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A novel PQ improvement in multi-parallel feeder distribution system using multi-convertible UPQC device

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ABSTRACT

In the current situation, the use of non-linear power electronic devices in automated industries, arc-furnaces, and adjustable speed drives. The nature of large-sized non-linear loads causes harmonic pollution, voltage interruptions, and voltage sag/swell issues, which are the main issues in modern multi-parallel feeder distribution network. Several mitigation techniques among the above, the multi-convertible universal power-quality conditioner has reliable performance, robust operation and also mitigation of both current-voltage allied power quality (PQ) issues accordingly. The multi-convertible universal power-quality conditioner (Mcon-UPQC) device mitigates power-quality issues by extracting deviated supply voltage and distorted load current by using feasible control algorithm. But, the computational delay, complex mathematical transformation and response delay are the major problem identified in conventional control algorithms. In this work, a novel generalized vector reference control algorithm has been proposed for extraction of fundamental reference voltage-current signals. The performance and effectiveness of proposed control algorithm of Mcon-UPQC device is validated by using MATLAB-Simulink computing tool, simulated outcomes are illustrated with valid comparisons.

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1. INTRODUCTION

At current scenario, the multi-parallel feeder distribution networks are also facing critical power-quality (PQ) problems [1], [2], due to automated industries, increased usage of non-linear power-electronic loads, arc-furnaces, and adjustable speed drives. All these are the primary causes of PQ distortions and deviations. The negative impacts of these PQ distortions/variations may create significant deviations in supply terminal voltage, current, and frequency from their nominal values, causing damage to the loads and the whole distribution network. Harmonic current distortions, unbalanced loads, reactive-power drop, non-ideal power-factor, and other factors are the primary origins and causes of current quality aberrations. Likewise, the primary origins and causes of voltage quality distortions, voltage harmonics, voltage sags-swells, voltage imbalance, and voltage interruptions. Power pollution is caused by distortions in voltage and current quality, which affects the quality of power transmission to point of common coupling (PCC) of a multi-parallel feeder distribution network [3]–[6]. The report on power-quality of electric supply to customers in India, which is connected to the increase of PQ concerns, is provided.

In view of the above, electrical engineers and researchers are forced to develop advanced power-quality enhancement methods known as customized power compensation (CPC) technology [7]. Some practical case studies on series/shunt connected compensation device for enhanced PQ features are clearly presented in [8]. This CPC technique uses custom-power devices (CPDs) to compensate for current and/or voltage associated PQ difficulties, resulting in a multi-feeder network that is simple, stabilized fundamentally important and sinusoidal in shape. The multi-feeder CPDs are categorized based on definite issues such as interline-dynamic voltage restorer (IDVR) [9], interline power-flow controller (IPFC) [10], and interline universal power-quality compensator (IUPQC) [11]. These compensation devices are operated individually for mitigation of either voltage allied PQ problem or current allied PQ problems. The multi-convertible universal power-quality conditioner (Mcon-UPQC) has been developed for mitigation of both voltage and current allied PQ problems combinedly in multi-parallel feeder distribution network. Although, it can exchange real-reactive power between the feeders and ensures to deliver continuous power-supply to loads during sudden interruptions [12].

Generally, the conventional synchronous reference frame (SRF) control algorithm [13] and instantaneous real-power (IRP) control algorithm [14] driven Mcon-UPQC is not suitable for the present-day systems because of moderate compensation characteristics. This conventional controller is highly suffering with various issues like complex transformations, difficult mathematical notations, and high response delay [15]–[19]. Moreover, these schemes employ non-sinusoidal reference currents with high switching frequencies which increase the dv/dt stress, switching losses and thus reducing the overall system efficiency [20]–[26]. For extraction of unique fundamental voltage/current reference signals, a novel generalized vector reference (GVR) control algorithm has been employed to achieve better compensation strategy. The extracted fundamental voltage/current reference signals are used to produce switching states to the respective voltage source inverters (VSIs) of Mcon-UPQC device with reliable gate circuitry.

The suggested Mcon-UPQC device is the most important device among the several multi-parallel feeder compensating devices that alleviate both voltage and current-related PQ concerns in a multi-parallel feeder distribution network. Furthermore, power sharing is allowed between the current and neighbor feeds during abrupt disruptions from either the source or the load side, and no energy storage device is required. The suggested GVR control algorithm generates viable reference current and voltage signals, which aid in the successful functioning of the Mcon-UPQC device in reducing any distribution network distortions and deviations. The crucial effectiveness of the proposed GVR control algorithm driven Mcon-UPQC is validated in this study utilizing the MATLAB-Simulink computing tool under multiple PQ signatures. The results are shown in accordance with IEEE standards. Finally, the suggested GVR control algorithm's outcomes are compared to standard SRF and IRP control systems.

2. PROPOSED METHOD

Figure 1 shows the block diagram of proposed GVR control algorithm driven Mcon-UPQC device for enhancing power-quality. The Mcon-UPQC comprised of three individual 3-level VSIs which are integrated to common-coupling area of multi-parallel feeder distribution system. In that, two VSIs are developed and integrated in series-shunt manner (VSI-2 & VSI-3) to feeder-2 enabling the multi-convertible UPQC device for compensation of both voltage and current allied PQ problems. The other VSI is developed and integrated in series manner (VSI-1) to feeder-1 acting as the series-active power filter for mitigation of voltage allied PQ problems. The VSI-1 & VSI-2 are connected to multi-parallel feeders through 1:1 linear line interfacing transformer for isolation and voltage injection between the VSI-1,2 and multi-feeder distribution network. The three VSIs in Mcon-UPQC device are powered by common DC capacitor ($C_{dc.c}$) with a constant DC capacitor voltage of $V_{Cdc.c}$.

The proposed Mcon-UPQC device has eminent capability to compensate both voltage and current allied PQ issues in multi-parallel feeder distribution network. The shunt VSI-3 of Mcon-UPQC device is used for compensation of harmonics current distortions coming from non-linear sensitive load. It is integrated to feeder-2 through line interfacing filter which helps to filtering the uneven notches in injected currents coming from VSI-3 of Mcon-UPQC device. The VSI-3 of Mcon-UPQC functions as active-compensation for riddling the mitigation of harmonic current distortions as in-phase current compensation technique. The shunt VSI-3 of Mcon-UPQC device administers the source currents for attaining harmonic-free currents, load balancing, reactive-power control, and power-factor correction. The series VSI-1, 2 of Mcon-UPQC device are treated as series-active power filters for compensation of various voltage allied PQ problems coming from main supply terminal voltage. These are integrated to feeder-1 and 2 through line interfacing filters for filtering the uneven notches in injected voltages coming from VSI-1, 2 of Mcon-UPQC device. The operation of VSI-1, 2 of Mcon-UPQC is established as active-compensation for riddling the compensation of voltage problems as in-phase voltage compensation technique. The Mcon-UPQC device series VSI-1, 2 manages load voltages such as harmonic-free response, voltage sags-swells correction, voltage interruption mitigation, and load voltage balancing, among other things. As a result, the Mcon-UPQC device improves power-quality features in the common-coupling area of a multi-feeder distribution network while adhering to IEEE standards via the suggested GVR control method.

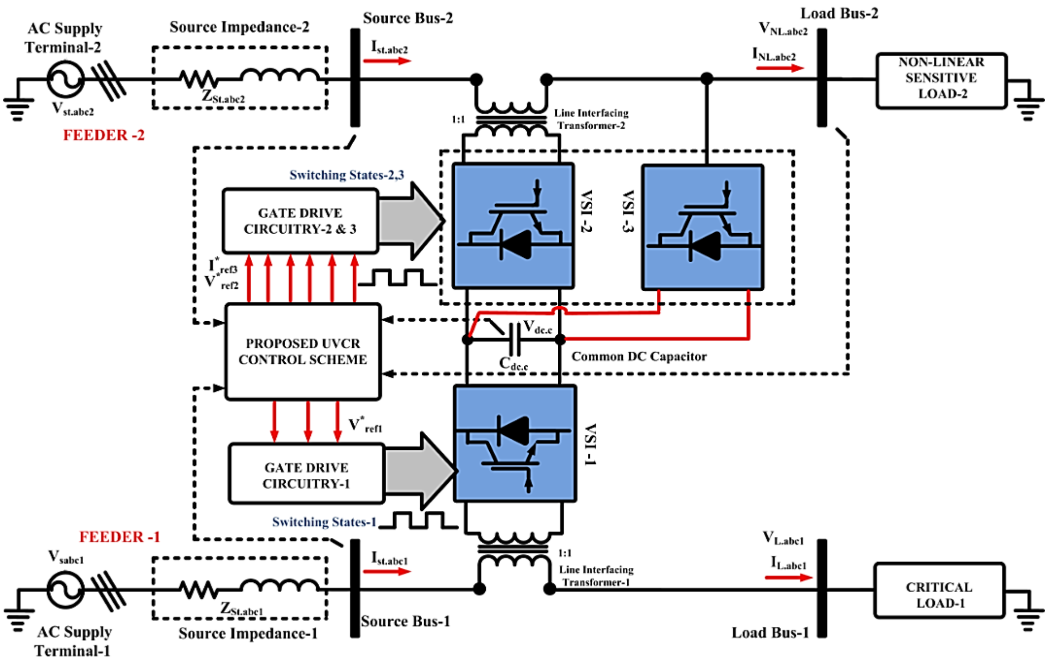


Figure 1. Block diagram of proposed GVR control algorithm driven Mcon-UPQC device

3. PROPOSED CONTROL ALGORITHM

The proposed GVR control algorithm extracts the appropriate reference current and voltage signals to respective VSIs of Mcon-UPQC device without need of complex transformations and complicated mathematical notations. Also, it can produce reference signals with low computational delays which help in flexible switching the VSIs of Mcon-UPQC device. The schematic diagram of proposed GVR control algorithm for VSI based Mcon-UPQC device is depicted in Figure 2. The proposed algorithm generates the reference signals by sensing the load voltages in both feeders and processing the load voltage to obtain unified vector signals in a pre-synchronized angle (θ_s) through phase-locked loop (PLL). It composes of the non-complex vectors of load voltages which are described in (1) and (2).

$$\begin{aligned} V_{L.a12} &= V_{st.a12} \sin \theta s \\ V_{L.b12} &= V_{st.b12}\, sin\left(\theta s - {}^{2\pi}/_{3}\right) \\ V_{L.c12} &= V_{st.c12}\, sin\left(\theta s + {}^{2\pi}/_{3}\right) \end{aligned} \tag{1}$$

The non-complex unified vector signals are represented as (2).

$$V_{st.abc12} = \left\{\frac{2}{3}\left(V_{L.a12}^2 + V_{L.b12}^2 + V_{L.c12}^2\right)\right\}^{1/2} \tag{2}$$

The extracted non-complex signals are composed as in-phase quadrature component is illustrated as (3).

$$\begin{aligned} UV_{st.a12} &= \frac{V_{L.a12}}{V_{st.abc12}} = sin\theta s \\ UV_{st.b12} &= \frac{V_{L.b12}}{V_{st.abc12}} = sin\left(\theta s - {}^{2\pi}/_{3}\right) \\ UV_{st.c12} &= \frac{V_{L.c12}}{V_{st.abc12}} = sin\left(\theta s + {}^{2\pi}/_{3}\right) \end{aligned} \tag{3}$$

The extracted non-complex vector ($UV_{st.abc12}$) is approximated with actual voltage signals ($V_{r.m}$) for generation of reference voltage ($V^*_{refabc.12}$) signals to both series VSI-1, 2 of Mcon-UPQC device and stated as (4).

$$V^*_{ref.a12} = UV_{st.a12} * V_{r.m}$$
$$V^*_{ref.b12} = UV_{st.b12} * V_{r.m}$$
$$V^*_{ref.c12} = UV_{st.c12} * V_{r.m} \quad (4)$$

Similarly, the magnitude of the reference current signal is taken from the primary GVR control algorithm's common DC capacitor control unit. This DC capacitor control unit regulates circulation currents, decreases VSI loss amounts, and keeps the DC capacitor voltage constant. Through careful selection of PI controller gain settings in the DC control unit, the common DC capacitor voltage of VSIs is always kept constant. The DC control unit is used to eliminate error sequences that occur as a result of the propagation of observed DC capacitor voltage ($V_{dc.c}$) and reference DC voltage ($V^*_{dc.r}$). According to (5) and (6) indicate the response of the PI control unit at the nth position.

$$V_{dc.cer} = V^*_{dc.r} - V_{dc.c} \quad (5)$$

$$I_{r.mag} = K_{p.d} * \left(V_{dc.cer(n)} - V_{dc.cer(n-1)}\right) + K_{i.d} * \left(V_{dc.cer(n)}\right) \quad (6)$$

The extracted non-complex vector ($UV_{st.abc12}$) is approximated with actual supply current signals ($I_{r.m}$) for generation of reference current ($I^*_{refabc.2}$) signals to shunt VSI-3 of Mcon-UPQC device and stated as (7).

$$I^*_{refa.2} = UV_{st.a2} * I_{r.m}$$
$$I^*_{refb.2} = UV_{st.b2} * I_{r.m}$$
$$I^*_{refc.2} = UV_{st.c2} * I_{r.m} \quad (7)$$

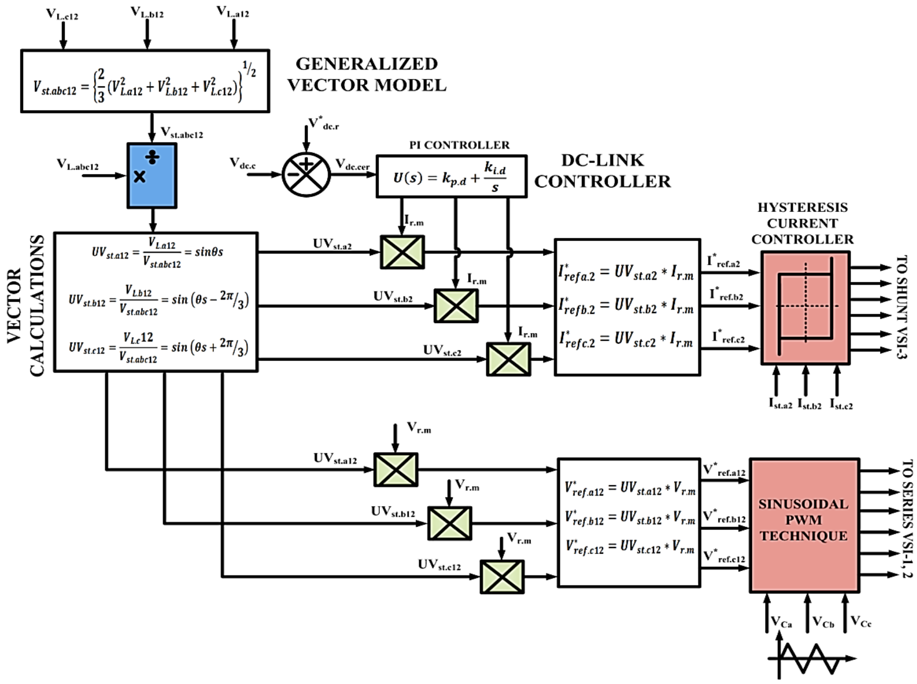


Figure 2. Schematic diagram of proposed GVR control algorithm for VSI based Mcon-UPQC device

Ultimately, reference currents are retrieved from the recommended GVR control algorithm and contrasted to real input currents for the production of switching modes to the VSI-3 of the Mcon-UPQC device using hysteresis current-control (HCC). With HCC band-limits, the HCC is used to generate practical switching pulses to VSI-3 of Mcon-UPQC. These boundaries are regarded as compensating current barrier values, which are rotated in both upper/lower limitations of reference currents and real supply currents. When the real current exceeds the reference signal, the switches are conduction or switched-ON. Otherwise, they are non-conducting or shut off. Hysteresis bands are regarded as VSI-3 ON/OFF signals. The switching operation of the VSI-3 is always based on-wise, with real currents continually rotating inside the lower/upper hysteresis strings, resulting in a reference current signal. Figure 3 depicts the overall design of the proposed

GVR control driven Mcon-UPQC system for PQ improvement. The crucial effectiveness of the proposed GVR-controlled Mcon-UPQC system is validated using the MATLAB-Simulink computing tool and the results are reported. Table 1 depicts the system specifications and values.

Table 1. System specifications of the proposed GVR controlled Mcon-UPQC device

No	Specifications	Values	
		Feeder-2	Feeder-1
1	Supply terminal voltage	$V_{st.abc1,2}$ = 415 Vrms, 50 Hz	
2	Load parameters	$V_{L.abc2}$ = 415 Vrms, 50 Hz, $R_{L.abc1}$ = 30 Ω, L_{L1} = 20 mH	$V_{L.abc1}$ = 415 Vrms $P_{Load.abc1}$ = 10 KW, $Q_{Load.abc1}$ = 5 Kvar
3	Feeder impedance	$R_{st.1}$ = 0.15 Ω, $L_{st.1}$ = 0.9 mH	
4	1:1 linear line interface transformer	$V_{t1,2}$ = 415 V, P_{t12} = 5 KVA, $X_{t1,2}$ = 10% of leakage reactance	
5	Series VSI-12-line interface filter	$L_{se.1,2}$ = 3 mH, $C_{se.1,2}$ = 100 µF	
6	Shunt VSI-3-line interface filter	$R_{sh.2}$ = 0.001 Ω, $L_{sh.2}$=10 mH	
7	Common DC capacitor	$C_{dc.L}$ =1500 µF, $V_{dc.L}$= 880 V	

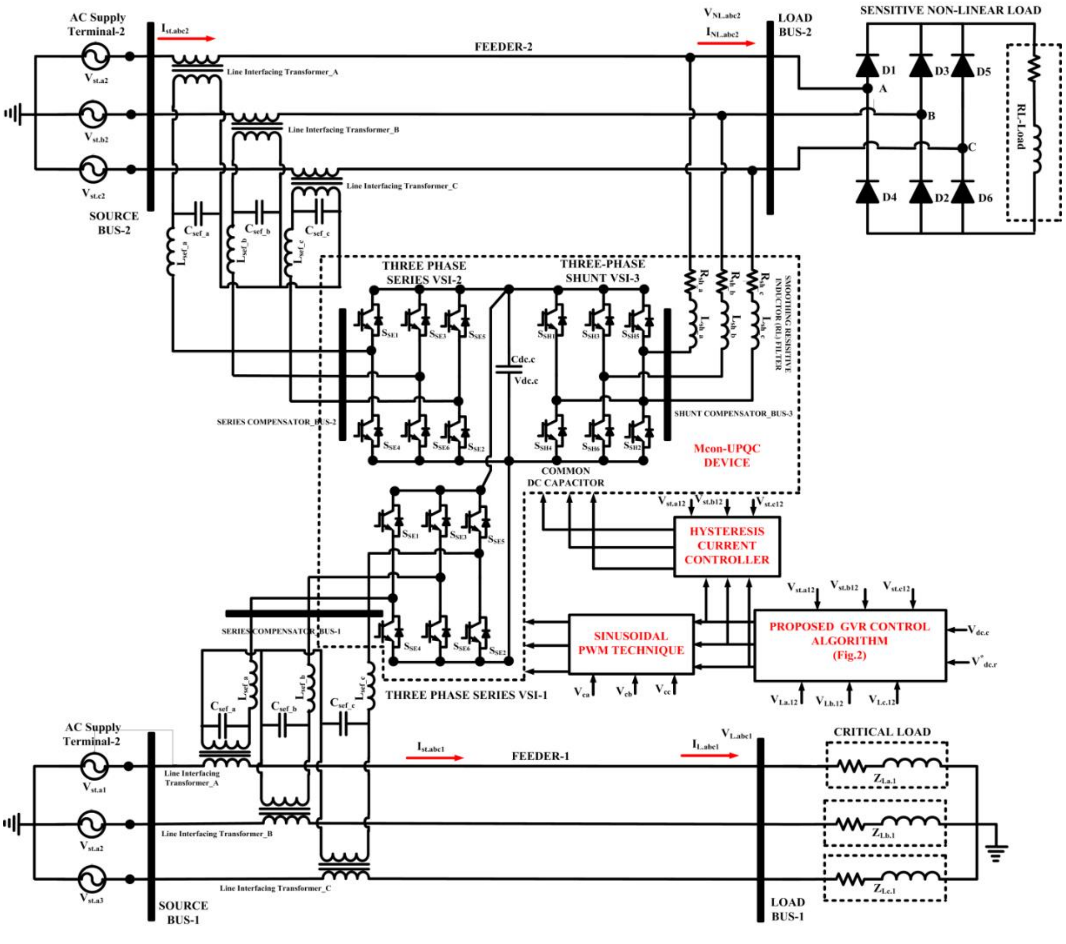


Figure 3. Over-all schematic diagram of proposed GVR control algorithm driven Mcon-UPQC device for PQ enhancement

4. RESULTS AND DISCUSSION

4.1. Simulation results of proposed GVR controlled Mcon-UPQC device for compensation of voltage allied PQ problems in feeder-1

The simulation results of proposed GVR controlled Mcon-UPQC device for compensation of voltage allied PQ problems in feeder-1 are depicted in Figures 4(a)-4(e). These figures contain: i) supply terminal voltage in feeder-1, ii) critical load voltage in feeder-1, iii) series VSI-1 injected voltage, iv) total harmonic distortion (THD) spectrum of source voltage in feeder-1, and v) THD spectrum of critical load voltage in feeder-1, respectively. The distribution network's feeder-1 is powered by a 3-phase supply terminal voltage of 415 Vrms and a fundamental frequency of 50 Hz to power the key linear load. In this scenario, the critical linear load has been shielded from unequal harmonic distortions in the supply terminal voltage, which would otherwise affect the flexible operation of the critical linear load in feeder-1. During pre-harmonic distortions before t=0.1 sec, the supply terminal voltage is retained as sinusoidal and constant at a voltage of 340 V. During the time period of 0.1 sec < t < 0.2 sec, the supply voltage is distorted due to existence of 5^{th} and 7^{th} order harmonic distortions. When sensor elements provide observed voltage values, the Mcon-UPQC series VSI-1 adjusts for harmonic voltage aberrations in load voltage and keeps the 340 A load voltage sinusoidal and fundamental.

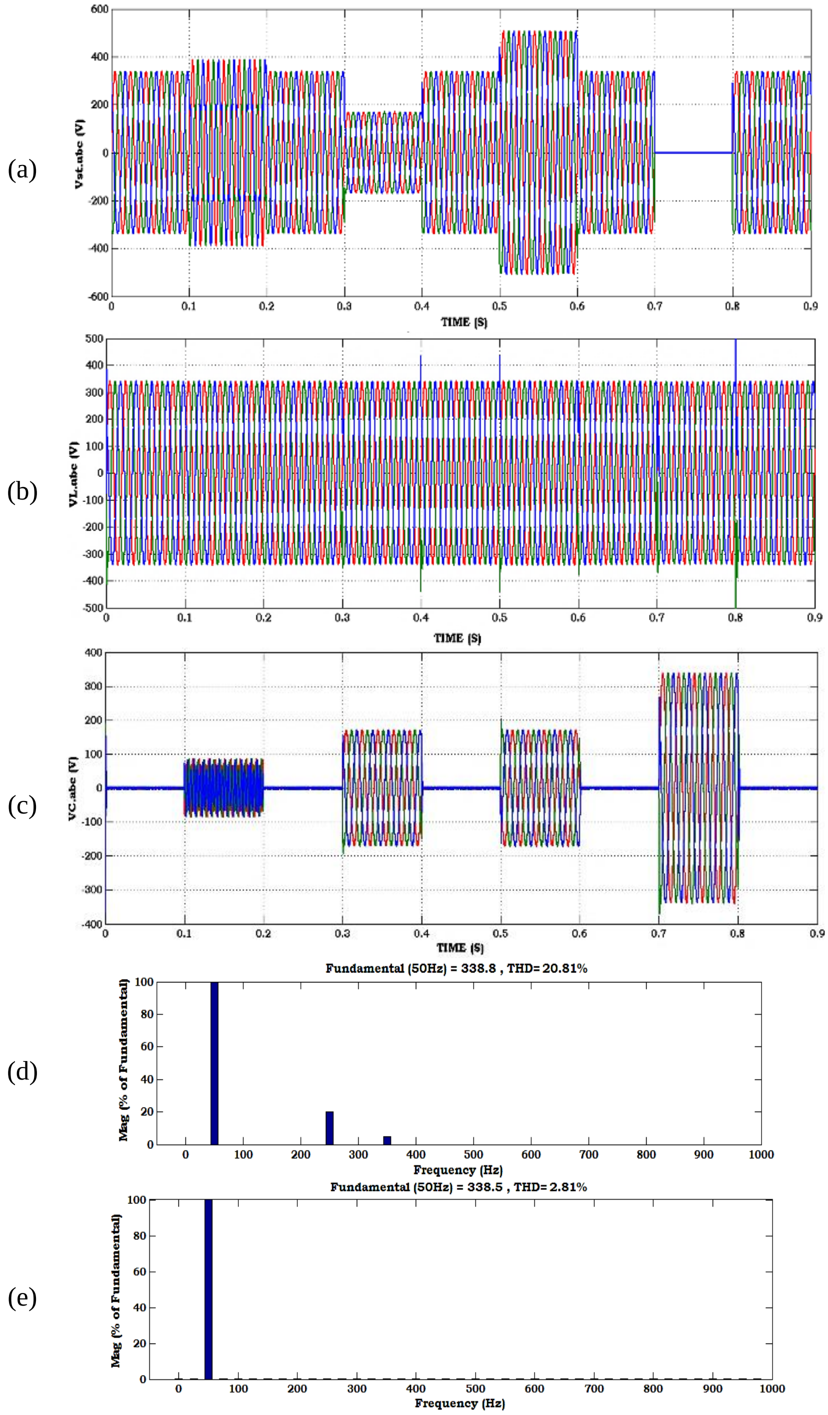


Figure 4. Simulation results of proposed UVCR controlled MFUPQC device for compensation of voltage allied PQ problems in feeder-1: (a) supply terminal voltage in feeder-1, (b) critical load voltage in feeder-1, (c) series VSI-1 injected voltage, (d) THD spectrum of source voltage in feeder-1, and (e) THD spectrum of critical load voltage in feeder-1

During pre-sag condition before t=0.3 sec, the supply terminal voltage is retained as sinusoidal and constant at a terminal voltage of 340 V. During the time period of 0.3 sec < t < 0.4 sec, the supply terminal voltage is decreased to a voltage of 170 V, due to presence of voltage-sag and effecting the flexible functioning of critical linear load in feeder-1. In this time period, the series VSI-1 of Mcon-UPQC injects the required voltage of 170 V and maintains the critical load voltage as constant and balanced nature at a value of 340 V. During pre-swell condition before t=0.5 sec, the supply terminal voltage is retained as sinusoidal and constant at a terminal voltage of 340 V. During the time period of 0.5 sec < t < 0.6 sec, the supply terminal voltage is increased to 510 V, due to presence of voltage-swells and effecting the flexible functioning of critical linear load in feeder-1. In this time period, the series VSI-1 of Mcon-UPQC absorbs the additional voltage of 170 V and maintains the critical load voltage as constant and balanced nature at a value of 340 V.

During pre-voltage interruptions before t=0.6 sec, the supply terminal voltage is retained as sinusoidal and constant at a terminal voltage of 340 V. During the time period of 0.7 sec < t < 0.8 sec, the supply terminal voltage is decreased to 0 V, due to presence of voltage-interruptions and effecting the flexible functioning of critical linear load in feeder-1. In this time period, the series VSI-1 of Mcon-UPQC injects the full-rated voltage of 340 V and maintains the critical load voltage as constant and balanced nature at a value of 340 V and thus maintain continuous operation of critical load. The THD spectrum of supply terminal voltage in feeder-1 is obtained as 20.81% and THD spectrum of critical load voltage during voltage harmonic compensation is obtained as 2.81%, complying with IEEE-519/1992 standards.

4.2. Simulation results of proposed GVR controlled MCon-UPQC device for compensation of current allied PQ problems in feeder-2

The simulation results of proposed GVR controlled Mcon-UPQC device for compensation of current allied PQ problems in feeder-2 are depicted in Figures 5(a)-5(h) (see Appendix). The figures contain: i) Figure 5(a) shows supply terminal voltage in feeder-2; ii) Figure 5(b) shows supply current in feeder-2; iii) Figure 5(c) shows non-linear load current in feeder-2, iv) Figure 5(d) shows shunt VSI-3 injected current in feeder-2; v) Figure 5(e) shows supply terminal voltage & current in-phase condition; vi) Figure 5(f) shows common DC capacitor voltage; vii) Figure 5(g) shows THD spectrum of non-linear load current in feeder-2; and viii) (h) THD spectrum of supply current in feeder-2, respectively. To drive the sensitive non-linear load, the feeder-2 of a multi-feeder distribution network is supplied by a three-phase supply terminal voltage of 415 Vrms and a fundamental frequency of 50 Hz. The non-linear sensitive load is a huge diode-bridge rectifier that pulls distorted currents from feeder-2's supply current. The non-linear sensitive load distorts the supply currents, changing the sinusoidal wave-shape of the 20 A supply current. It creates extra heat and harms other loads by exceeding the thermal loading of appropriate load devices. Harmonic distortions in supply currents are adjusted using the Mcon-UPQC device's shunt VSI-3, which acts as an in-phase compensation approach. As a result, it manages the load reactive power and the source power-factor to make the feeder-2 sinusoidal in shape stabilised, linear in nature, and fundamentally important. Furthermore, the supply current is in phase with the supply voltage, indicating a power-factor of unity. As a result, the higher power-quality in feeder-2 of the multi-parallel feeder distribution network is enabled. In addition, the common DC capacitor voltage is kept constant at 880V and is controlled by the main GVR control scheme's DC voltage control unit. The THD spectrum of sensitive non-linear load currents is 30.15%, while the THD spectrum of supply currents is 3.87%, both of which are close to IEEE-519/1992 standards.

4.3. Simulation results of proposed GVR controlled Mcon-UPQC device for compensation of voltage allied PQ problems in feeder-2

The simulation results of proposed GVR controlled Mcon-UPQC device for compensation of voltage allied PQ problems in feeder-2 are depicted in Figures 6(a)-6(e) (see Appendix). The figures contain: i) Figure 6(a) shows supply terminal voltage in feeder-2; ii) Figure 6(b) shows critical load voltage in feeder-2; iii) Figure 6(c) shows series VSI-2 injected voltage; iv) Figure 6(d) shows THD spectrum of source voltage in feeder-2; and v) Figure 6(e) shows THD spectrum of critical load voltage in feeder-2, respectively. The distribution network's feeder-2 is powered by a 3-phase supply terminal voltage of 415 Vrms at an initial frequency of 50 Hz to power the non-linear sensitive. In this case, the non-linear sensitive load has been protected from uneven voltage harmonic distortions in supply side effecting the flexible functioning of sensitive non-linear load in feeder-2. During pre-harmonic distortions before t=0.3 sec, the supply terminal voltage is retained as sinusoidal and constant at a voltage of 340 V. During the time period of 0.3 sec < t < 0.4sec, the supply voltage is distorted due to existence of 5^{th} and 7^{th} order harmonic distortions. When sensor elements provide observed voltage values, the Mcon-UPQC series VSI-2 adjusts for harmonic voltage aberrations in load voltage and keeps the 340 A load voltage sinusoidal and fundamental.

During pre-sag condition before t=0.5 sec, the supply terminal voltage is retained as sinusoidal and constant at a terminal voltage of 340 V. During the time period of 0.5 sec < t < 0.6 sec, the supply terminal voltage is decreased to 170V, due to presence of voltage-sag and effecting the flexible functioning of non-linear sensitive load in feeder-2. In this time period, the series VSI-2 of Mcon-UPQC injects the required voltage of 170 V and maintains the non-linear sensitive load voltage as constant and balanced nature at a value of 340 V. During pre-swell condition before t=0.7 sec, the supply terminal voltage is retained as sinusoidal and constant at a terminal voltage of 340 V. During the time period of 0.7 sec < t < 0.8 sec, the supply terminal voltage is increased to 510 V, due to presence of voltage-swells and effecting the flexible functioning of critical linear load in feeder-2. In this time period, the series VSI-2 of Mcon-UPQC absorbs the additional voltage of 170 V and maintains the critical load voltage as constant and balanced nature at a value of 340 V. The THD spectrum of supply terminal voltage in feeder-2 is obtained as 20.81% and THD spectrum of critical load voltage during voltage harmonic compensation is obtained as 2.96%, under IEEE-519/1992 standards.

4.4. Extraction reference current of shunt VSI-3 of traditional IRP based Mcon-UPQC device

The non-sinusoidal reference signal is produced via the standard IRP control approach, as shown in Figures 7(a)-7(b). It is composed of high switching frequency pulses that raise dv/dt stress, incur switching loss, and degrade overall system efficiency. The THD spectrum of reference current in the typical IRP control system is 53.23%, which violates IEEE-519/1992 regulations. The sinusoidal reference current signal is produced by the suggested GVR control technique, as shown in Figures 8(a)-8(b). It has a fundamental frequency that decreases dv/dt stress, has minimal switching losses, and maximizes total system efficiency. The THD spectrum of the reference current in the proposed GVR control method is 3.56%, which is in accordance with IEEE-519/1992 standards.

Table 2 shows THD comparisons of supply terminal voltage and load voltages of standard IRP and proposed GVR driven Mcon-UPQC device in feeders 1 and 2. Figure 9 depicts a graphical view of THD comparisons of Supply Terminal Voltage and Critical Load Voltage of Traditional IRP and Proposed GVR controlled MCon-UPQC device in feeder-1 and 2. Table 3 shows the THD comparison of supply current and non-linear load current of standard IRP and suggested GVR controlled Mcon-UPQC device in feeder-1, and Figure 10 shows the graphical perspective. When compared to the typical IRP control system, the suggested GVR controlled Mcon-UPQC generates practical reference voltage and current signals and mitigates voltage and current allied difficulties. The suggested GVR control schemes outperform the existing IRP control scheme in terms of compensating features and THD profile enhancement.

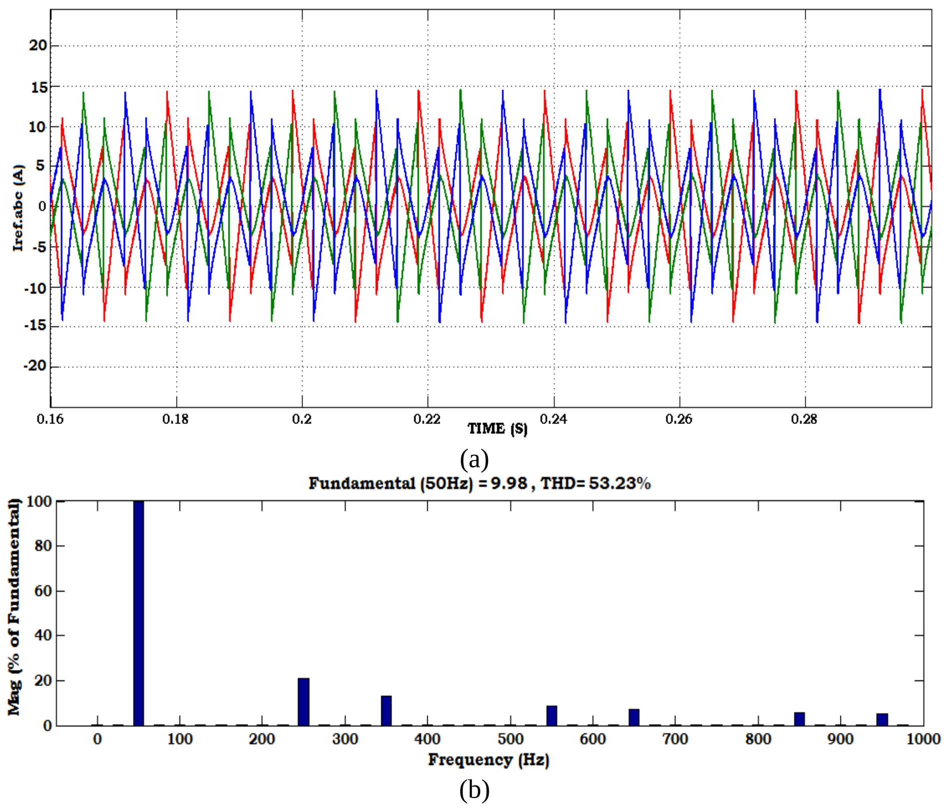
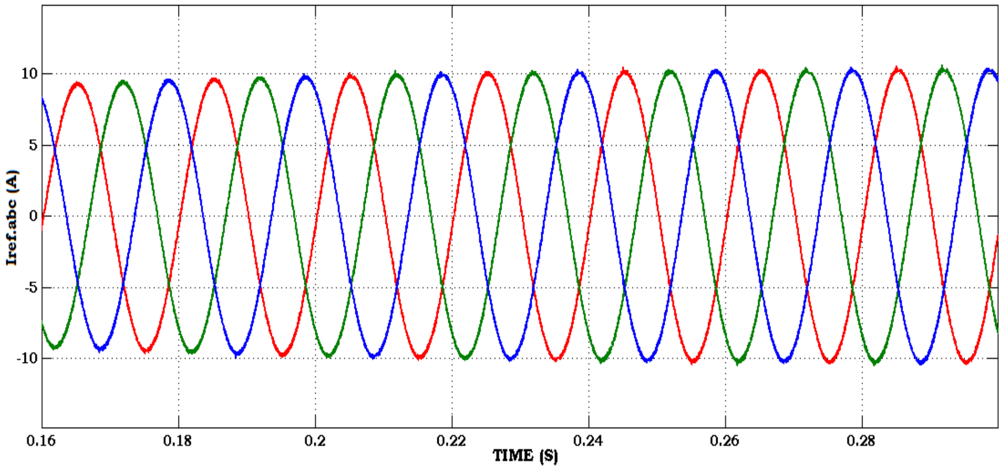
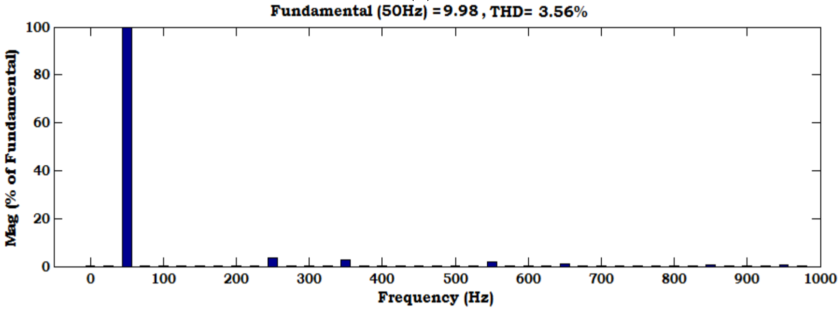


Figure 7. Reference current extraction of shunt VSI-3 of traditional IRP controlled Mcon-UPQC device: (a) reference current of shunt VSI-3 and (b) THD of reference current



(a)



(b)

Figure 8. Reference current extraction of shunt VSI-3 of proposed GVR controlled Mcon-UPQC device: (a) reference current of shunt VSI-3 and (b) THD of reference current

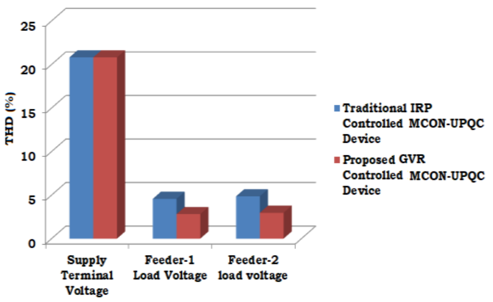


Figure 9. Graphical view of THD comparisons of supply terminal voltage and critical load voltage of traditional IRP and proposed GVR controlled Mcon-UPQC device in feeder 1 and 2

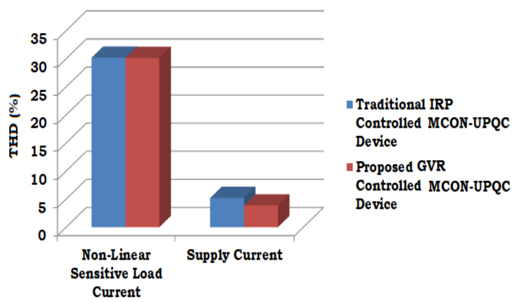


Figure 10. Graphical view of THD comparisons of supply current and non-linear sensitive load current of traditional IRP and proposed GVR controlled Mcon-UPQC device in feeder-1

Table 2. THD comparison of supply terminal voltage and critical load voltage of traditional SRF and proposed GVR controlled Mcon-UPQC device

THD (%)	Supply terminal voltage	Load voltage	
		Feeder-1	Feeder-2
Traditional SRF controlled Mcon-UPQC device [13]		4.56%	4.85%
Proposed GVR controlled Mcon-UPQC device	20.81%	2.81%	2.96%

Table 3. THD comparisons of supply current and non-linear sensitive load current of traditional IRP and proposed GVR controlled Mcon-UPQC device in feeder-1

THD (%)	Non-linear sensitive load current	Supply current
Traditional IRP controlled Mcon-UPQC device [14]	30.19%	5.20%
Proposed GVR controlled Mcon-UPQC device	30.15%	3.87%

5. CONCLUSION

A novel GVR control system is presented in this paper to achieve an affective compensation approach for the extraction of unique fundamental voltage/current reference signals to the Mcon-UPQC device. The viable reference signal improves the performance of the Mcon-UPQC device, which adjusts both voltage and current allied PQ faults in both feeds extremely effectively. The GVR control approach generates fundamental frequency-based reference voltage and current signals, reducing dv/dt stress, minimizing switching losses, and increasing overall system efficiency. Finally, the result of proposed GVR control scheme is compared with traditional SRF and IRP control schemes. The THD spectrum of supply terminal voltage and load voltages of traditional IRP controlled Mcon-UPQC device in feeder-1, 2 is measured as 20.81%, 4.56%, and 4.85%. The THD spectrum of supply terminal voltage and load voltages of proposed GVR controlled Mcon-UPQC device in feeder 1 and 2 is measured as 20.81%, 2.81%, and 2.96%. The THD comparison of supply current and non-linear load current of traditional IRP controlled Mcon-UPQC device in feeder-1 is measured as 30.19% and 5.20%. The THD comparison of supply current and non-linear load current of proposed GVR controlled Mcon-UPQC device in feeder-1 is measured as 30.15% and 3.87%. The THD spectrum of supply current during current harmonics compensation and non-linear load voltage during voltage harmonic compensation are complying with IEEE-519/1992 standards (less than 5%).

APPENDIX

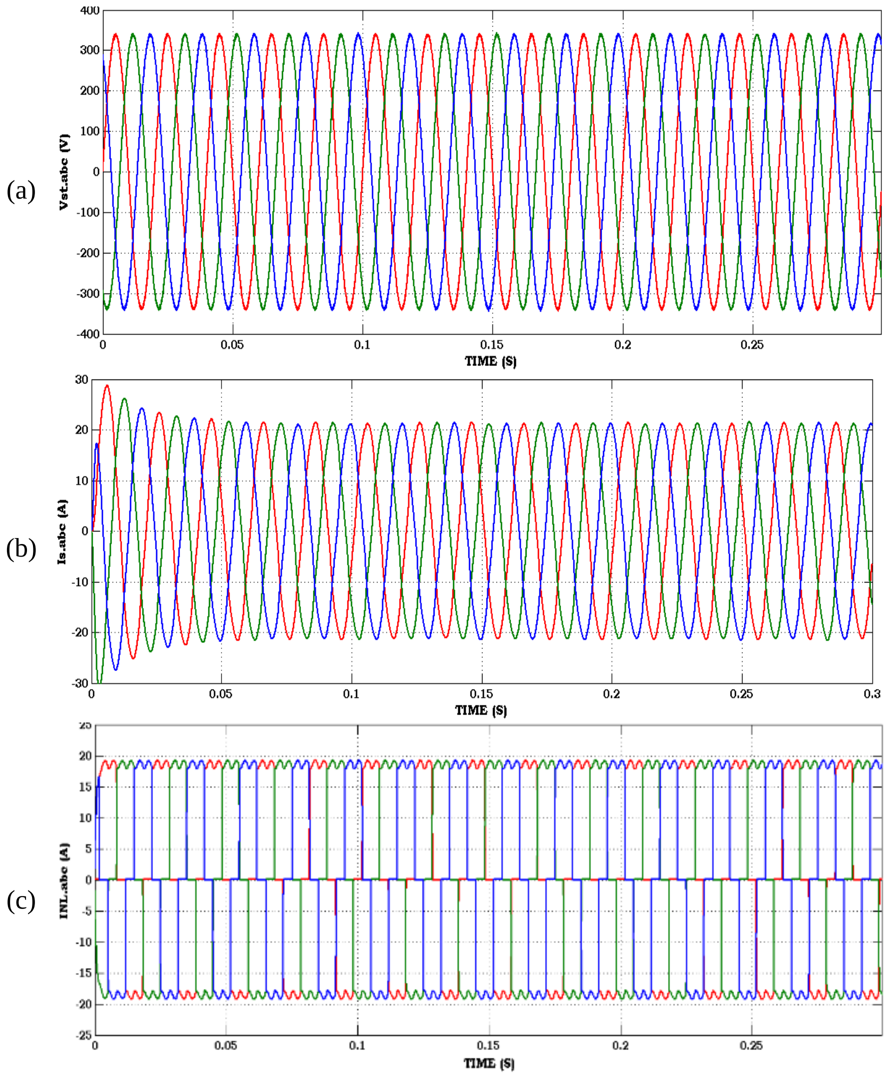


Figure 5. Simulation results of proposed GVR controlled Mcon-UPQC device for compensation of current allied PQ problems in feeder-2: (a) supply terminal voltage in feeder-2, (b) supply current in feeder-2, and (c) non-linear load current in feeder-2

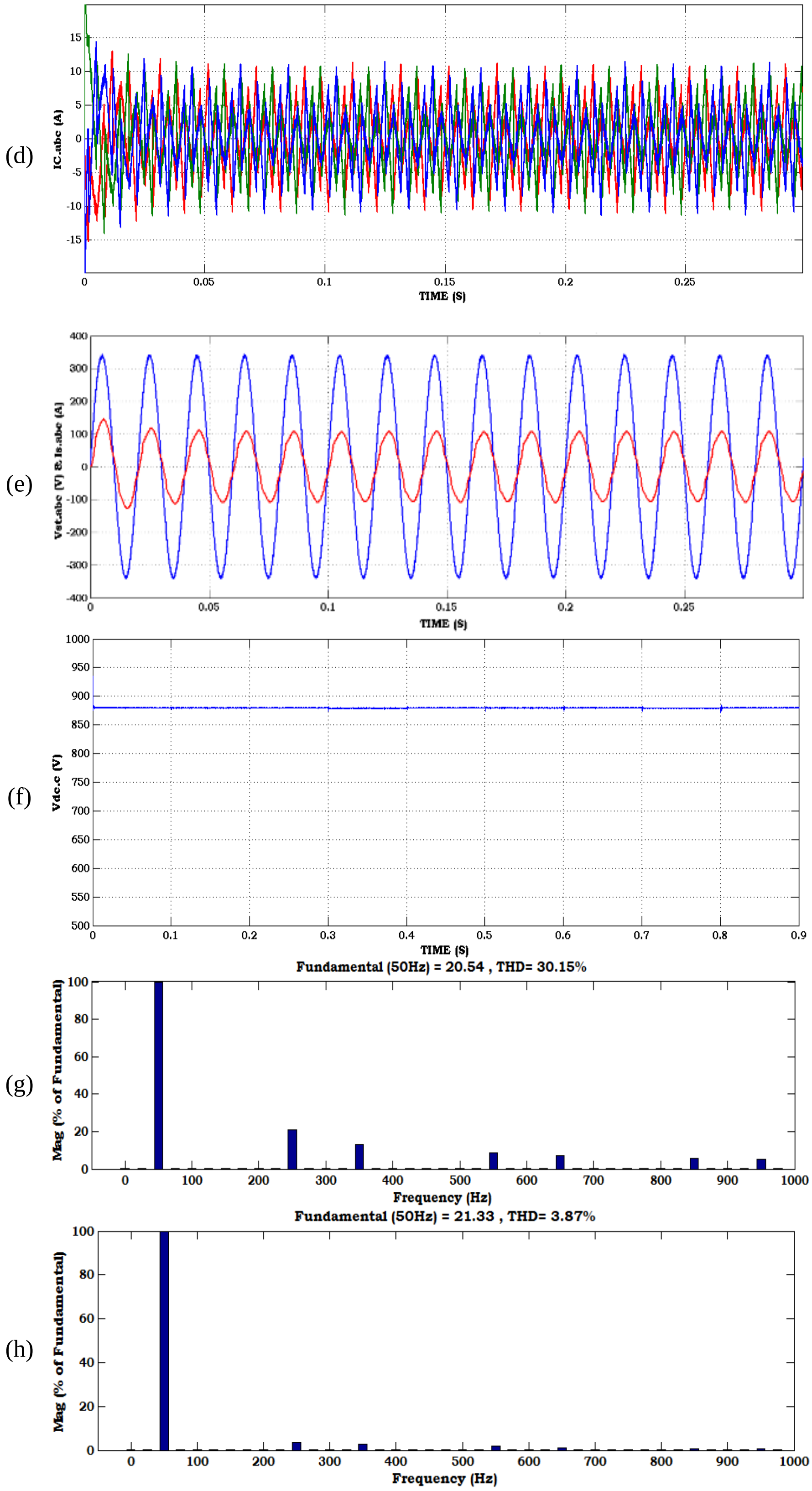


Figure 5. Simulation results of proposed GVR controlled Mcon-UPQC device for compensation of current allied PQ problems in feeder-2: (d) Shunt VSI-3 injected current in feeder-2, (e) supply terminal voltage & current in phase, (f) common DC capacitor voltage, (g) THD of non-linear load current in feeder-2, and (h) THD of supply current in feeder-2 (continued)

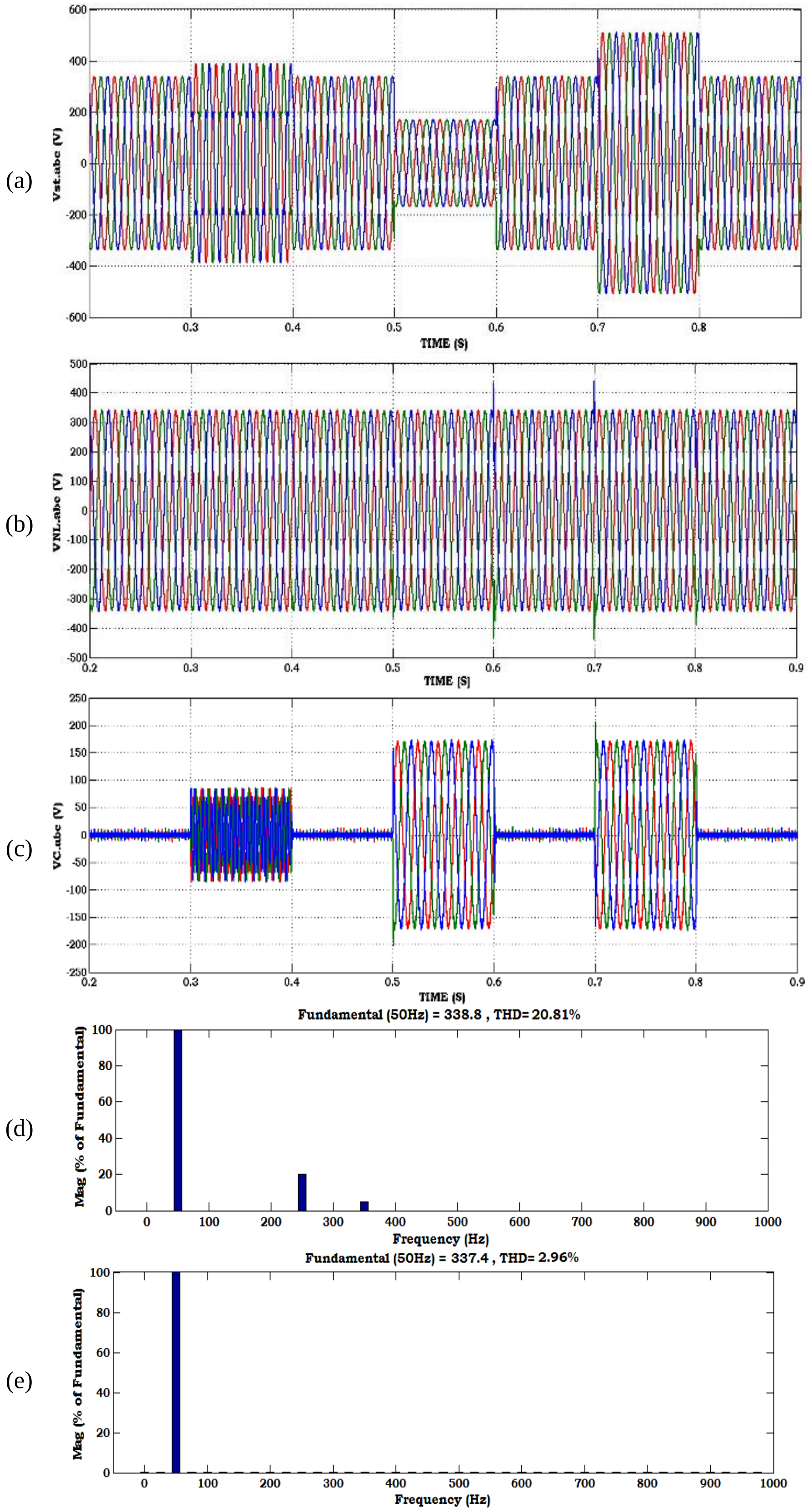


Figure 6. Simulation results of proposed GVR controlled Mcon-UPQC device for compensation of voltage allied PQ problems in feeder-2: (a) supply terminal voltage in feeder-2, (b) sensitive non-linear load voltage in feeder-2, (c) series VSI-2 injected voltage, (d) THD of source voltage in feeder-2, and (e) THD spectrum of critical load voltage in feeder-2

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