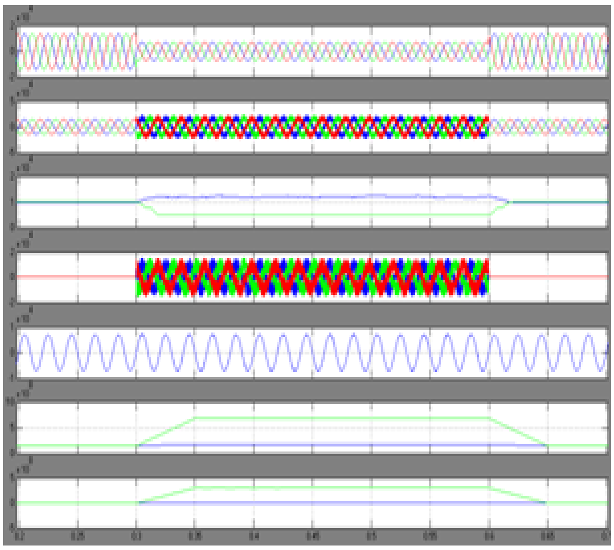
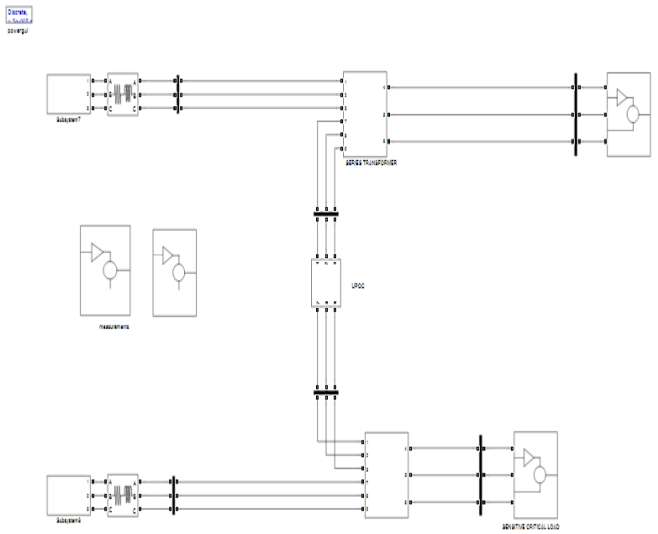


Fig. 4 Simulation results- Mitigation of voltage sag (impulsive) Using IUPQC

(a) Instantaneous source voltage (kV)
(b) Instantaneous load voltage (kV)
(c) Three phase load and source r.m.s voltage

(d) Voltage injected by UPQC (kV)
(e) Load current (KA)
(f) Source and load active powers (MW)
(g) Source and load reactive powers (MVAR).

Simulation model and corresponding waveforms of voltage swell:



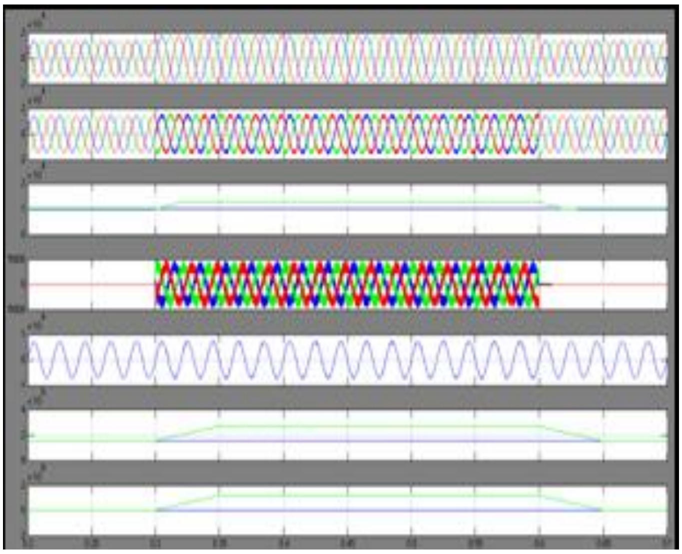


Fig.5. Simulation results- Mitigation of a voltage swell (momentary)

(a) Instantaneous source voltage (kV)
(b) Instantaneous load voltage (kV)
(c) 3-Φ load and source r.m.s voltage (pu)
(d) Voltage injected by UPQC (kV)
(e) Load current (kA)
(f) Source and load active powers (MW)
(g) Source and load reactive powers (MVAR

Comparison of Pi and Fuzzy results

	Pi results		**fuzzy results**				
THD			**THD**	**Currents1**	**currents**	**currents1**	**currents**
Voltage sag	**0.90**	**0.04**	**0.45**	**0.04**			
Voltage swell	**1.11**	**0.04**	**0.90**	**0.04**			

VI. CONCLUSIONS

The Sinusoidal Pulse Width Modulation based control scheme for the proposed IUPQC has been described. The control scheme for IUPQC with shunt (FUZZY) controller and series voltage controller has been developed. By using the fuzzy controller instead of PI controller the transient response of the IUPQC is very fast. In this paper we have taken fuzzy logic controller. From the conventional PI dc-link voltage controller PI controller is replaced by fuzzy logic controller and is taken as conventional fuzzy logic controller and from the fast acting dc-link voltage controller the PI controller is replaced by fuzzy controller and is taken as fast acting fuzzy logic controller. The fuzzy logic dc-link voltage controller gives fast transient response than that of PI dc-link voltage controllers. The transient response of the conventional and fast acting fuzzy logic dc-link controllers in figs

The simulation results shows that fuzzy controller of the shunt filter (current control mode), series filter (voltage control mode) compensates of all types of interruptions in the load current and source voltage, so as to maintain sinusoidal voltage and current at load side. The series filter was tested with different types of interruptions. The simulated results show that in all the stages of circuit operation, the feeder-2 load voltages and load currents are restored close to ideal supply.

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