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Original Article

Enhancement of Power Quality using Single Phase Generalised Unified Power Quality Conditioner in Distribution System

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Abstract *- The main function of Custom Power Devices (CPDs) is to provide Quality Electrical Power per the customer's requirements in the distribution system. For this purpose, CPDs are connected to medium or low-voltage level distribution systems with high- speed power electronic converters/static controllers. In this paper, a CPD called GUPQC consisting of three voltage inverters connected to a common DC-link energy storage capacitor is used in the three-bus distribution system to address power quality issues. The GUPQC simulation model in a single-phase system is simulated in MATLAB. The p-q theory control strategy is used to obtain the required compensating signal to compensate for harmonics of load current at bus-1, and the UVT control strategy is used to generate compensating signal to mitigate the voltage variations during voltage sag / swell at the source bus.*

Keywords *- Custom Power Devices (CPDs), Active Power Filter (APF), GUPQC, Voltage Sag, Voltage Swell, Electrical Power Quality (EPQ) and Distribution System (DS).*

1. Introduction

The electrical utilities aim to deliver continuous sinusoidal voltage with a fixed magnitude and frequency to their consumers and regulated sinusoidal currents at the AC mains. Today's AC distribution systems face serious Electrical Power Quality (EPQ) issues, such as high reactive power requirements, unbalanced loads, harmonic-rich load currents and very high neutral currents [1].EPQ enhancement in DSs is, therefore, crucial to counteract the inevitability of excessive use of nonlinear loads in electrical devices which are prone to EPQ issues. The consistency and price of EPQ for the new economy in the smart grid distribution system (DS) have now become a priority as electrical utilities shift towards the smart grid [2-3]. The main function of CPDs is to provide EPQ as per the customer's requirements in the distribution system. For this purpose, CPDs are connected in medium or low-voltage level distribution systems with high-speed power electronic converters or static controllers [4-5].In 2011, a recent GUPQC configuration was proposed, combining two series and one shunt VSCs connected to three independent distribution feeders/buses. It mitigates two feeder/bus voltage imperfections and other feeder/bus current imperfections. GUPQC improves the EPQ of a multi-bus/multi-feeder DS by reducing harmonics caused by the distorted supply voltage and nonlinear loads [6]. GUPQC-based cascade multilevel converter (CMC) consists of one feeder/bus with a five-level CMC as shunt compensator and three-level CMCs in other feeders [12]. [8] The proposed to control the output of the VSCs is composed of a series of six open/close circuit switches that can be configured in at least seventeen configurations to make the CUPQC work as APFs, UPQC, IUPQC, MC-UPQC and GUPQC [9-11].

2. Block Diagram of GUPQC

The GUPQC consists of three bus systems. Bus-1 is connected with non-linear loads, and bus-2 and bus-3 are connected with sensitive loads, as shown in Figure-1. Due to the non-linear load present at bus-1, current harmonics are generated. These harmonics will propagate from load to source and other loads connected within the GUPQC system. In order to compensate for these current harmonics, DSTATCOM is used. With respect to bus-2 and bus-3, source side variations in terms of voltage sag and swell are analysed. As bus-2 and bus-3 are connected with sensitive loads, any variation source in terms of voltage sag and/or swell for these buses needs to be compensated and required to maintain the load voltage of 1 p.u. In order to compensate for these voltages variation, DVR-1 at bus-2 and DVR-2 at bus-3 are used.

3. Simulation Results and Discussions

In this section, the following simulation case studies are considered to study the performance of GUPQC to compensate for current harmonics, voltage sag and voltage swell conditions.

The first case study presents the DSTATCOM ability to compensate for the non-linear load's current harmonics at bus-1.

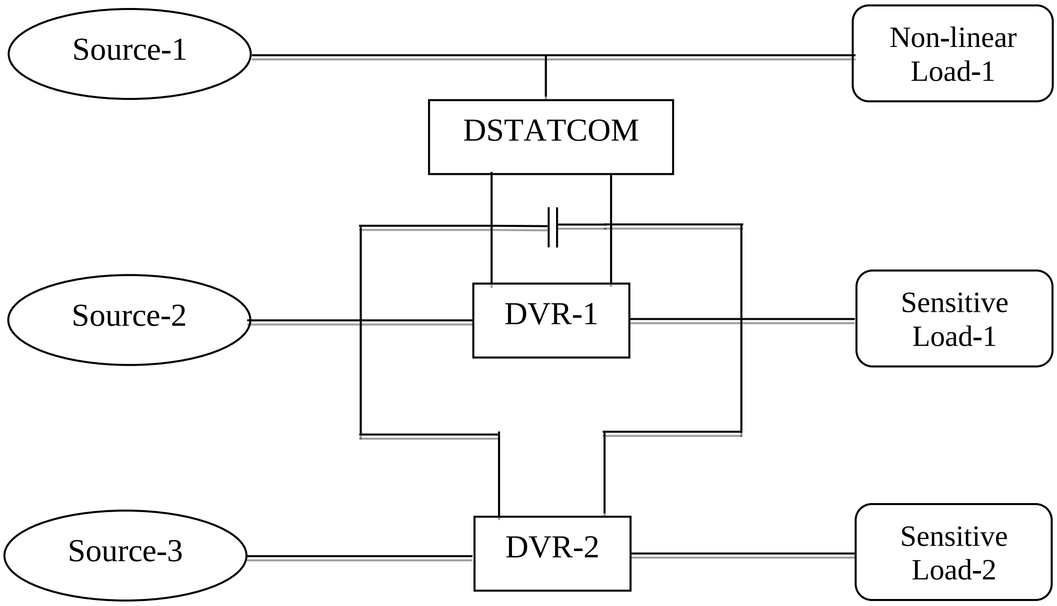


Fig. 1 Block diagram of GUPQC connected to DS

The second & third case studies reveal the DVR's voltage harmonics compensation.

The fourth case study shows the DVR's performance ability for voltage sag at bus-2 and voltage swell at bus-3.

3.1. Current Harmonics Compensation at bus-1

In this case, the p-q control strategy is used to compensate current harmonics of nonlinear load at bus-1. Before compensation, source and load currents are similar, as shown in Figure-2. The source current or load current THD before compensations is 87.07%, as shown in Figure-4. Due to the presence of DSTATCOM, it injects the required current component to make the source current harmonic-free, as represented in Figure-3(b). After compensation source current becomes nearly sinusoidal in shape, as shown in Figure-3(c). The THD of the source is current after compensations are decreased to 0.01%, as shown in Figure-5. The THD before and after DSTATCOM compensations are mentioned in Table-1.

Table 1. Simulation case study THD at bus-1

Bus	THD before compensation		THD after compensation	
	Source Current	**Load Current**	**Source Current**	**Load Current**
1	73.26%	73.26%	0.01%	73.26%

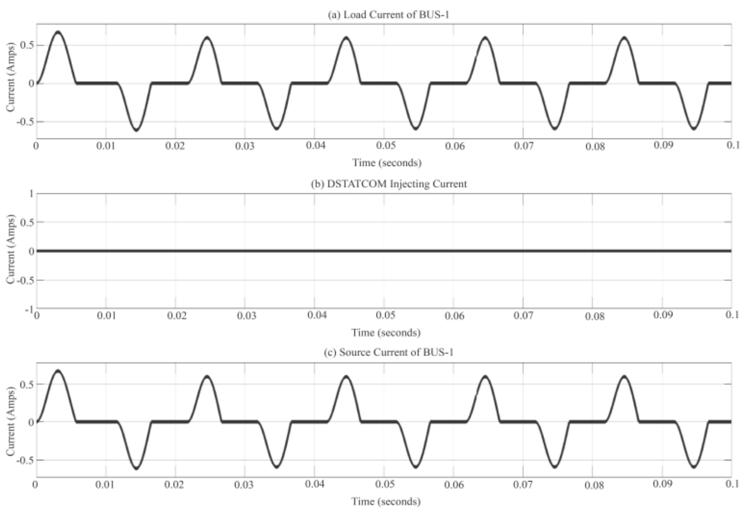


Fig. 2 Before current harmonic compensations at bus-1
(a) Load current, (b) DSTATCOM injecting current and (c) Supply current

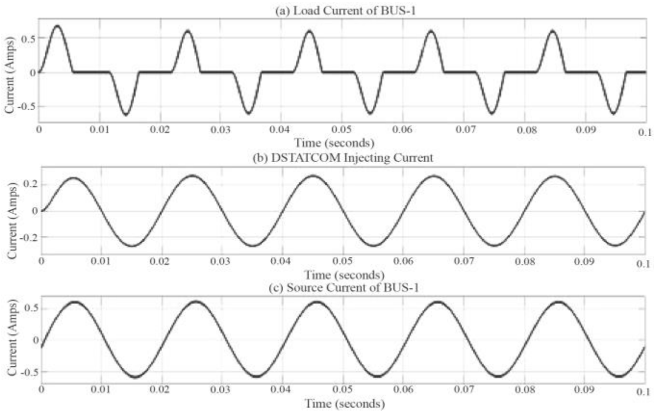
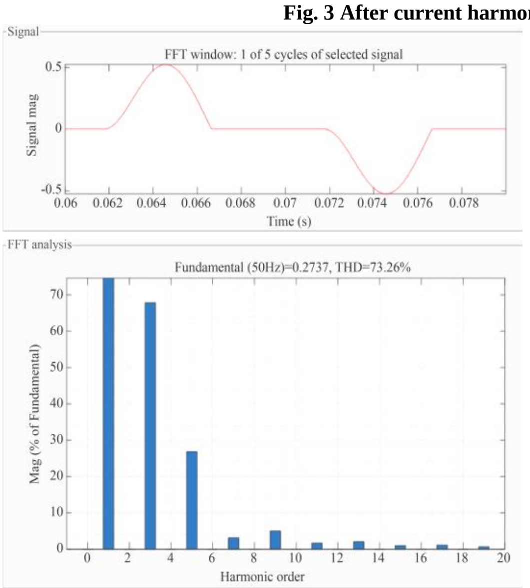
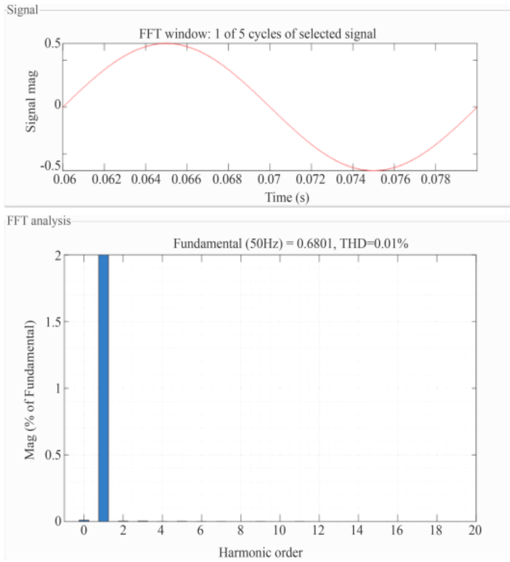


Fig. 3 After current harmonic compensations at bus-1





(a) Load current, (b) DSTATCOM injecting current and (c) Supply current

Fig. 4 THD spectrum of the load/source current of bus-1 **Fig. 5 THD spectrum of the source current of bus-1**

3.2. Voltage Harmonics Compensation at bus-2 and bus-3

In order to assess the performance of the GUPQC series compensators using the UVT control strategy, supply voltages of bus-2 and bus-3 are distorted with voltage harmonics at their respective source by injecting 20 % magnitude of 3rd and 5th harmonics. The supply, compensation and load voltages of bus-2 and bus-3 are shown in Figures 6 (a) to (c) and Figures8 (a) to (c), respectively. In order to mitigate bus-2 supply voltage harmonics, at t = 0 sec, DVR-1 came into operation (Figure-6 (b)), and the load voltage of bus-2 became nearly sinusoidal, as depicted in Figure-6 (c). Similarly, to compensate for bus-3 source voltage harmonics, at t = 0 sec, DVR-2 came into operation (Figure-8 (b)), and the load voltage of bus-2 became nearly sinusoidal, as shown in Figure-8 (c). After the DVRs compensation, the THD of the load voltages of bus-2 and bus-3 decreased from 28.32% to 1.36% and 28.32% to 0.92%, respectively, as depicted in Figures 7 and 9. This demonstrated the DVRs performance in reducing the THD of load voltages.

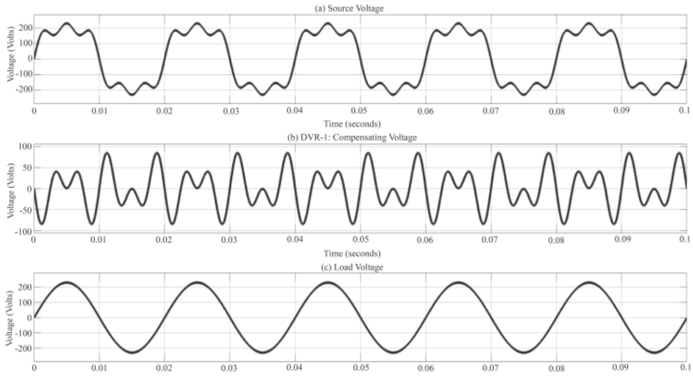


Fig. 6 Voltage harmonics compensations at bus-2
(a) Source voltage, (b) DVR-1 compensation voltage and (c) Load voltage

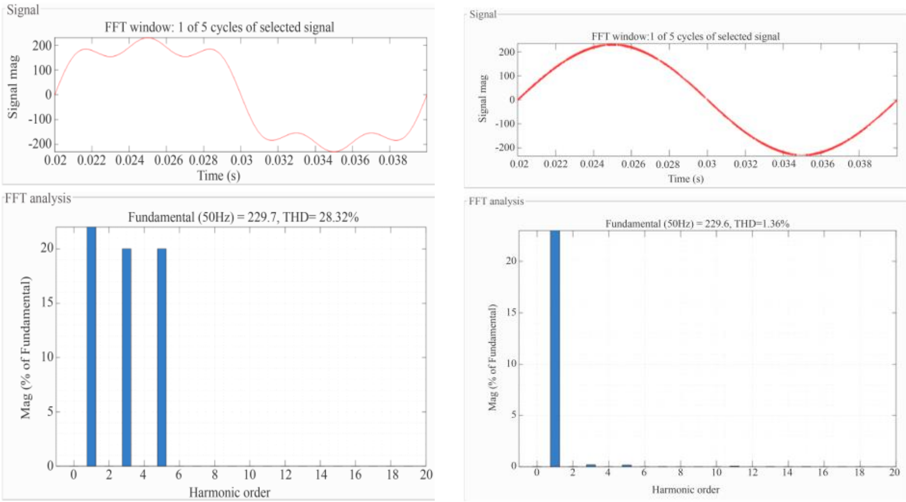


Fig. 7 THD spectrum of the source and load voltages of bus-2

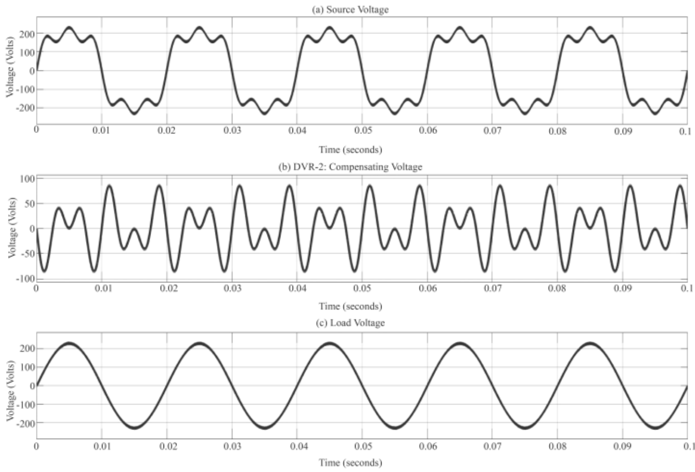


Fig. 8 Voltage harmonics compensations at bus-3
(a) Source voltage, (b) DVR-1 compensation voltage and (c) Load voltage
(b)

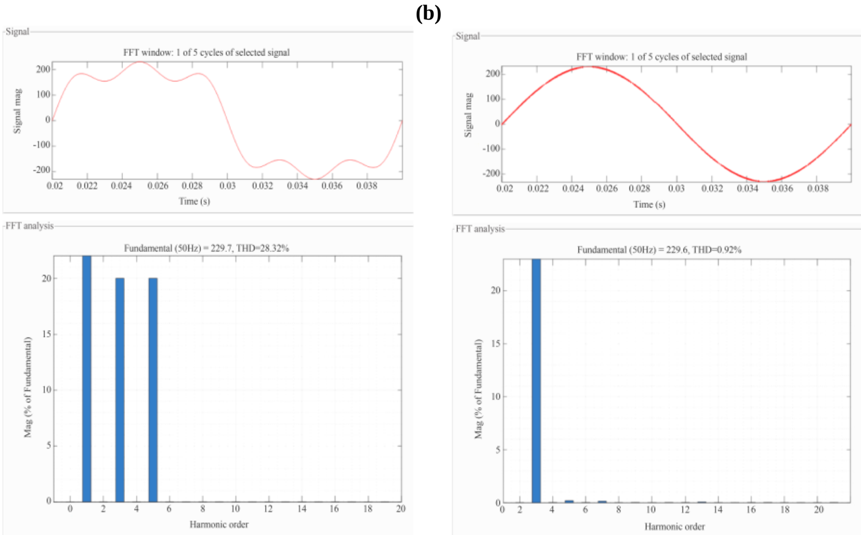


Fig. 9 THD spectrum of the source and load voltages of bus-3

3.3. Voltage Sag at Bus-2 and Voltage Swell at Bus-3

In this case, a voltage sag of 0.1 p.u at bus-2 and a voltage swell of 0.15 p.u at bus-3 were subjected simultaneously in the GUPQC's system. During this condition, active and reactive power flow within the GUPQC's system are mentioned in Table-2 (compared with normal conditions) and shown in Figure-10. To compensate for voltage sag of 0.1p.u at bus-2, DVR-1 supplies the active and reactive power, and to compensate for the voltage swell of 0.15 p.u at bus-3, DVR-2 absorbs the active and reactive power.

Table 2. Active and Reactive power flow during voltage sag at bus-2 and voltage swell at bus-3

BUS	VS (p.u)	Ps (W)	PDVR (W)	PL (W)	Qs (VAR)	QDVR (VAR)	QL (VAR)
2	1	60	0	60	19	0	19
	0.9	54	6	60	17	2	19
3	1	68	0	68	21	0	21
	1.15	78	-10	68	24	-3	21

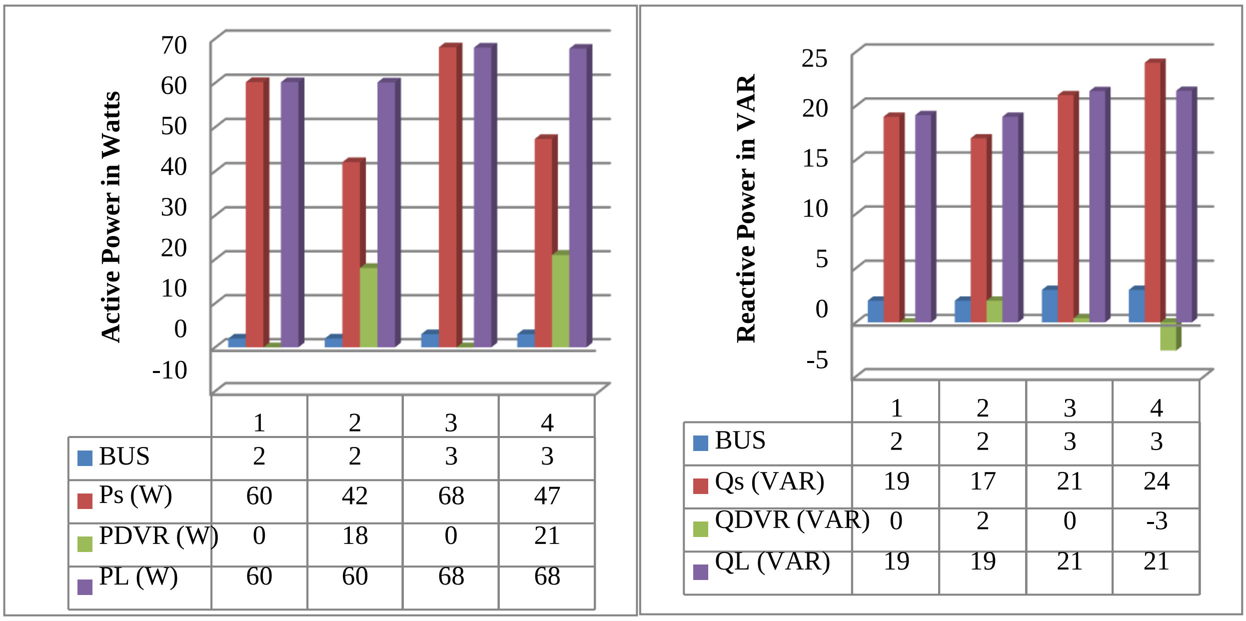


Fig. 10 Active power and reactive power flow during voltage sag at bus-2 and voltage swell at bus-3

Figure-11 shows the ability of DVR-1 to compensate for the voltage sag of 0.1p.u at bus-2. Due to sagging at source-2 during the time interval of 0.02 to 0.08 sec, the bus-2 voltage is decreased to 0.9 p.u, as shown in Figure-11(a).

The required compensating voltage of 0.1 p.u, which is an in-phasecomponent of voltage, is supplied by DVR-1 (Figure-11(b)) and load-2 voltage is maintained at 1 p.u as depicted in Figure-11(c).

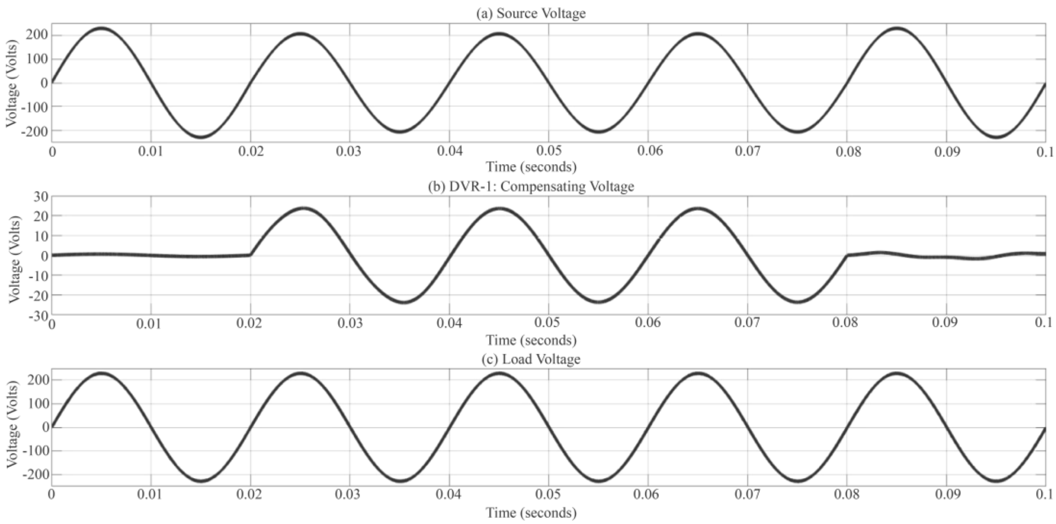


Fig. 11 Bus-2 Voltage sag compensation
(a) Supply voltage, (b) DVR-1: compensation voltage and (c) Load voltage

Similarly, Figure-12 shows the ability of DVR-2 to compensate for the voltage swell of 0.15 p.u at bus-3. Due to 0.15 p.u swell at source-3 during the time interval 0.02 to 0.08 sec, the bus-3voltage is increased to 1.15 p.u as shown in Figure-12 (a).

The required compensating voltage of 0.15 p.u, which is an out-of-phase component of voltage, is supplied by DVR-2 (Figure-12(b)) andload-3 voltage is maintained at 1 p.u as represented in Figure-12(c).

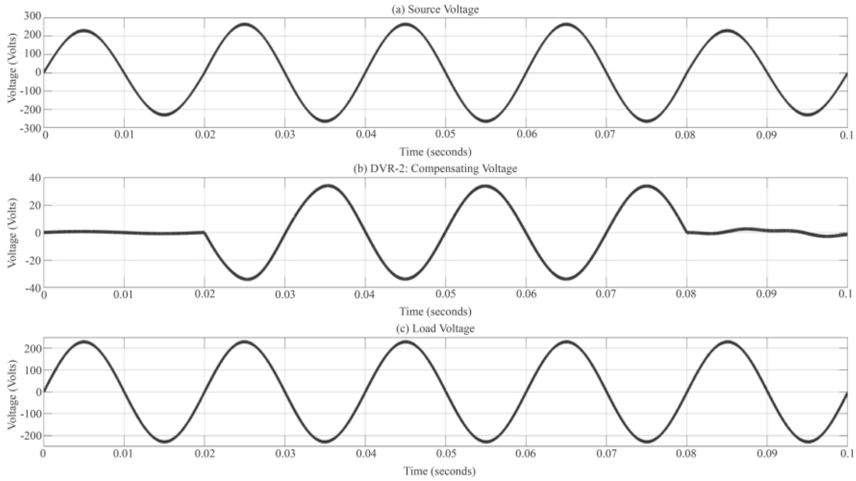


Fig. 12 Bus-3 voltages swell compensation
(a) Supply voltage, (b) DVR-2: compensation voltage and (c) Load voltage

4. Conclusion

In this work, an attempt has been made through the simulation of GUPQC with a control strategy to address the enhancement of power quality issues. In this study, DSTATCOM is connected at bus-1, and DVR's (DVR-1 and DVR-2) are connected at bus-2 and bus-3. From the study, the following specific conclusions are drawn.

- DSTATCOM at bus-1 compensated the current harmonics, and THD of source current decreased from 73.26% to 0.01% after the compensation.
- DVR at the buses compensates the voltage harmonics, and due to the presence of DVR-1 at bus-2,
- THD of load-2 voltage decreased from 28.32% to 1.36%, DVR-2 at bus-3 THD of load-3 voltage decreased from 28.32% to 0.92%.
- Power studies during voltage sags and swells are also shown to demonstrate the DVRs ability to maintain the load side voltage of one per unit.

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