A Quasi-Harmonic Voltage Feed forward Control for Improving Power Quality in VSG-Based Islanded Microgrid

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ABSTRACT: The virtual synchronous generator (VSG)-based islanded microgrid's ability to operate safely and steadily is significantly impacted by the voltage harmonics brought on by nonlinear loads. First, using the impedance approach, the voltage distortion mechanism and properties of the VSG-based islanded microgrid are disclosed. The islanded microgrid's power quality may deteriorate as a result of the harmonic current generated by the nonlinear load, which is caused by the enormous impedance of VSG and results in a considerable distorted voltage. Second, depending on the rated voltage and sampling voltage, a quasi-harmonic voltage feedforward control of VSG is suggested as a solution to this problem. By drastically lowering the VSG's impedance, the suggested control can improve the voltage robustness by making the upgraded VSG more akin to an ideal voltage source. In contrast to the conventional harmonic suppression technique, the suggested control can reduce wideband harmonics without prior knowledge of the harmonic frequency and does not require a harmonic extraction filter. Finally, the proposed control and theoretical analysis are validated by simulation results.

KEYWORDS: MICROGRID, VSG, POWER QUALITY, HARMONICS.

I.INTRODUCTION: WITH the development of renewable electricity generations, microgrids are increasing swiftly [1]. Microgrid can perform in grid-related [2] and islanded mode [3]. Since the islanded microgrid lacks voltage help from the general public grid, the voltage stability of the islanded microgrid is terrible. By simulating the voltage and frequency traits of a synchronous generator, digital synchronous generator (VSG) control is proposed, that could offer inertia and damping for the islanded microgrid [4]. Presently, the VSG-primarily based islanded microgrid has received widespread studies because of its outstanding control traits [5], [6], [7]. However, because of the small capability, the VSG-based totally islanded microgrid is liable to cause voltage harmonics underneath nonlinear load disturbance, which requires extra interest [8]. Currently, the harmonic suppression schemes of islanded microgrids are usually divided into two classes: one is to feature the specialized harmonic suppression device, and the opposite is to optimize the unique manipulate algorithm. The widely used harmonic suppression devices include passive power filters [9], active strength filters [10], [11], [12], and many others. Compared to the specialized tool, it's far extra inexpensive to suppress harmonic via optimizing the manipulate algorithm.

Thus, scholars have performed massive studies on manage algorithm optimization for suppressing harmonics [7-10]. To minimize the harmonic distortion of the islanded microgrid on line, an wise controller primarily based at the particle swarm optimization algorithm is proposed. Since the voltage reference of each dispensed generator is based at the primary controller to iteratively correct, the designed controller calls for a substantial computational workload and has a lengthy dynamic process. To reduce the total harmonic distortion (THD) of the microgrid below rectifier load disturbance, a present day controller based totally on repetitive manipulate and H∞ is proposed. Because the present day manipulate signal desires to be corrected by using the previous manipulate, the dynamic performance of the designed manipulate is fantastically terrible. As is widely known, the harmonic modern as a result of the nonlinear load will bring about a harmonic voltage on the inverter impedance.

Therefore, by means of reducing the inverter impedance, the voltage harmonics of the islanded microgrid can be successfully suppressed. In digital impedance manipulate of the islanded microgrid is proposed, which suppresses voltage harmonics by using reducing the inverter impedance at the harmonic frequency factor. As the voltage harmonics need to be extracted one by one, the designed harmonic suppression method is very complex and may most effective suppress the harmonics extracted via the clear out. In a a couple of harmonic collection issue observer (MHSCO) is proposed, that may mitigate the regarded harmonics for the reason that designed MHSCO can best extract the harmonics at a fixed frequency. With the improvement of strength electronics generation, the load sorts of the islanded microgrid grow to be numerous, which include the heart beat load. Due to the time-varying characteristics, the voltage harmonics as a result of the heartbeat load are usually unknown earlier. The existing harmonic suppression strategies are especially designed for integer harmonics, together with 5th, 7th, and eleventh, that may hardly ever suppress the uncertain inter-harmonics caused by way of the heartbeat load. Thus, it needs to research greater superior harmonic suppression algorithms.

In addition, the widely used theoretical evaluation methods of energy exceptional are the kingdom-space approach and the impedance technique. The nation-area version of the islanded microgrid turns into complex as the gadget scale grows, that may motive a dimensional catastrophe. Meanwhile, the nation-area technique analyzes the islanded microgrid from a mathematical angle and lacks practical physical significance. Compared with the nation-area method, the impedance technique can version every a part of the islanded microgrid one by one, that is notably simple [3]. Moreover, thanks to the clear bodily which means, the impedance version of the islanded microgrid can provide theoretical steerage for designing the harmonic suppression method. Based at the above analysis, the impedance approach is a good choice for reading the energy nice of the islanded microgrid.

II.LITARATURE SURVEY:

1) Synchronverters: Inverters that mimic synchronous generators

In this paper, the idea of operating an inverter to mimic a synchronous generator (SG) is motivated and developed. We call the inverters that are operated in this way synchronverters. Using synchronverters, the well-established theory/algorithms used to control SGs can still be used in power systems where a significant proportion of the generating capacity is inverter-based. We describe the dynamics, implementation, and operation of synchronverters. The real and reactive power delivered by synchronverters connected in parallel and operated as generators can be automatically shared using the well-known frequency- and voltage-drooping mechanisms. Synchronverters can be easily operated also in island mode, and hence, they provide an ideal solution for microgrids or smart grids.

Both simulation and experimental results are given to verify the idea.

2) A DC Hybrid Active Power Filter and Its Nonlinear Unified Controller Using Feedback Linearization

In current power system, the conversion between DC and AC is widely existing and dc side harmonic problem is prominent. To suppress the second-harmonic current (SHC) at the dc side of single-stage single-phase inverter, a dc hybrid active power filter (DC-HAPF) structure is presented, which composes of bidirectional dc-dc circuit based active power filter and CL passive filter. Here, the CL passive filter is used to mitigate the high frequency harmonics and the active power filter is applied to compensate the low frequency harmonic current. Meanwhile, the influence of filter parameters on harmonic suppression is analyzed based on the average switching model. In addition, for the control of the DC-HAPF, a nonlinear unified controller via feedback linearization is proposed, where the voltage and current dual-loop control is converted to a single loop control of energy. By analyzing the control system stability and DC-HAPF's performance, appropriate control parameters are selected. To verify the feasibility of the proposed topology and control strategy, a 500W single-stage single-phase inverter with the DC-HAPF is built and a good performance of dc side harmonic suppression has been achieved.

III.SYSTEM CONFIGARATION: In this paper a quasi-harmonic voltage feed forward control is proposed to improve the power quality of the VSG-based islanded microgrid. The main work and contribution are given as follows:

1) To suppress the voltage harmonics of the VSG-based islanded microgrid under load disturbances, a quasi harmonic voltage feedforward control is proposed based on the rated voltage and sampling voltage, which does not need harmonic-extraction filter and can suppress wideband harmonics without knowing the harmonic frequency in advance.

2) The parameter design principle of the proposed control is introduced, and the reason why the proposed control can automatically suppress the wideband harmonics is revealed from the impedance perspective.

3) The small-signal model of the improved VSG is built, and the stability of VSG before and after improvement is compared theoretically. Moreover, the proposed control and theoretical analysis are validated by simulation results.

Fig. 1 shows the topology and control diagram of the VSG-based islanded microgrid, where Vdc represents the dc-side voltage; L_f , C_f , and Rd represent the filter inductor, filter capacitor, and damping resistor, respectively; Rl , Ll , and Cl represent the resistor, inductor, and capacitor of the linear load, respectively; Ln and Cn represent the inductor and capacitor of the nonlinear load, respectively; Rn and Rp represent the rectifier resistor and pulse resistor, respectively; f pu represents the pulse frequency; iabc and vabc represent the inductor current and microgrid voltage, respectively; eabc represents the inner electric potential of VSG; and Zin(s) represents the impedance of VSG. From Fig. 1, the active and reactive power controllers can be expressed as follows:

$$\begin{cases} (\omega_n - \omega_m)\, D_p + P_{\text{ref}}/\omega_n - P_m/\omega_n = J s \omega_m \\ \sqrt{2}\,(V_n - V_m)\, D_q + Q_{\text{ref}} - Q_m = \sqrt{2} E_m K s \end{cases} \quad (1)$$

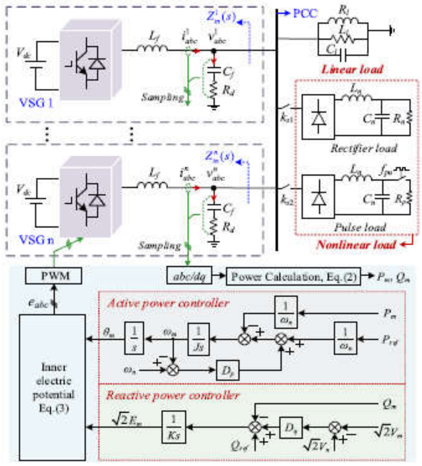


Fig. 1. Topology and control diagram of the VSG-based islanded microgrid.

where Pref and Qref represent the rated values of the active and reactive power, respectively; Vm and Vn represent the root mean square (rms) value and rated rms value of the microgrid voltage, respectively; θm and Em represent the phase angle and rms value of eabc, respectively; Dp and Dq represent the active and reactive droop factors, respectively; ωm represents the angular frequency, which can be expressed as ωm = sθm; ωn represents the rated angular frequency; J represents the virtual inertia; K represents the damping coefficient; and Pm and Qm represent the instantaneous active and reactive power respectively, which can be calculated as follows:

$$\begin{cases} P_m = 1.5(v_\alpha i_\alpha + v_\beta i_\beta) \\ Q_m = 1.5(v_\beta i_\alpha - v_\alpha i_\beta) \end{cases} \quad (2)$$

Where vα and vβ represent the microgrid voltage in αβ domain, respectively; iα and iβ represent the inductor current in αβ domain, respectively.

In Fig. 1, the inner electric potential eabc of VSG can be calculated as follows:

$$\begin{cases} e_a = \sqrt{2}E_m \cos\theta_m \\ e_b = \sqrt{2}E_m \cos(\theta_m - 2\pi/3) \\ e_c = \sqrt{2}E_m \cos(\theta_m + 2\pi/3). \end{cases} \quad (3)$$

According to [27], the sequence impedance of VSG can be expressed as follows:

$$\begin{cases} Z_{sp}(s) = \dfrac{0.75V_1 M(s - j2\pi f_1) K_{\text{pwm}} K_1(s) e^{j\theta_d}/\omega_n + sL_f}{1 + 0.75 I_1 M(s - j2\pi f_1) K_{\text{pwm}} K_1(s) e^{j(\theta_d - \theta_{i1})}/\omega_n} \\ Z_{sn}(s) = \dfrac{0.75V_1 M(s + j2\pi f_1) K_{\text{pwm}} K_1(s) e^{-j\theta_d}/\omega_n + sL_f}{1 + 0.75 I_1 M(s + j2\pi f_1) K_{\text{pwm}} K_1(s) e^{-j(\theta_d - \theta_{i1})}/\omega_n} \end{cases} \quad (4)$$

where Zsp(s) and Zsn(s) represent the positive- and negative-sequence impedances without considering the filter capacitor and damping resistor, respectively; V1, I1, and f1 represent the fundamental voltage amplitude, the fundamental current amplitude, and the fundamental frequency, respectively; θi1 represents the initial phase angle of I1; θd = arcsin[PmωnLf /(EmV1)] + π/2, arcsin[Pmωn Lf /(EmV1)] represents the power angle of VSG; Kpwm ≈ (1 + 1.5Tss), and Ts represents the switching period. K1(s) = √ 2Em/[1 + s/ωv)(1 + s/ωi)], where ωi and ωv represent the cutoff frequencies of current and voltage sampling filters, respectively, M(s) = 1/(Js2 + Dps). Considering the filter capacitor C f and damping resistor Rd, the equivalent impedance of VSG can be expressed as follows:

$$\begin{cases} Z_{\text{in}p}(s) = Z_{sp}(s) \parallel \left(R_d + \dfrac{1}{sC_f}\right) \\ Z_{\text{in}n}(s) = Z_{sn}(s) \parallel \left(R_d + \dfrac{1}{sC_f}\right) \end{cases} \quad (5)$$

Where Zinp(s) and Zinn(s) represent the positive- and negative-sequence impedance of VSG, respectively. Fig. 2 shows the frequency response of the impedance Zinp(s) and Zinn(s). As seen in Fig. 2, when the frequency is above 100 Hz, the impedance response curves of Zinp(s) and Zinn(s) are basically the same. Since this article focuses on the impedance above 100 Hz, Zinp(s) and Zinn(s) are uniformly represented by Zin(s) in this article. Fig. 3 depicts the equivalent circuit of the studied islanded microgrid. In Fig. 3, ˜ vpcc represents the microgrid voltage; ˜i f and ˜ih represent the fundamental current and harmonic current of load, respectively. From Fig. 3, the harmonic voltage ˜ vpcch can be expressed as follows:

$$\tilde{v}_{\text{pcch}} = \tilde{i}_h[Z^1_{\text{in}}(s) \parallel \cdots \parallel Z^n_{\text{in}}(s)] = \tilde{i}_h \frac{1}{\sum_{i=1}^{n} \frac{1}{Z^i_{\text{in}}(s)}}. \quad (6)$$

From (6), the harmonic current ˜ih induced by the load can cause a harmonic voltage ˜ vpcch on the equivalent impedance of the islanded microgrid. The harmonic frequency of ˜ vpcch is related to load. In the case of a typical rectifier load, voltage harmonics are mainly integer harmonics, such as 5th and 7th.

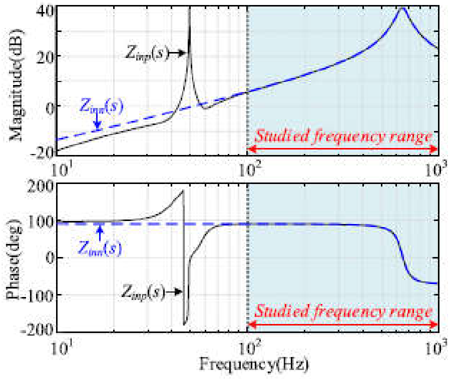


Fig. 2. Frequency response of the impedance $Z_{inp}(s)$ and $Z_{inn}(s)$.

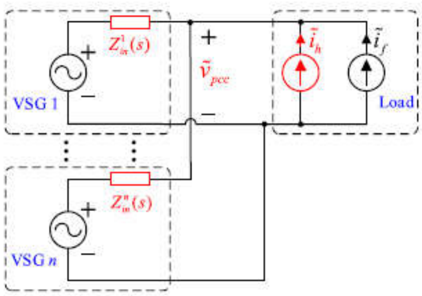


Fig. 3. Equivalent circuit of the studied islanded microgrid.

TABLE I
SIMULATION PARAMETERS

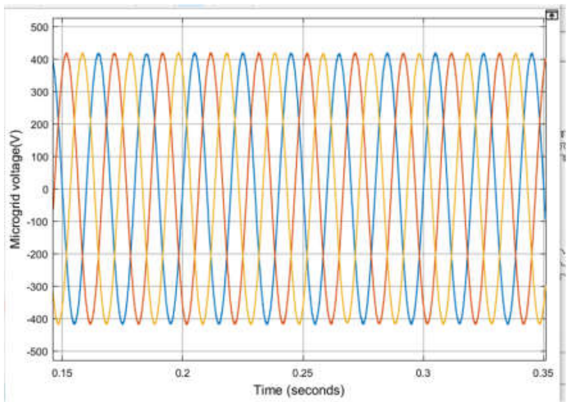
Parameter	Value	Parameter	Value	Parameter	Value
V_{dc} /V	700	D_q	321	L_l/mH	5
V_n/V	220	J	0.057	C_l/uF	300
P_{ref} /kW	10	K	7.1	R_n/Ω	40
Q_{ref} /kVar	0	L_f/mH	3	L_n/mH	1
f_l/Hz	50	C_f/uF	20	C_n/uF	10
$f_s(1/T_s)$/kHz	20	R_d/Ω	1.7	R_p/Ω	50
D_p	5	R_l/Ω	10	f_{pu}/Hz	180

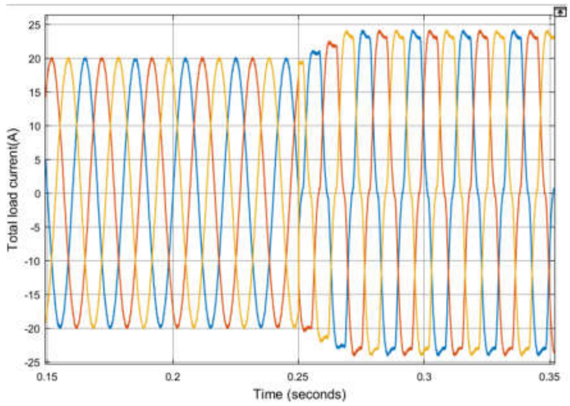
Under the pulse load disturbance, the harmonic frequency caused by the pulse load changes with the pulse frequency, which is usually time-varying and unknown.

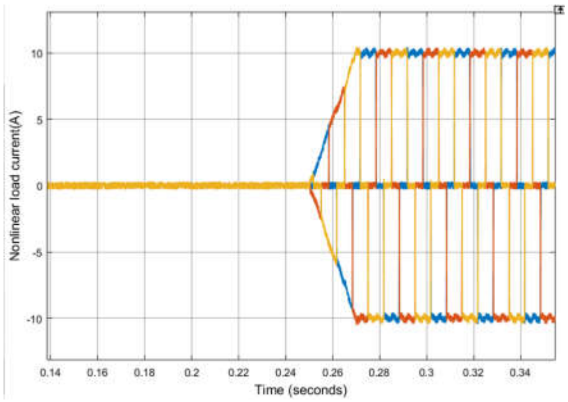
To verify the theoretical analysis above, an islanded microgrid controlled by VSG, as shown in Fig. 1, is simulated in MATLAB/Simulink. Simulation parameters are listed in Table I.

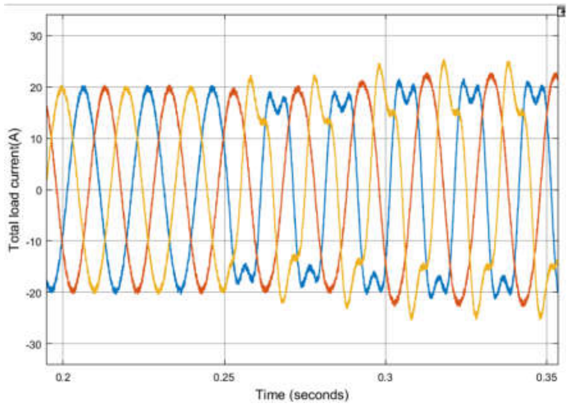
IV.SIMULATION RESULTS:

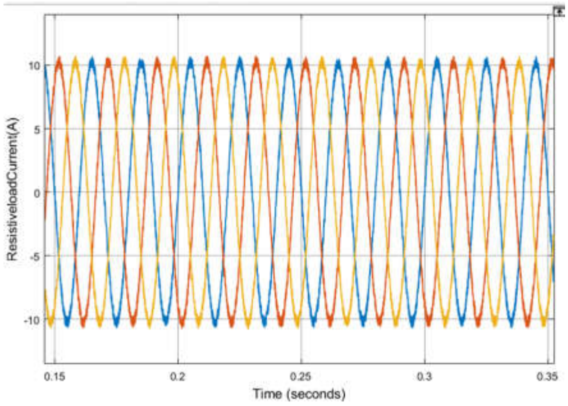
Conventional method
Case1

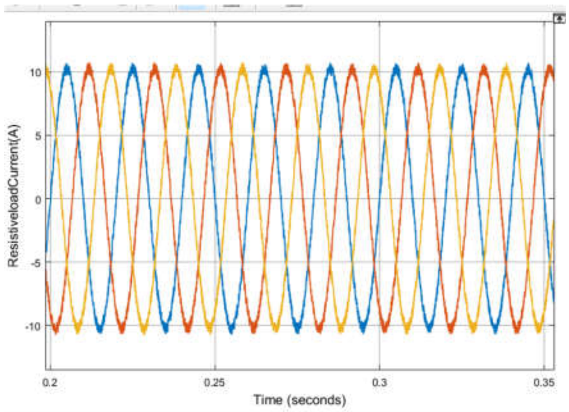




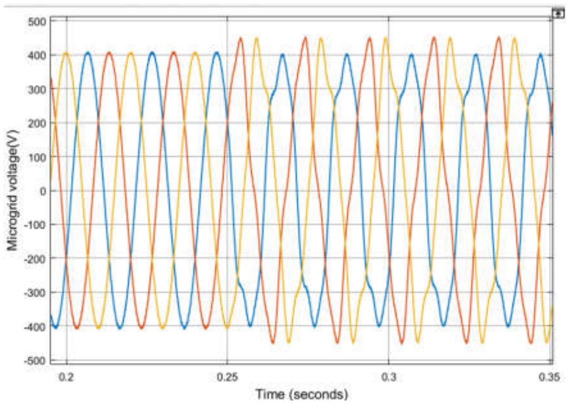


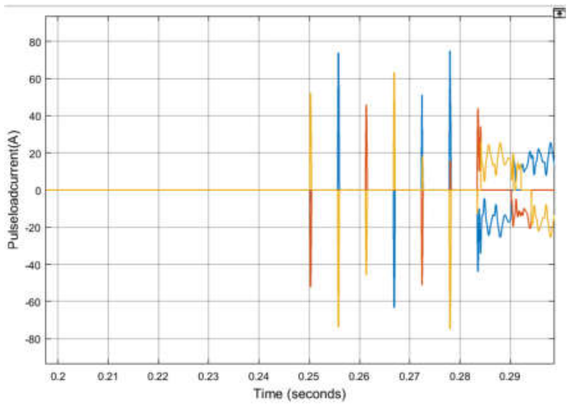




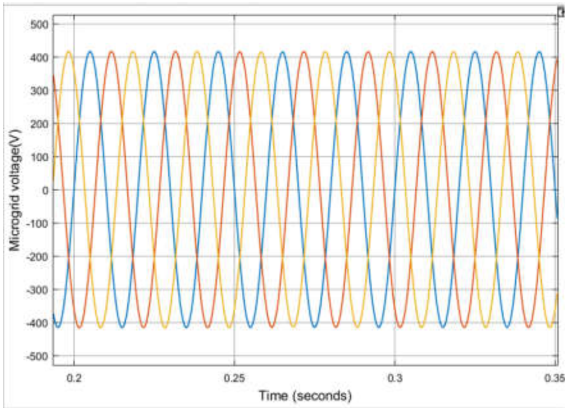


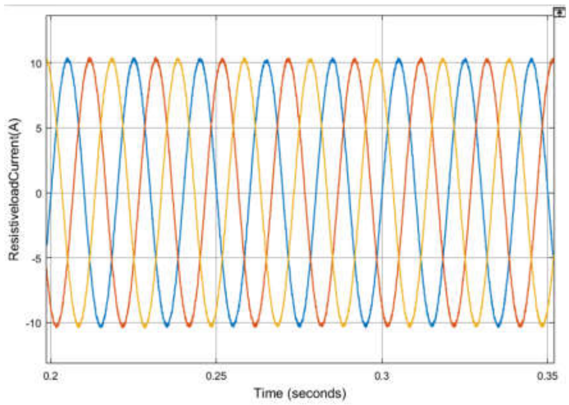
Case2

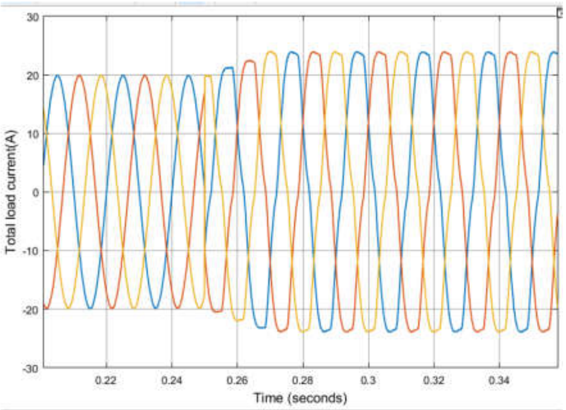


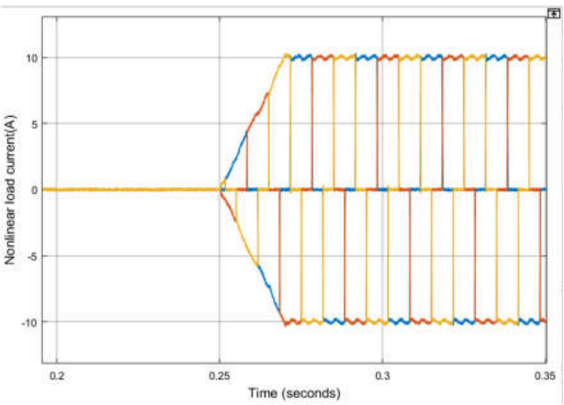


Proposed method
Case1

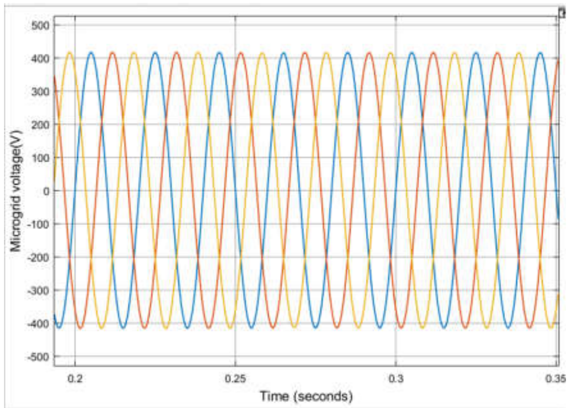

Microgrid voltage(V)
500
400
300
200
100
0
-100
-200
-300
-400
-500
0.2
0.25
0.3
0.35
Time (seconds)

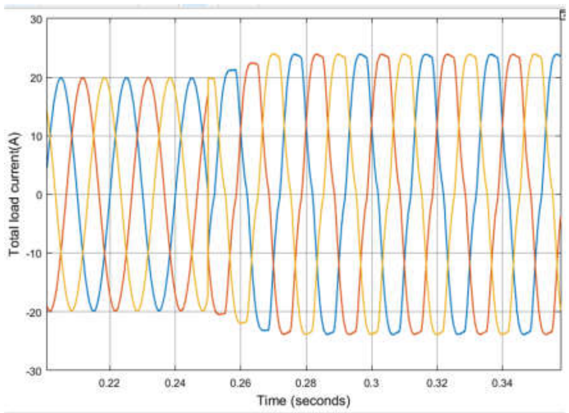

ResistiveloadCurrent(A)
10
5
0
-5
-10
0.2
0.25
0.3
0.35
Time (seconds)


Total load current(A)
30
20
10
0
-10
-20
-30
0.22
0.24
0.26
0.28
0.3
0.32
0.34
Time (seconds)


Nonlinear load current(A)
10
5
0
-5
-10
0.2
0.25
0.3
0.35
Time (seconds)

Case2


Microgrid voltage(V)
500
400
300
200
100
0
-100
-200
-300
-400
-500
0.2
0.25
0.3
0.35
Time (seconds)


Total load current(A)
30
20
10
0
-10
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0.22
0.24
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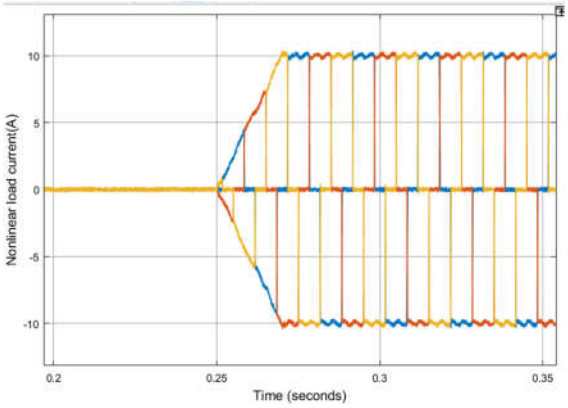
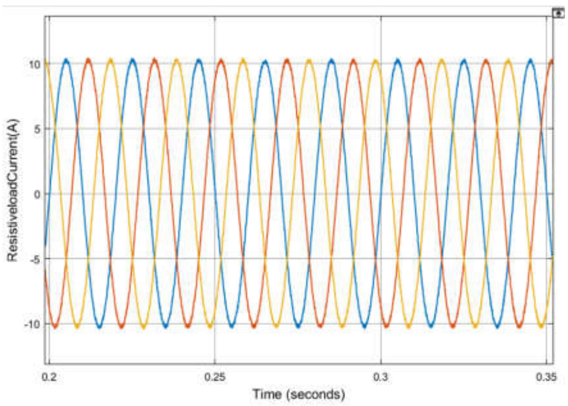
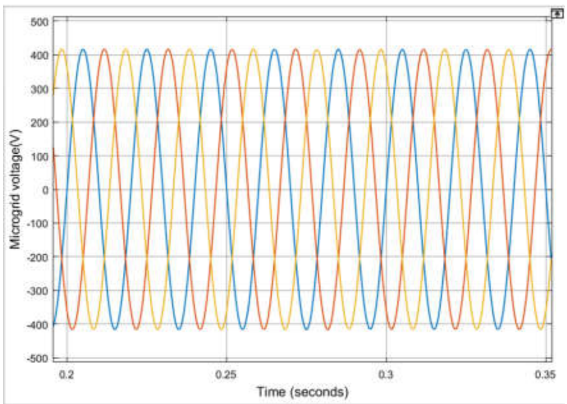
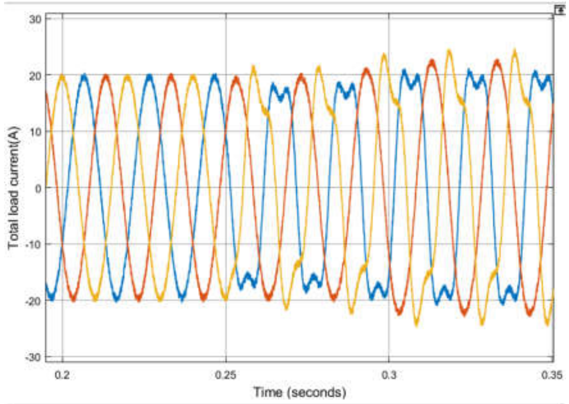
0.28
0.3
0.32
0.34
Time (seconds)

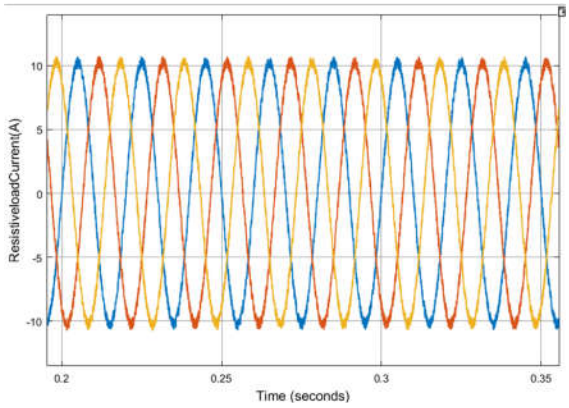


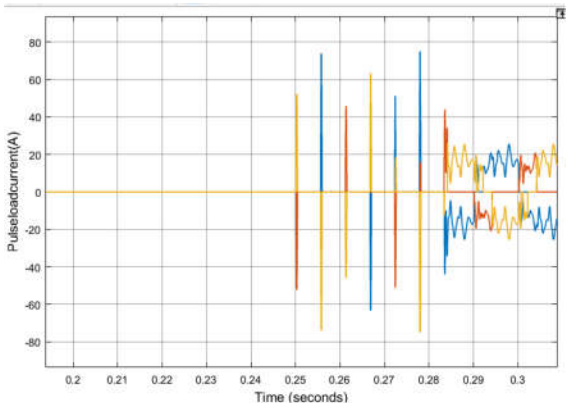


Case3









V.CONCLUSION: In order to enhance the power quality of the VSG-based islanded microgrid, a quasi-harmonic voltage feedforward control is suggested in this study. The following is a summary of the key conclusion:

1) The islanded microgrid's power quality deteriorates as a result of the enormous impedance of VSG, which causes the

harmonic current caused by the nonlinear load to produce considerable voltage harmonics.
2) The islanded microgrid based on the enhanced VSG can automatically suppress harmonics above 100 Hz without the need for harmonic-extraction filters since the suggested control can significantly lower the VSG impedance above 100 Hz.
3) The suggested control method can be readily applied to the islanded microgrid managed by other control strategies, like droop control, because it is superimposed on the modulation signal.

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