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Reduction of Voltage Imbalance in a Two Feeder Distribution System Using Iupqc

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Abstract: - Day by day the use of sophisticated electronic devices is increased. Unfortunately these devices are very sensitive to power quality disturbances. Power quality disturbances is an occurrence manifested as a nonstandard voltage, current, or frequency that results in tripping or failure of end use equipments. One of the major problems dealt here are power sag/swell. To solve this problem custom devices are used. Among these, the distribution static compensator, dynamic voltage restorer and unified power quality conditioner which are based on the VSC principle are used for power quality improvement. This paper mainly proposes a new connection for a interline unified power quality conditioner (IUPQC) to improve the power quality between two feeders in a distribution system. The proposed configuration of the UPQC is developed and verified for various Power quality disturbances by simulating the model using MATLB/SIMULINK.

Index Terms: - Power Quality, PQ disturbances, Interline unified power flow controller (IUPQC), Unified power quality conditioner (UPQC), PI controller, Fuzzy logic controller (FLC), total harmonic distortion (THD).

I. INTRODUCTION

This paper mainly presents improvement of power quality between two feeders in a distribution system using IUPQC. With the development in the process control and digital electronics communications, a number of sensitive critical loads which require sinusoidal supply voltage for their proper operation are extensively used. At the same time increased use of nonlinear loads by both electric utilities and end users has been affecting the quality of electric power, by causing major power quality disturbances in the distribution system such as voltage and current harmonics, imbalances, voltage flicker, voltage sag/swell and voltage interruptions etc. As such improvement of power quality in distribution systems is a major issue for utilities. It is well established by the application of custom power controllers in distribution sector that power quality can be significantly improved.
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 [2, 3]. 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 D-STATCOM 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 [4]. It is also possible to connect two VSCs to two different feeders in a distribution system is called Interline Unified Power Quality Conditioner (IUPQC) which is the most sophisticated mitigating device for the power quality disturbances. It was firstly introduced to mitigate the current harmonics and voltage disturbances. The main aim of the IUPQC is to hold the voltages V_{t1} and V_{t2} 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. Control schemes of UPQC based on PI controller has been widely reported [5, 6].The PI control based techniques are simple and reasonably effective. However, the tuning of the PI controller is a tedious job. Further, the control of UPQC based on the conventional PI control is prone to severe dynamic interaction between active and reactive power flows. In this work, the conventional PI controller has been replaced by a fuzzy controller (FC). The FC has been used in APFs in place of conventional PI controller for improving the dynamic performance [7, 8]. The FC is basically nonlinear and adaptive in nature. The results obtained through FC are superior in the cases where the effects of parameter variation of controller are also taken into consideration. The FC is based on linguistic variable set theory and does not require a mathematical model. Generally, the input variables are error and rate of change of error. If the error is coarse, the FC provides coarse tuning to the output variable and if the error is fine, it provides fine tuning to the output variable. In the normal operation of UPQC, the control circuitry of shunt APF calculates the compensating current for the current harmonics and the reactive power compensation. In the conventional methods, the DC link capacitor voltage is sensed and is compared with a reference value. The error signal thus derived is processed in a controller. A suitable sinusoidal reference signal in-phase with the supply voltage is multiplied with the output of the PI controller to generate the reference current. Hysteresis band is normally (most often but not always) is imposed on top and bottom of this reference current. The width of the hysteresis band is so adjusted such that the supply current total harmonic distortion (THD) remains within the international standards.

II. POWER QUALITY PROBLEMS & ISSUES

A recent survey of Power Quality experts indicates that 50% of all Power Quality problems are related to grounding, ground bonds, and neutral to ground voltages, ground loops, ground current or other ground associated issues. Electrically operated or connected equipment is affected by Power Quality. Determining the exact problems requires sophisticated electronic test equipment [9]. The following symptoms are indicators of power quality problems:

- Piece of equipment mis operates at the same time of day.
- Circuit breakers trip without being overloaded.
- Equipment fails during a thunderstorm.
- Automated systems stop for no apparent reason.
- Electronic systems fail or fail to operate on a frequent basis.
- Electronic systems work in one location but not in another location.

The commonly used terms those describe the parameters of electrical power that describe or measure power quality are Voltage sags, Voltage variations, Interruptions Swells, Brownouts, Blackouts, Voltage imbalance, Distortion, Harmonics, Harmonic resonance, Inter harmonics, Notching, Noise, Impulse, Spikes (Voltage), Ground noise, Common mode noise, Critical load, Crest factor, Electromagnetic compatibility, Dropout, Fault, Flicker, Ground, Raw power, Clean ground, Ground loops, Voltage fluctuations, Transient, Dirty power, Momentary interruption, Over voltage, Under voltage, Nonlinear load, THD, Triples, Voltage dip, Voltage regulation, Blink, Oscillatory transient etc.,

Solutions to power quality problems:

There are two approaches to the mitigation of power quality problems. The solution to the power quality can be done from customer side or from utility side. First approach is called load conditioning, which ensures that the equipment is less sensitive to power disturbances, allowing the operation even under significant voltage distortion. The other solution is to install line conditioning systems that suppress or counteract the power system disturbances. Currently they are based on PWM converters and connect to low and medium voltage distribution system in shunt or in series. Series active power filters must operate in conjunction with shunt passive filters in order to compensate load current harmonics. Shunt active power filters operate as a controllable current source and series active power filters operate as a controllable voltage source. Both schemes are implemented preferable with voltage source PWM inverters, with a dc bus having a reactive element such as a capacitor. However, with the restructuring and dispersed generation, the line conditioning systems or utility side solutions will a play a major role in improving the inherent supply quantity.

III. 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.

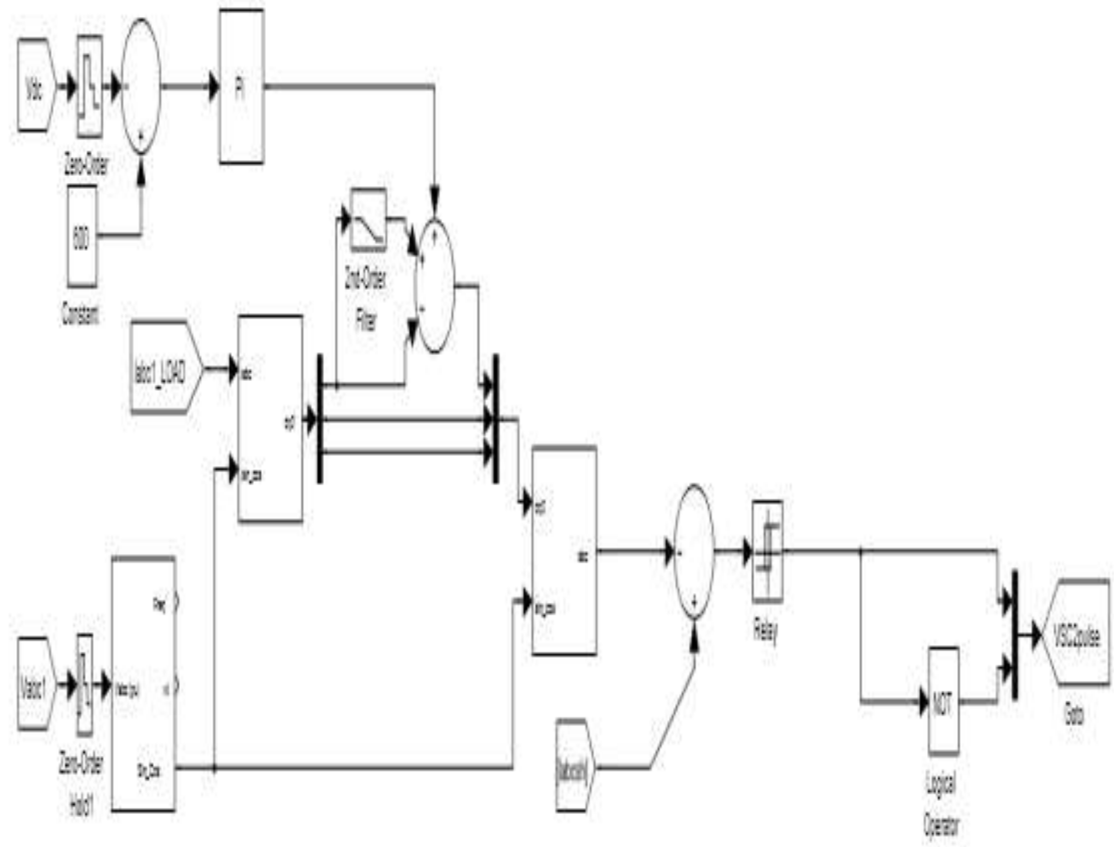


Figure: 1 PWM based control scheme

IV. SYSTEM DESCRIPTION

The IUPQC shown in Figure 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 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 C_{dc} and each inverter has a transformer connected at its output. 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 C_f and C_k 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 (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_{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 V_{t1}, V_{t2}, and V_{l2}, respectively.

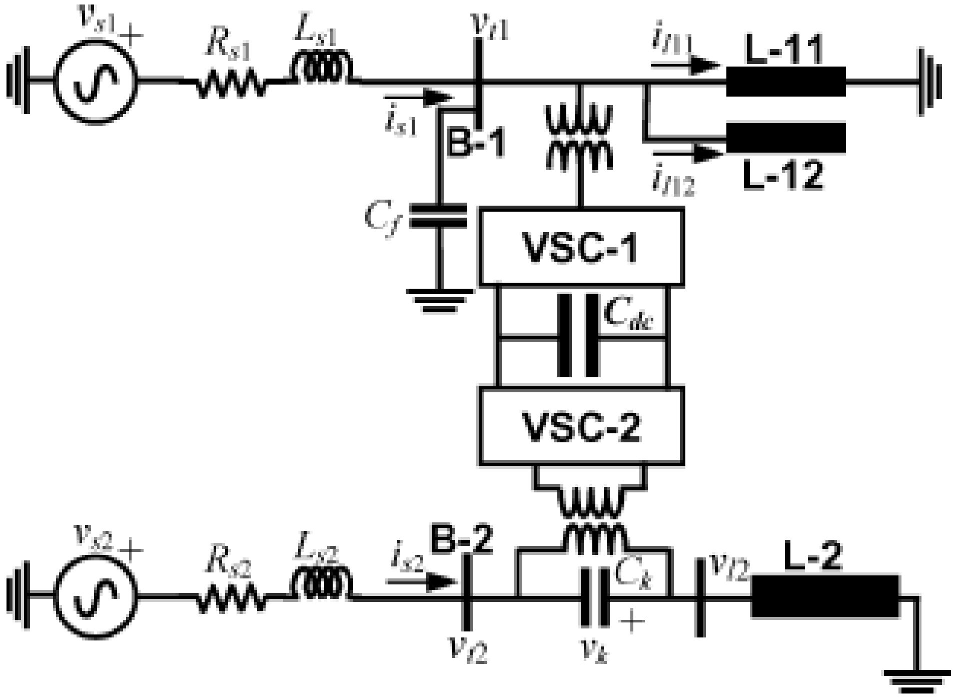


Figure 2: Typical IUPQC connected in a distribution system

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 across the sensitive load. The length of Feeder-1 is arbitrarily chosen to be twice that of Feeder-2. The shunt VSC (VSC-1) holds the voltage of bus B-1 constant. This is accomplished by making VSC-1 to track to a reference voltage across the filter capacitor Cf. It is assumed that the dc capacitor is initially charged and both the feeders along with the IUPQC are connected at time zero. Once the three-phase B-1 voltages become balanced, the currents drawn by Feeder-1 also become balanced. The load L-2 bus voltages are also perfectly sinusoidal with the desired peak as the converter VSC-2 injects the required voltages in the system. The bus B-2 voltages will have a much smaller magnitude.

V. FUZZY LOGIC CONTROLLER

Fuzzy control system is a control system based on fuzzy logic –a mathematical system that analyzes along input values in terms of logical variables that take on continuous values between 0 and 1. Controllers based on fuzzy logic give the linguistic strategies control conversion from expert knowledge in automatic control strategies. In the fuzzy control scheme, the operation of controller is mainly based on fuzzy rules, which are generated using fuzzy set theory. Fuzzy controller plays an important role in the compensation of PQ problem the steps involved in fuzzy controller are fuzzification, decision making, and defuzzification. Fuzzification is the process of changing the crisp value into fuzzy value. The fuzzification process has no fixed set of procedure and it is achieved by different types of fuzzifiers. The shapes of fuzzy sets are triangular, trapezoidal and more. Here, a triangular fuzzy set is used. The fuzzified output is applied to the decision making process, which contains a set of rules.

Using the fuzzy rules, the input for bias voltage generator is selected from FIS. Then, the defuzzification process is applied and the fuzzified calculated voltage (V_{dc}) is determined. The structure of designed FLC is illustrated as follows. And the steps for designing FLC are pointed below.

- Fuzzification strategy
- Data base building
- Rule base elaboration
- Interface machine elaboration
- Defuzzification strategy

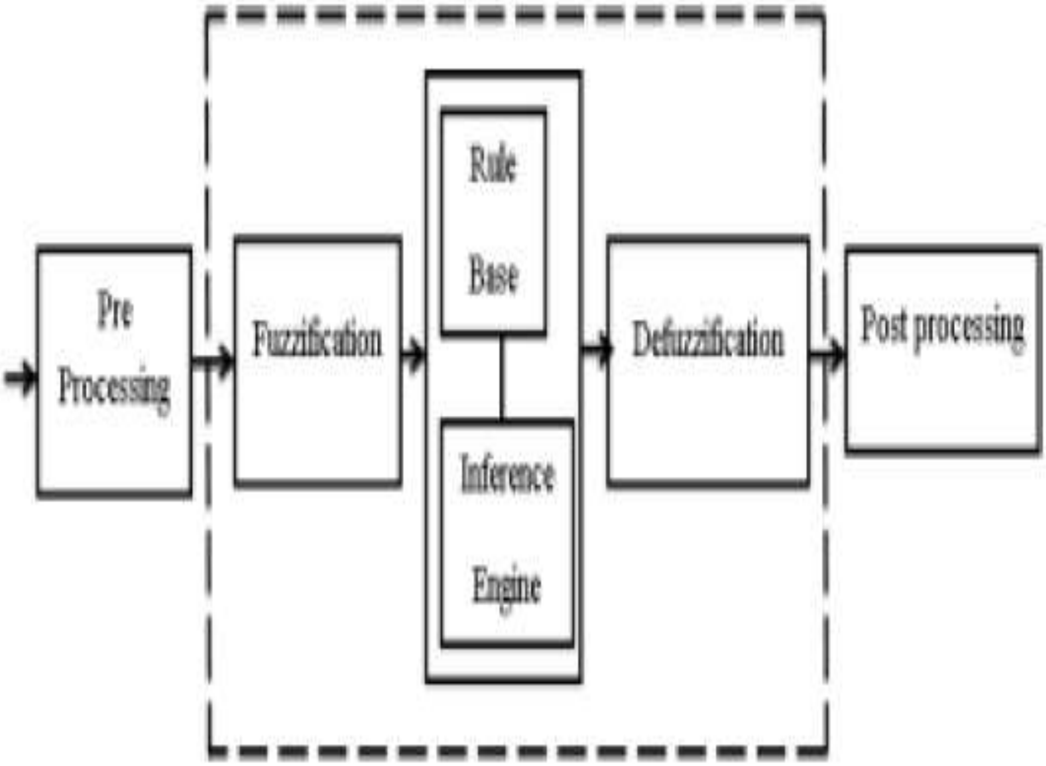


Figure 3: Fuzzy Logic Controller

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. .The inputs of FLC are defined as the voltage error, and change of error. 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 response to a particular situation. Fig.2 shows the block diagram of a fuzzy logic controller .The block diagram presented in Fig 3.shows a FLC controller in the MATLAB simulation. The simulation parameters are shown in Table1. The performance of degree of member ship functions are shown in Fig 4.

Error

W↓	**w Prime →**	**NL**	**NM**	**NS**	**ZE**	**PS**	**PM**	**PL**
NL		**NL**	**NL**	**NL**	**NL**	**NM**	**NS**	**ZE**
NM		**NL**	**NL**	**NL**	**NM**	**NS**	**ZE**	**PS**
NS		**NL**	**NL**	**NM**	**NS**	**ZE**	**PS**	**PM**
ZE		**NL**	**NM**	**NS**	**ZE**	**PS**	**PM**	**PL**
PS		**NM**	**NS**	**ZE**	**PS**	**PM**	**PL**	**PL**
PM		**NS**	**ZE**	**PS**	**PM**	**PL**	**PL**	**PL**
PL		**ZE**	**PS**	**PM**	**PL**	**PL**	**PL**	**PL**

Table.1 Fuzzy Rules

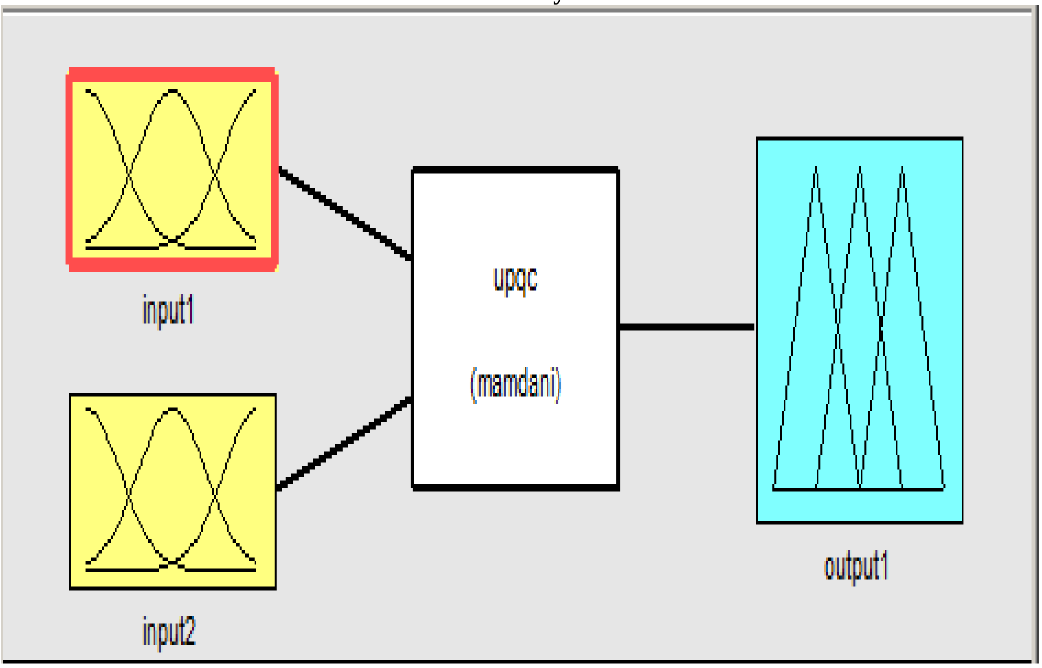


Figure 4: The block diagram presented in Figure above shows a FLC controller in the MATLAB simulation

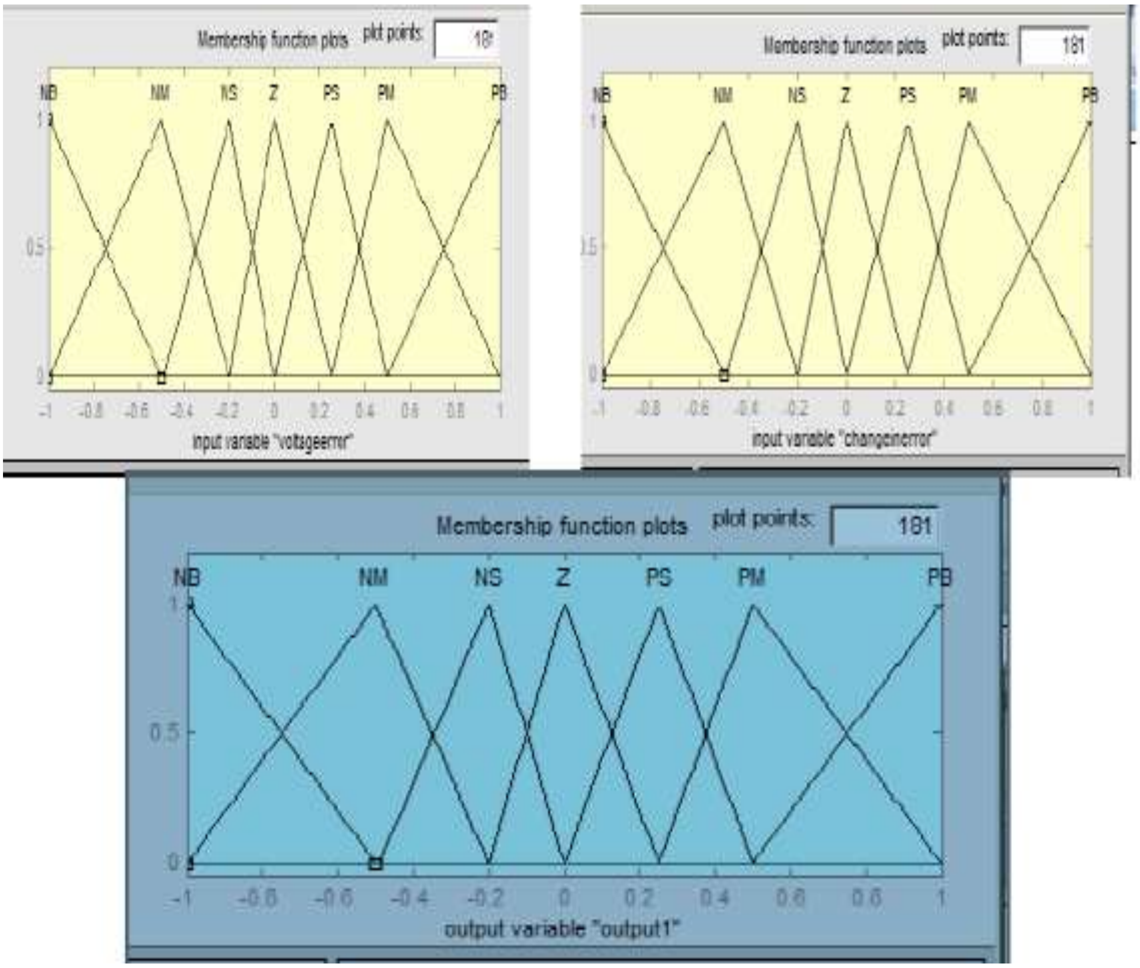


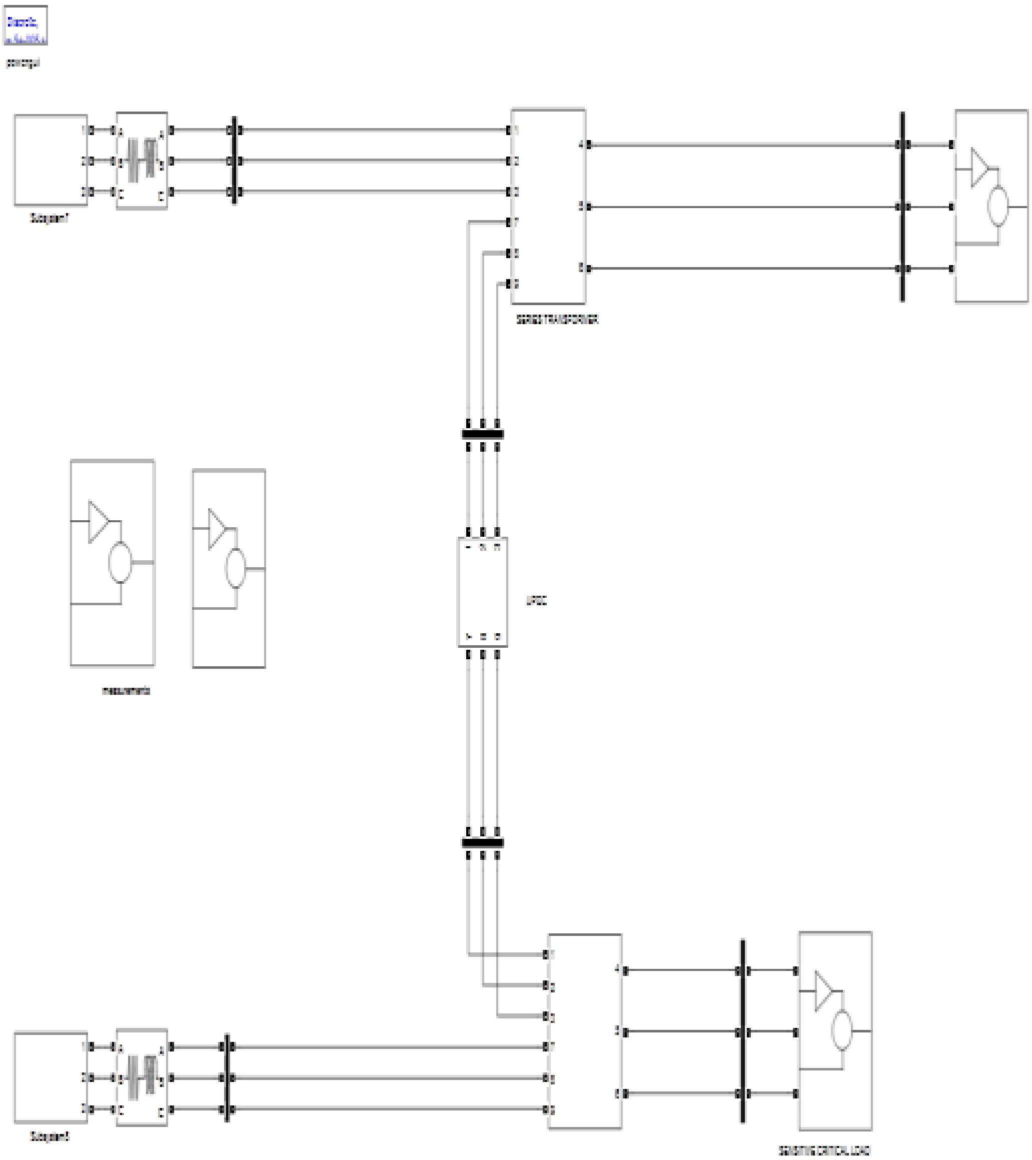
Figure 5: Performance of Membership Function (i) Error Voltage, (ii) Change of Error Voltage and (iii) Output Voltage.

VI. IMULATION RESULTS

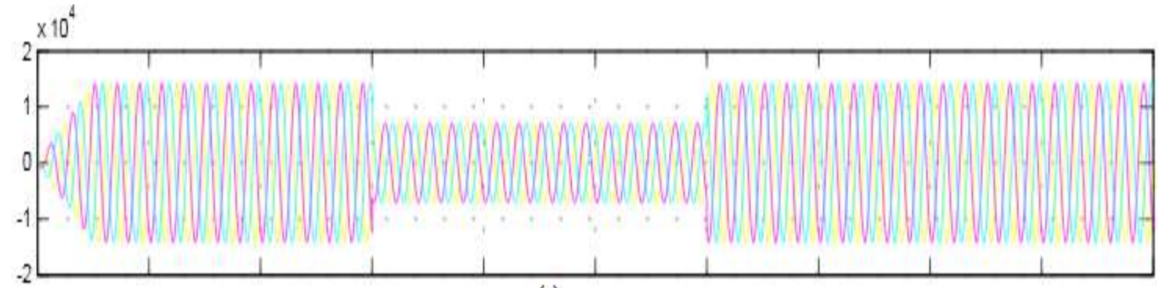
Simulation circuit and corresponding waveforms of voltage sag:

A. *MITIGATION OF VOLTAGE SAG:*

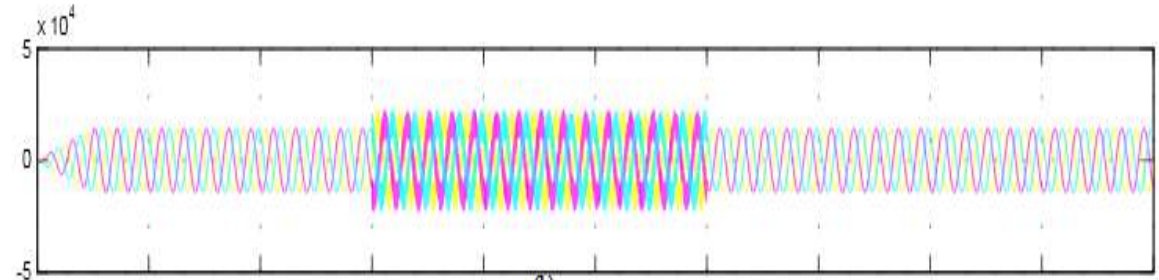
A 3-phase supply voltage (11kv, 50Hz) with impulsive sag of 0.5 p.u magnitude and the duration about 0.5 to 30 cycles is taken. With the system operating in the steady state, 15 cycle impulsive voltage sag of 0.5 p.u magnitudes is occurring at 0.3 msec for which the peak of the supply voltage reduces from its nominal value of 10kv to 5kv.



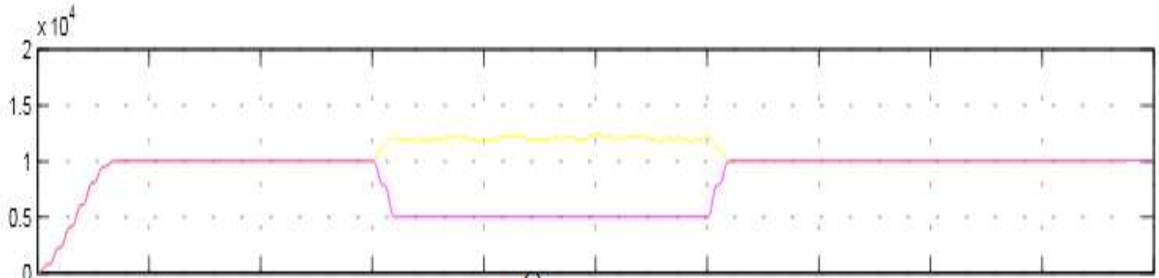
With PI controller:



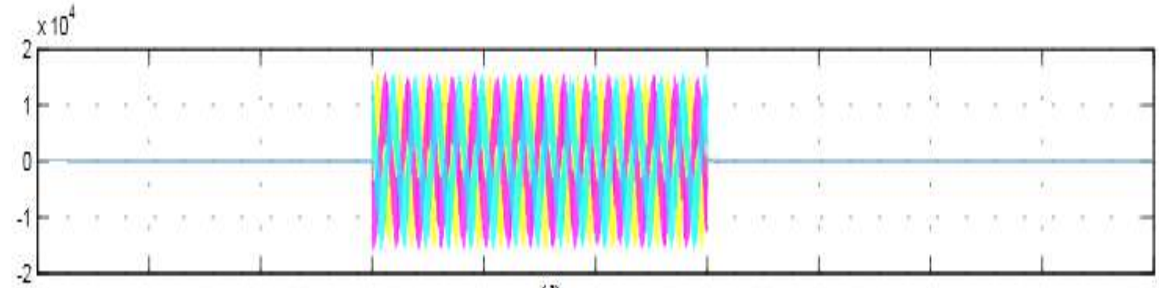
(a)



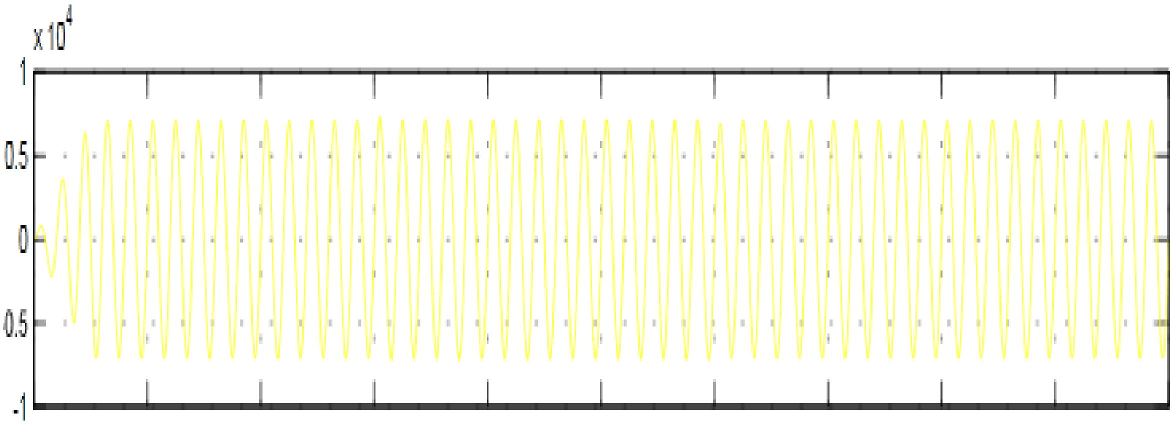
(b)



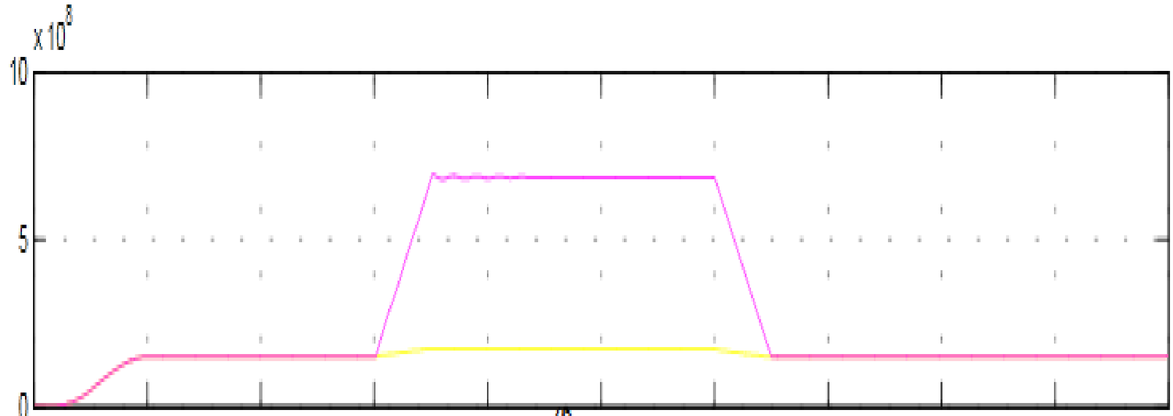
(c)



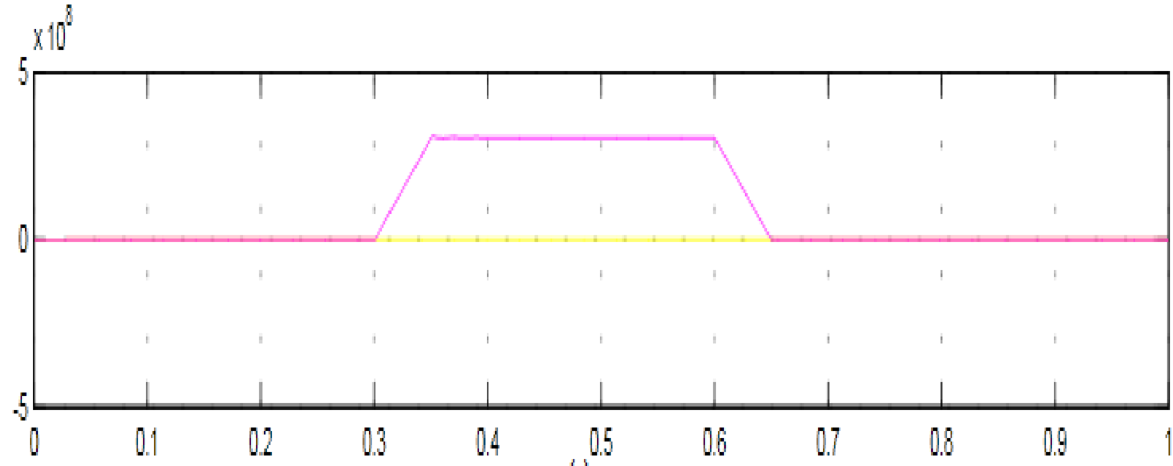
(d)



(e)

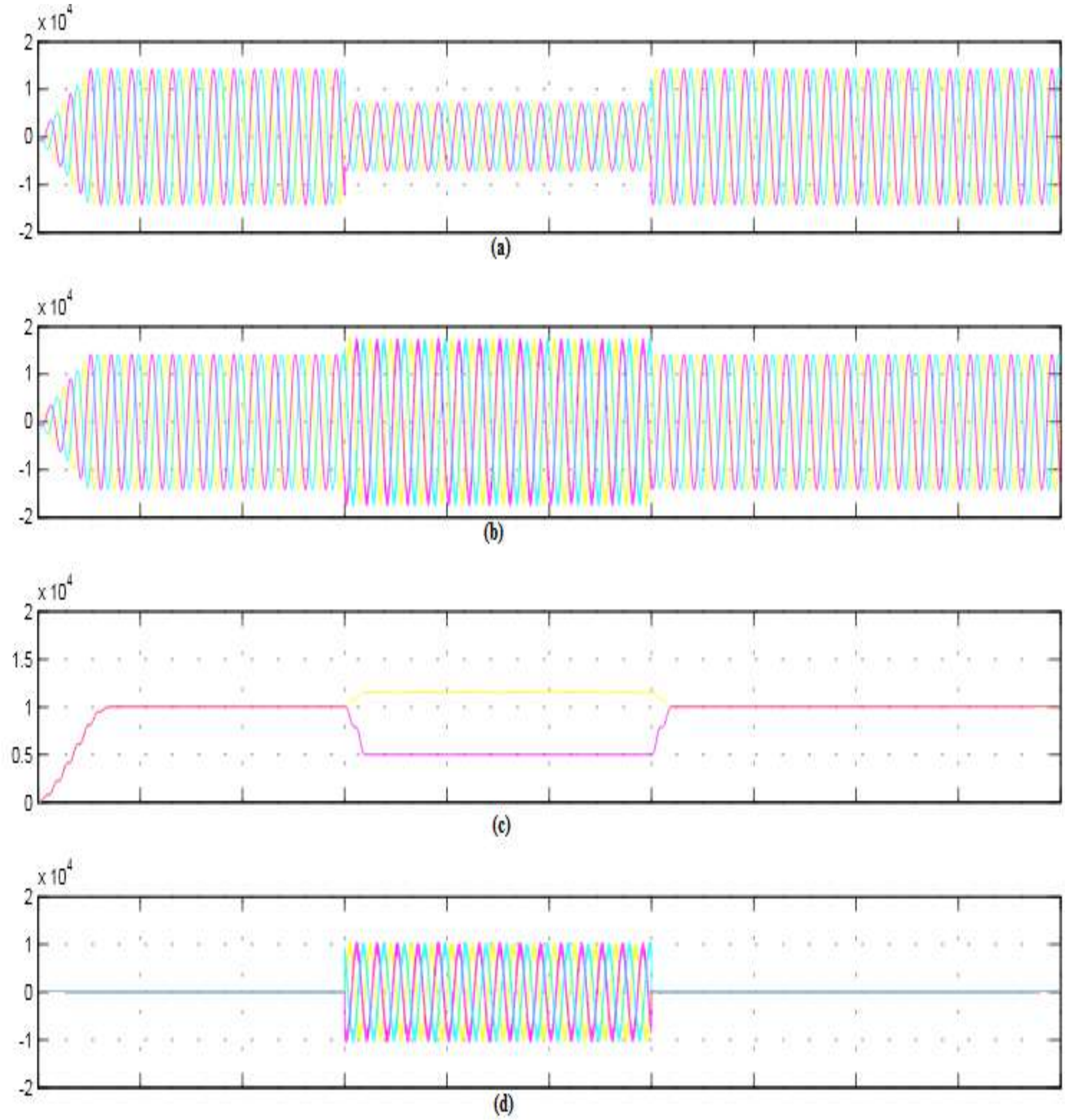


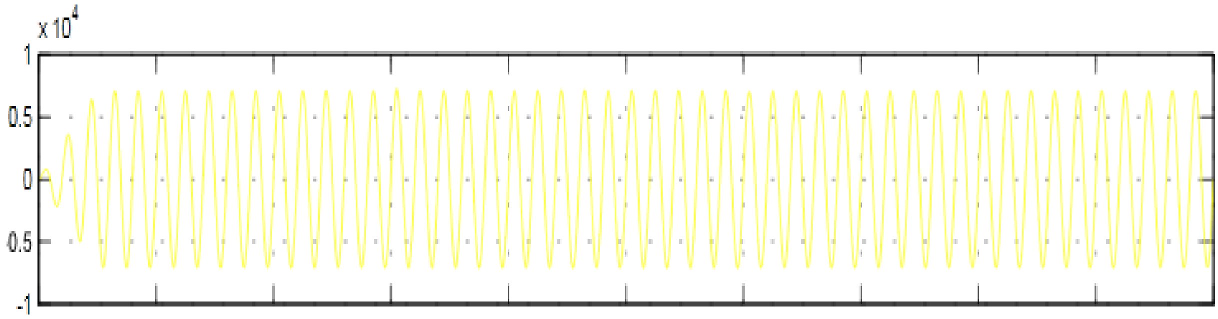
(f)



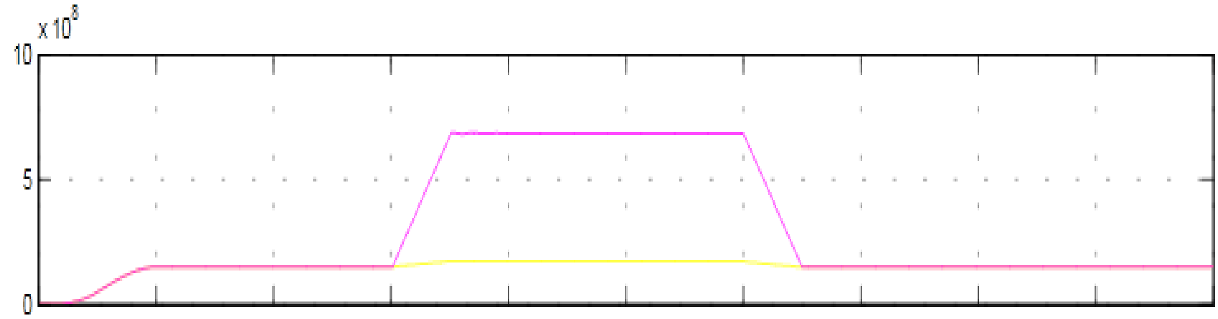
(g)

With Fuzzy controller:

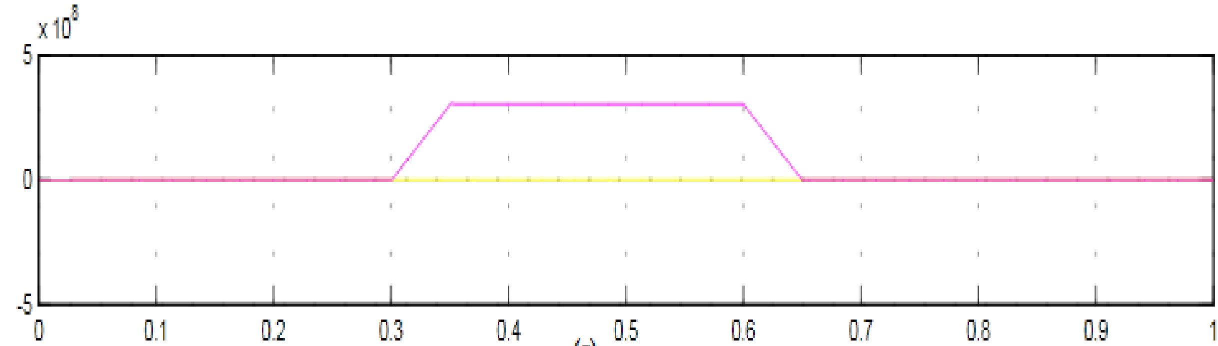

x 10^4
2
1
0
-1
-2
(a)
x 10^4
2
1
0
-1
-2
(b)
x 10^4
2
1.5
1
0.5
0
(c)
x 10^4
2
1
0
-1
-2
(d)



(e)



(f)



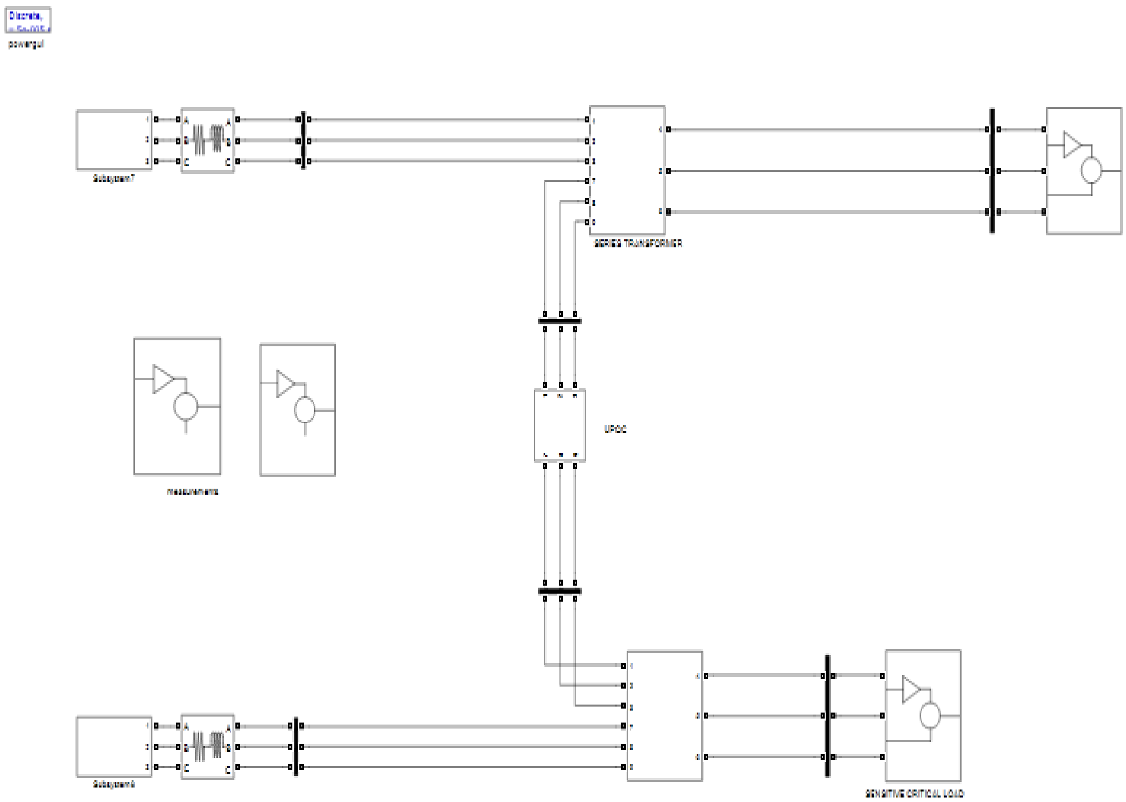
(g)

Figure 5: Simulation results- Mitigation of voltage sag for PI controller & Fuzzy controller equipped with 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).

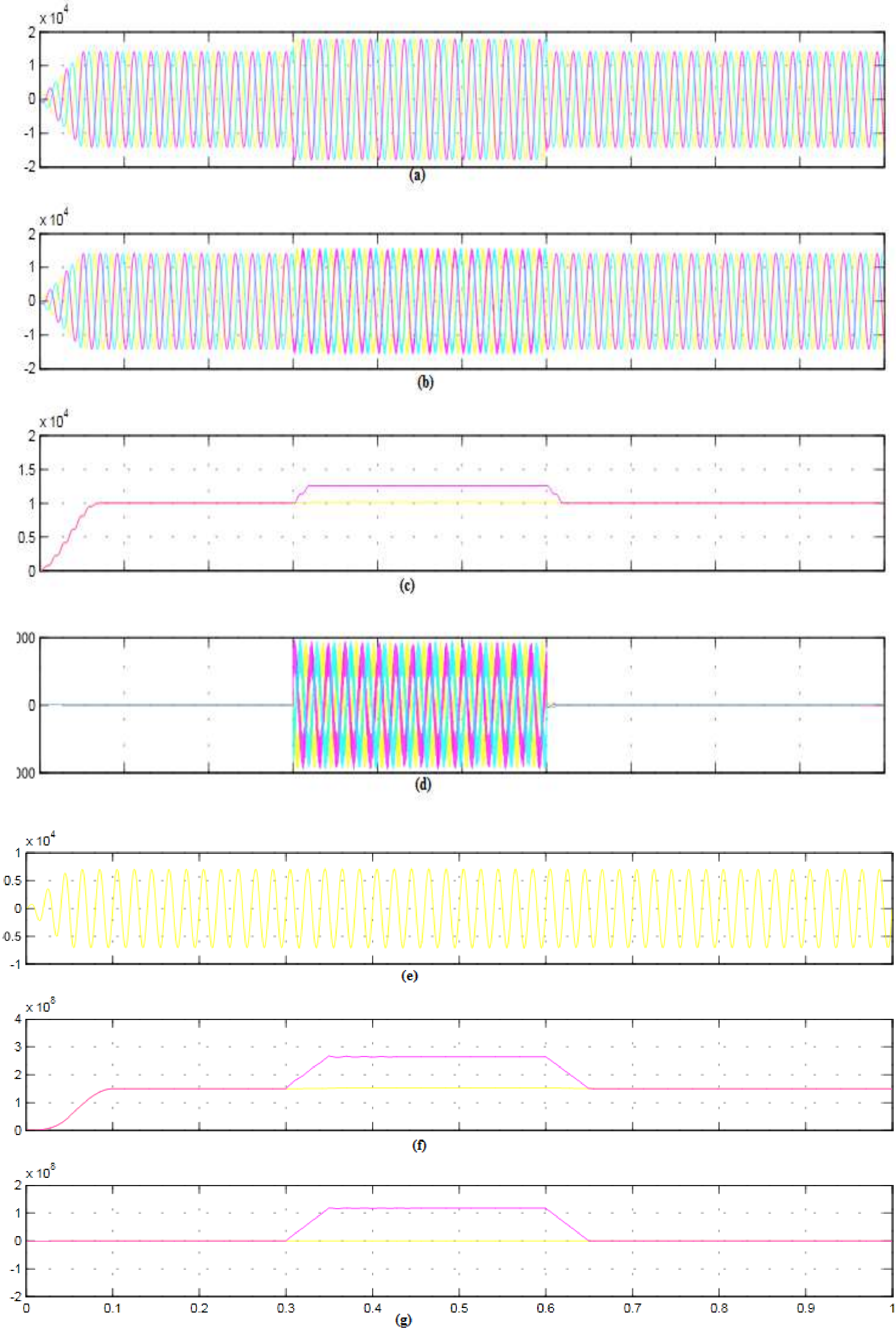
Simulation circuit and corresponding waveforms of voltage swell:

B. MITIGATION OF VOLTAGE SWELL:

A 3-phase supply voltage (11kv, 50Hz) with momentary swell of 0.26 pu 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 msec 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.



With PI controller:


x 10^4
2
1
0
-1
-2
(a)
x 10^4
2
1
0
-1
-2
(b)
x 10^4
2
1.5
1
0.5
0
(c)
0
(d)
x 10^4
1
0.5
0
-0.5
-1
(e)
x 10^8
4
3
2
1
0
(f)
x 10^8
2
1
0
-1
-2
0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1
(g)

With Fuzzy controller:

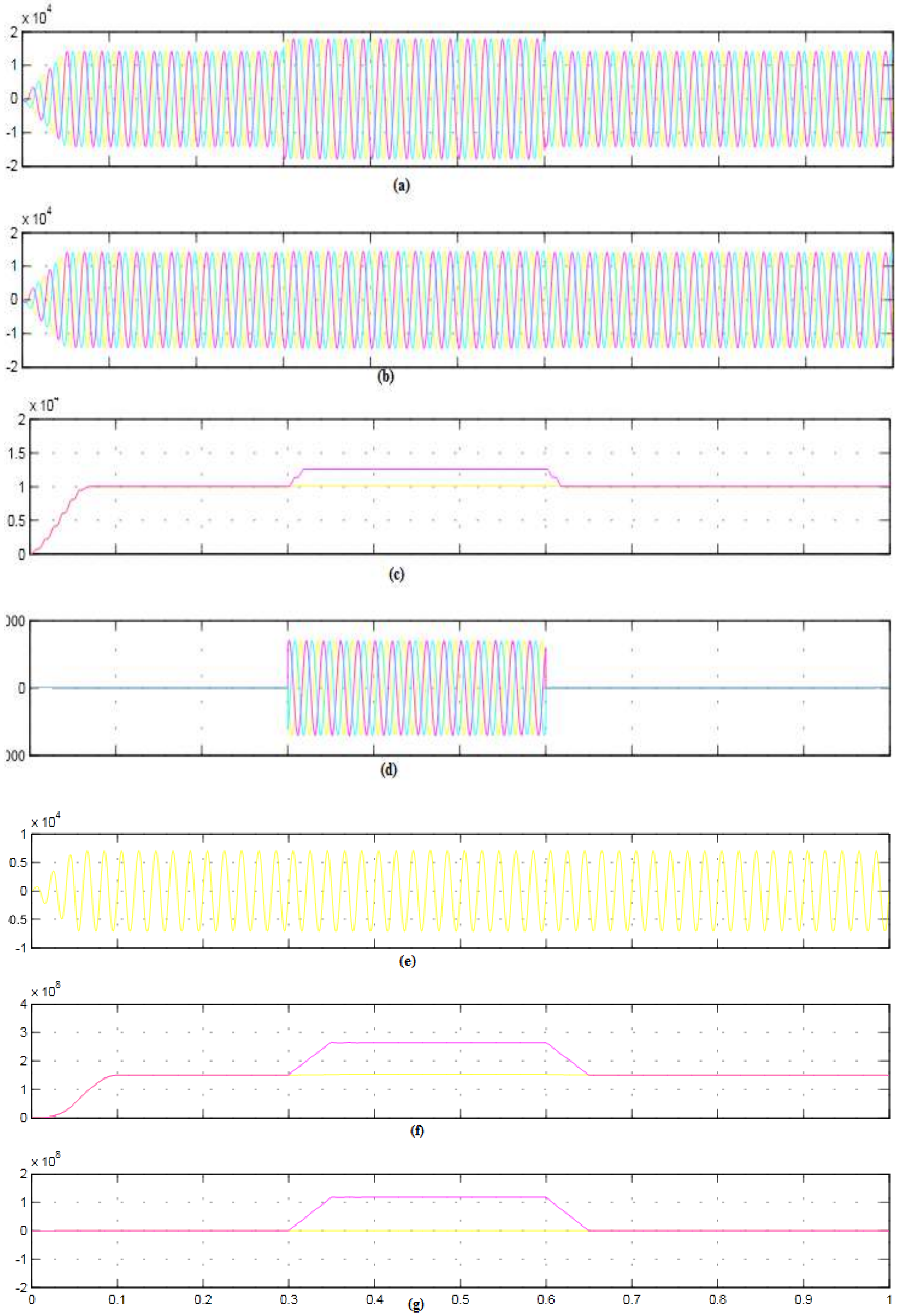


Figure 6: Simulation results-Mitigation of a voltage swell for PI controller & Fuzzy controller equipped with IUPQC

(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

The IEEE standard is that it should be below 5%. The current obtained when UPQC is in the operation with the proportional integral controller the THD is 0.90 and 1.11 which is quite low and satisfy the IEEE standard. And when the UPQC is in operation with the Fuzzy logic controller the THD is **0.45 and 0.90** which much more less than the pi controller.

Comparison of Pi and Fuzzy results

	Pi results THD		**fuzzy results 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**

VII. CONCLUSION

A new custom power device named as IUPQC mitigate current and voltage harmonics, to compensate voltage sag/swell and to improve voltage regulation. The compensation performance of shunt and a novel series compensator are established by the simulation results on a two-feeder, two bus distribution system. After simulation the results compensates the input voltage harmonics and current harmonics caused by non-linear load effectively by the control strategy. From the results it is observed that the THD of the source current at 0.15 s is **0.90** in the case of the PI controller while it is **0.45** in the case of the fuzzy logic controller scheme. Similarly, the THD of the source current at 0.25 s is **1.11** in case of the PI controller while it is **0.90** in case of the fuzzy logic controller scheme. Thus by seeing the result obtained through the simulation of IUPQC with both the controller PI and Fuzzy logic Controller it can be conclude that for the same load the THD obtained is less as compared to the conventional PI controller.

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