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Power Quality Mitigation by Generalized Unified Power Quality Conditioner

Veeresha K B, Thejaswi A H

Abstract: ***The network reconfiguring and compensating devices are the two different types of custom power solutions. The network reconfiguration devices consist of switchgear with current breaking, current restrict and current sending devices. The compensating device will compensate load by correcting power factor, unbalance etc. or supplied voltage quality will be improved. These devices are either connected in shunt (DSTATCOM) or in series (DVR) or a combination of both (UPQC) are the different types of custom power devices. This paper proposes compensating custom power device formed by the 3-phase, 3-level voltage source converters (VSC's) connected one on another through a common dc link to three independent feeders distribution system, which is known as Generalised unified power quality conditioner (G-UPQC). Simulations are performed using MATLAB/SIMULINK package to mitigate current imperfections in first feeder which is connected with unbalanced and Non-linear load and voltage imperfections in the other two feeders which are connected with unbalanced and sensitive loads.***

Keywords: ***Voltage Source Converters (VSC), Generalised unified power quality conditioner (G-UPQC), Active power filter (APF), Point of common coupling (PCC), Power quality (PQ) and Synchronous Reference Frame (SRF).***

I. INTRODUCTION

Electric utility companies are trying to narrow the gap between source and the demand. They are also sourcing their customers with constant magnitude of continuous sinusoidal voltage. Due to increase in size and number of nonlinear, poor power factor loads like adjustable speed drives, computing devices, furnaces, electronic ballasts, electronic power controls and traction drives this is increasingly difficult [1]. Distortion of voltage and current, voltage flicker, imbalances, voltage interruptions, sag/ swell in voltage and others are the power quality issues emerging in electric utilities and end users because of using more number of solid state electronic devices [2]. The non-sinusoidal voltage / current waveforms is nothing but the waveform distortion with integer multiples of fundamental frequency, referred as harmonics.

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Harmonic current flowing through source impedance form the utility creates the voltage distortion at the Point of Common Coupling (PCC). This causes a fault function of safety, metering equipment, control, protection, used in loads and devices used in system monitoring. Consonant flows can likewise make undesirable framework reverberation, capacitors over-burdening, expanded misfortunes causes decline in productivity,

obstruction with control and Communication signals, immersion of dispersion transformers and over-warming of lines. Burdens with a poor power factor show ineffectual utilization of the volt-ampere rating of utility gear, for example, generators, control transformers and dispersion lines [3]. Power quality problems can be mitigated either from the customer end or from the utility side. The customer end power quality mitigation also called as load conditioning, which is occasionally used because, it guarantees that the gear is less touchy to control unsettling influences, permitting activity even under noteworthy voltage waveform mutilation. The utility perspective, by introducing line molding frameworks control framework aggravations is relieved. The flywheels, super-capacitors and other vitality stockpiling frameworks, consistent voltage transformers, clamor channels, separation transformers, transient voltage flood silencers, symphonious channels, exchanged capacitor, thyristor controlled inductor combined with detached channels and so on., are the customary pay strategies don't have highlights like exact control with quick powerful reaction and on-line end of burden music. These conventional remuneration strategies are supplanted by Active Power Filters (APFs)/Voltage Source Converters (VSCs) in custom power applications for improving the power quality (PQ) of intensity circulation frameworks. There are basically, two kinds of APFs are shunt and arrangement APF. The shunt APF is additionally called as Distribution Static Compensator (DSTATCOM) can remunerate the unbalance and contortion in a heap with the end goal that a reasonable sinusoidal current moves through the feeder. It additionally controls the voltage of a dispersion transport. The arrangement Active Power Filter is called Dynamic Voltage Restorer (DVR) can relieve for twisting in the source side voltage with the end goal that the voltage over a touchy/basic burden terminal is impeccably controlled and voltage list/swell. Both DSTATCOM and DVR capacities can be performed by the Unified Power-Quality Conditioner (UPQC), however it has constraint as far as remuneration ability and bound to single conveyance feeder. Summed up Unified Power Flow Controller (GUPFC) is comprising of at least three VSCs, one associated in parallel and other at least two VSCs associated in arrangement with transmission lines fit for synchronous control of voltages at transport and free control of dynamic and receptive power streams of other transmission lines in a decade ago [4]. The concept of custom power devices [CPD] is emerged in the distribution system as like GUPFC which is used is used in transmission system. Currently, CPD consist of two back to back VSCs will be used in the most of research work on distribution system. An IUPQC (Interline Unified Power Quality Conditioner) consisting of two voltage source converters, one regulate the bus voltage which is connected in shunt and the other connected in series for voltage regulation across the sensitive load of the other feeder [5].

II. SYSTEM DESCRIPTION

A G-UPQC which is a modern and new custom power device was proposed in this paper for a multi-transport, three-feeder conveyance framework. It is acknowledged by three single-stage three-level VSCs associated consecutive by a typical dc interface capacitor as appeared in figure-1, let VS, VPPC, VL, VINJ are Source, purpose of regular coupling, burden, and remuneration voltages, separately, and iS, iL, iC are Source, burden and pay flows, individually. VSC1 is connected in shunt to a feeder1 which Source nonlinear load (Load1) and the two other VSCs (VSC2 and VSC3) are connected in series with their respective feeders (Feeder2 and Feeder3), which Source two separate critical sensitive loads (Load2 and Load3) in the distribution system. Shunt VSC will remunerate the responsive power and current flaws. It additionally mitigates the dynamic power required by the other two VSCs and manages dc interface capacitor voltage. Delicate burdens are secured by two arrangement VSCs and relieve voltage flaws, for example, voltage waveform bending, voltage hang/swell.

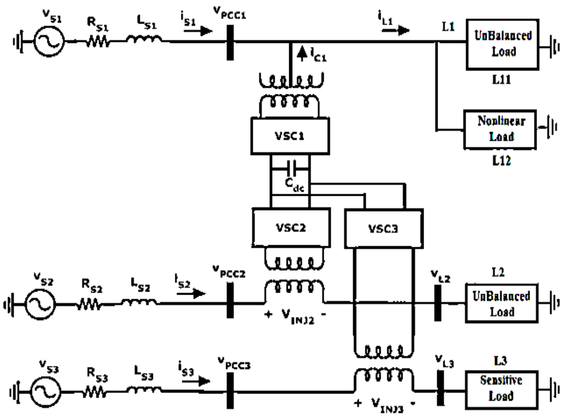

Fig. 1 Distribution system with the proposed G-UPQC

The conduct and wanted task are chosen by the control methodology utilized in the specific framework. The control procedure assumes a significant job in execution of a G-UPQC. The reference flag, for example, voltage and current acquired by G-UPQC control technique and, consequently, choose the exchanging moments of inverter switches, to such an extent that the ideal execution can be accomplished. Subsequently control methodology assumes the most critical job in any power gadgets based framework. There are a few control techniques/calculation accessible in the current writing those have effectively connected to G-UPQC frameworks. The control technique of G-UPQC might be actualized in three strategies:

Method-1: Voltage and current signals are sensed by their respective sensors.

Method-2: The compensating commands for GUPQC are generated by using time domain control techniques which are in terms of instantaneous active and reactive power. The pq theory and dq theory are used for used for obtaining the compensating signals. Both of these techniques exchange the voltage and current flag in ABC casing to stationary reference outline (pq hypothesis) or synchronously pivoting casing (dq hypothesis) to isolate the major and consonant amounts. In pq hypothesis, prompt dynamic and responsive forces are processed, while, the d-q hypothesis manages the present free of the source voltage. These techniques will results in dc amounts, that the genuine and responsive forces related with key segments (pq hypothesis), and the central part in misshaped voltage or current (dq hypothesis). Low pass channel or High pass channel are utilized to separate these amounts. DC signal extraction results in unfeeling toward any stage move blunders presented by LPF in αβ reference outline. The cutoff recurrence of LPF or HPF will influence the dynamic execution of the controller utilized.

Method-3: PWM based control techniques are used to derive the compensating commands in terms voltage and current for the gating signals of semiconductor switches of G-UPQC.

III. CONTROL STRATEGIES FOR SERIES AND SHUNT CONVERTER:

Generalised unified power quality conditioner simulation model was built using MATLAB Simulink. The simulations are carried out. A G-UPQC connected to a three feeder distribution system is shown in Fig. 4. The feeder impedances are denoted by the pairs (R_{s1}, L_{s1}), (R_{s2}, L_{s2}) and (R_{s3}, L_{s3}). The three feeders Source the loads L-1, L-2 and L-3. The load L-1 have two separate components—an unbalanced part (L-11) and a non-linear part (L-12). i_{l11} and i_{l12} be the currents drawn by these two loads. Load L-2 is an unbalanced load and load L-3 sensitive load that requires uninterrupted and regulated voltage. The shunt VSC (VSC-1) is connected to bus B-1 of Feeder-1, while the series two VSCs (VSC-2 and VSC-3) are connected at bus B-2 and B-3 at Feeder-2 and Feeder-3 respectively. Two control strategies like PQ theory and synchronous frame theory are implemented to G-UPQC to enhance the power quality with respect to voltage sag / swell and waveform distortion.

- **P-q hypothesis:** This hypothesis is utilized as a control technique for IGBTs of shunt compensator (VSC1) of G-UPQC for reference current sign age [24-25] as appeared in figure-2. Let iL1 be the momentary three-stage load flows of feeder-1 and VPCC1 is the regular coupling voltages are changed from a, b, c directions to α, β, 0 arranges by utilizing Clark change as in (1) and (2), individually, by utilizing the change framework (3).

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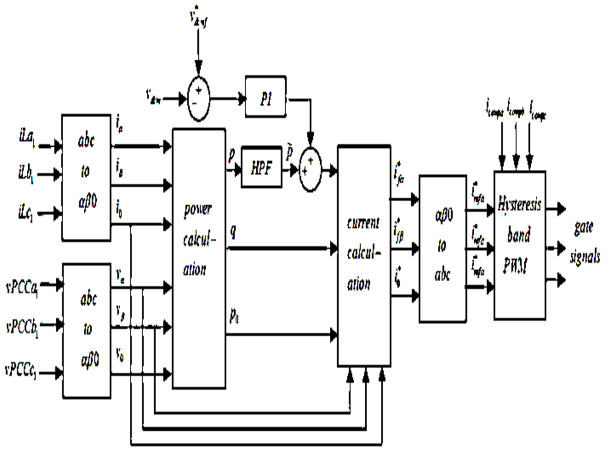

Fig. 2 Shunt Compensator Control

$$i_{\alpha\beta0} = C_{abc}^{\alpha\beta0} i_{L1\_abc} \quad (1)$$

$$v_{\alpha\beta0} = C_{abc}^{\alpha\beta0} v_{PCC1\_abc} \quad (2)$$

$$C_{abc}^{\alpha\beta0} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1/\sqrt{2} & 1/\sqrt{2} & 1/\sqrt{2} \\ 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix}, \quad C_{\alpha\beta0}^{abc} = C_{abc}^{\alpha\beta0^{-1}} \quad (3)$$

Give p a chance to be the three quick dynamic forces, q be the receptive power and p0 be zero succession control (p0) are characterized from the immediate three-stage load flows and regular coupling voltages dependent on α, β and 0 arranges as in (4).

$$\begin{bmatrix} p_0 \\ p \\ q \end{bmatrix} = \begin{bmatrix} v_0 & 0 & 0 \\ 0 & v_\alpha & v_\beta \\ 0 & -v_\beta & v_\alpha \end{bmatrix} \begin{bmatrix} i_0 \\ i_\alpha \\ i_\beta \end{bmatrix} \quad (4)$$

DC and oscillating component powers are expressed in terms of instantaneous powers as shown as in (5).

$$P = \bar{P} + \tilde{P}, \quad q = \bar{q} + \tilde{q}, \quad p_0 = \bar{p}_0 + \tilde{p}_0 \quad (5)$$

$\tilde{p}$, q and p_0 are source instantaneous powers that need to compensate shunt compensator when load receives only $\bar{p}$.

$\tilde{p}$ a chance to be the three quick dynamic forces, q be the receptive power and p0 be zero succession control (p0) are characterized from the immediate three-stage load flows and regular coupling voltages dependent on α, β and 0 arranges as in (6).

$$\begin{bmatrix} i_{f\alpha}^{*} \\ i_{f\beta}^{*} \end{bmatrix} = \frac{1}{v_\alpha^2 + v_\beta^2} \begin{bmatrix} v_\alpha & -v_\beta \\ v_\beta & v_\alpha \end{bmatrix} \begin{bmatrix} \tilde{p} + p_0 + p_{loss} \\ q \end{bmatrix} \quad (6)$$

α, β, 0 to a, b, c transformation is done following expression (7).

$$i_{abc}^{refc} = C_{\alpha\beta0}^{abc} i_{f\alpha\beta0}^{*} \quad (7)$$

- **d-q theory:** This theory is used to generate reference voltage for IGBTs of series compensators VSC2 and VSC3. The detailed control strategy used in reference voltage is shown in figure-3.

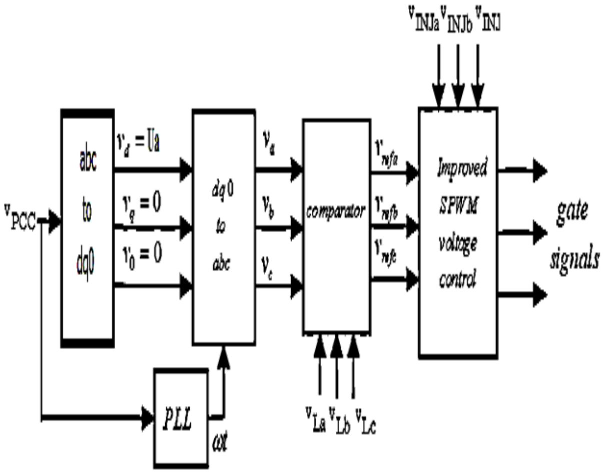

Fig. 3 Series Compensator Control

The drive signals for IGBT's of shunt compensator, as a kind of perspective flows as in (7) are contrasted and detected and three-stage shunt compensator yield flows. Mistake sign will be prepared by hysteresis band PWM controller before sending as sign to the drives of shunt compensator switches. The load-2 or load-3 will receive undistorted sinusoidal voltage that has constant amplitude even if the voltages sources of feeder-2 and feeder-3 are distorted. Opposite park change as in (8) which creates three stage adjusted sinusoidal burden voltages for feeder2 and feeder3 by changing from d, q, 0 to a, b, c.

$$\begin{bmatrix} v_{refa} \\ v_{refb} \\ v_{refc} \end{bmatrix} = \frac{2}{3} \begin{bmatrix} \sin(\omega t) & \cos(\omega t) & 1 \\ \sin(\omega t - 120^\circ) & \cos(\omega t - 120^\circ) & 1 \\ \sin(\omega t + 120^\circ) & \cos(\omega t + 120^\circ) & 1 \end{bmatrix} \begin{bmatrix} v_{L\max} \\ 0 \\ 0 \end{bmatrix} \quad (8)$$

The reference voltages are gotten by contrasting the three-stage voltages which are determined by utilizing (8) and the detected burden voltages VL2, VL3. The Improved sinusoidal heartbeat width balance (SPWM) strategy is utilized to process and produce gating signals for the IGBTs of arrangement compensators.

STAGE-4: The suitable rating G-UPQC model is implemented in three feeder distribution system. The control techniques, p-q theory and d-q theory are used to control the reactive power compensation and enhancement of power quality parameters. The obtained results are compared with the standard reference.

IV. RESULTS AND DISCUSSIONS

A. Without GG-UPQC at Feeder-1:

The Source voltage, PCC voltage of bus B-1 and load L-1 currents, Without G-UPQC in distribution system, are shown in Fig. 4. In all these figures wave forms shown are three phase waveforms with phases as R, Y and B respectively. Due to the presence of unbalanced and non-linear load in L-1, the voltages of L-1 are unbalanced and distorted. Load L-11 creates an unbalance in the current, while distortion is caused by load L-12. Let now we will show, how these waveforms can be improved using the G-UPQC as shown in Fig. 5. Before compensation Total Harmonic Distortion (THD) of load and source currents are identical and observed to be 15.28%. After compensation source currents THD reduced to 2.56% as shown in figure-5 and 6.Voltage at PCC before compensation is THD of 12.34%, after the compensation 4.2%.

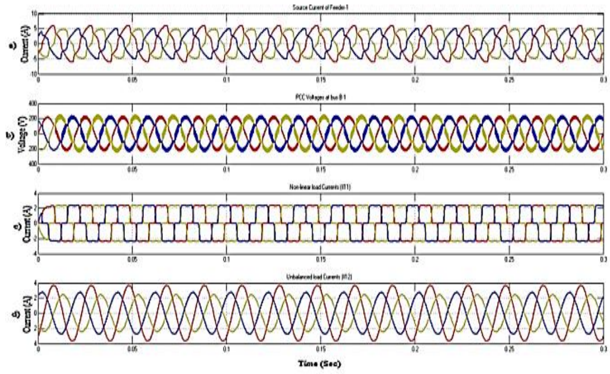

Figure-4: FEEDER -1 Bus Voltages and Currents in Absence of DSTATCOM

a) Source Currents b) PCC Voltages at bus B-1
c) Non-linear load Currents (I_{l11}) d) Unbalanced load Currents (I_{l12})

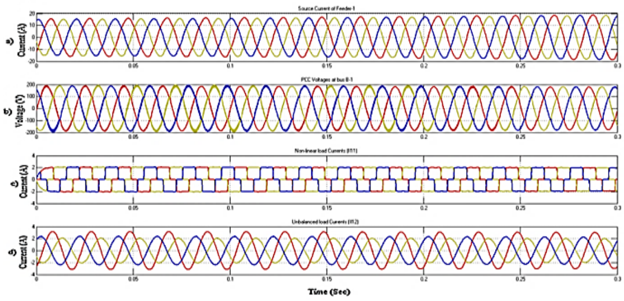

Figure-5: FEEDER -1 Bus Voltages and Currents in Presence of G-UPQC

a) Source Currents b) PCC Voltages at bus B-1
c) Non-linear load Currents (I_{l11}) d) Unbalanced load Currents (I_{l12})

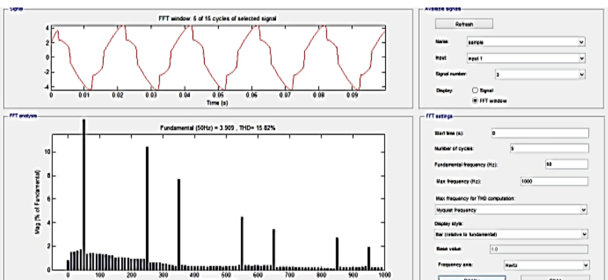

Figure 6: FFT Analysis of Source Currents without G-UPQC at Feeder-1

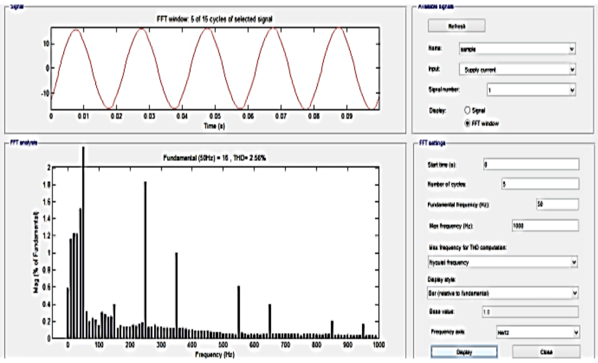

Figure 7: FFT Analysis of Source Currents with G-UPQC at Feeder-1

B. Compensation of Voltage Harmonics

Figs. 8(a) to 8(c) and Figs. 9(a) to 9(c), give the framework execution amid voltage music in feeder-2 and feeder-3 by G-UPQC. VSC2 infuses remuneration voltage as in Fig. 8(b) and thusly the heap voltage is seen to be sinusoidal as in Fig. 8(c). Thus, VSC3 in feeder3 infuses pay voltage as in Fig. 9(b) limiting the voltage contortion and improves the heap voltage to almost sinusoidal as in Fig. 9(c). The series compensators VSC2 and VSC3 of G-UPQC in feeder2 and feeder3 will reduce the THD from 19.95 % to 3% and 15.6%, to 4.85% respectively. G-UPQC improves the THD and frequency spectrum after compensation.

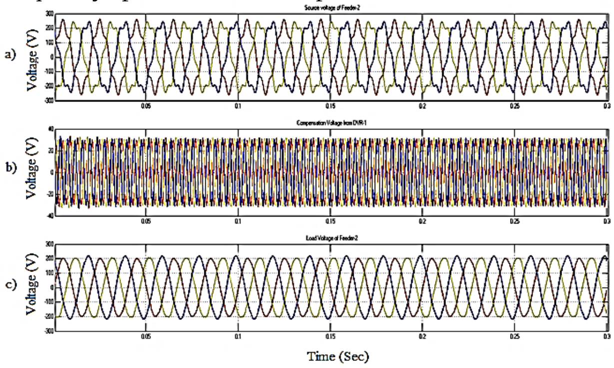

Figure-8: System response during Voltage harmonics FEEDER-2:

a) Source Voltages b) Compensation Voltages c) Load Voltages

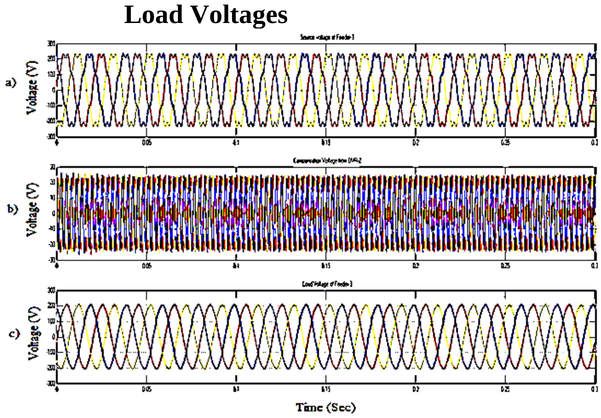

Figure-9: System response during Voltage harmonics Feeder-3:

a) Source Voltages b) Compensation Voltages c) Load Voltages

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C. *Sag and Swell Compensation at Feeder-2 and Feeder-3:*

The compensation performance of GUPQC for voltage sag and swell at feeder-2 and feeder-3 demonstrated in this case. 20% sag is created at 0.05 to 0.1 sec and swell at 0.2 to 0.25 sec for feeder-2, the compensation of GUPQC is as shown in figure-10 (in this figure-a are the source voltages, figure-b are the compensating voltages and figure-c are the load voltages). Similarly system response during sag at 0.1 to 0.15 sec and swell at 0.25 to 0.3 sec for feeder-3 is shown in figure-11.

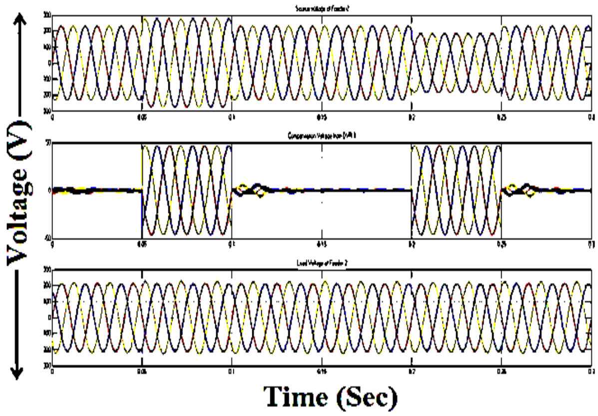

**Figure-10: System response during Voltage Sag and Swell in Feeder-2:
a) Source Voltages b) Compensation Voltages c) Load Voltages**

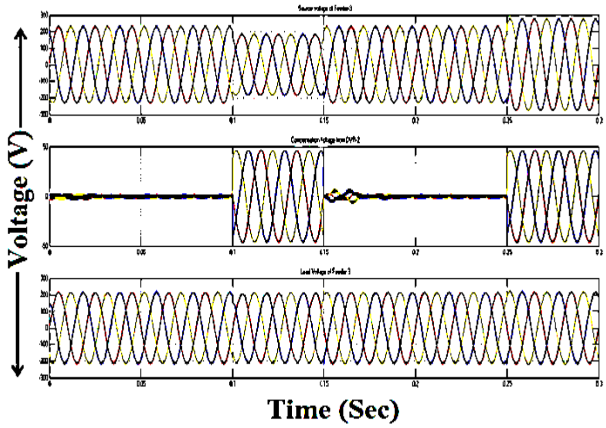

**Figure-11: System response during Voltage Sag and Swell in Feeder-3:
a) Source Voltages b) Compensation Voltages c) Load Voltages**

V. CONCLUSIONS

In this paper, G-UPQC a multiple series and shunt custom power device is proposed for three-feeder distribution systems. The proposed model can mitigate current imperfections in first feeder which is connected with unbalanced & Non-linear load and voltage imperfections sag and swell in the other two feeders which are connected with unbalanced & sensitive loads. Simulations are performed show the capability of G-UPQC in distribution system to minimize power quality problems. The Total Harmonic Distortion of voltage and current and other results obtained are within IEEE standards. The compensation functions of G-UPQC can be increased by incorporating more number of VSC's. The proposed custom power device can be attractive for power quality enhancement in multi-bus/ multi-feeder distribution system in near future.

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