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New triple-action controller for inverter power quality improvement[☆]

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A B S T R A C T

Harmonic distortion is a crucial power quality (PQ) issue especially in microgrids. Distributed energy resources employ either synchronous generator or voltage source inverter to interface microsource with loads. This paper presents the analysis of the proportional resonant (PR) controller along with a selective harmonic compensator (SHC) for a stand-alone distributed generation inverter. Furthermore, a new improved triple-action controller (TAC) design is proposed and implemented. The proposed TAC consists of a conventional PR along with SHC, in addition to, a feed-forward current controller to achieve seamless sinusoidal voltage. This mitigate not only the total harmonic distortion (THD) but also individual harmonics to a level below the stated in IEEE/IEC standards. Moreover, optimize the TAC parameters to ensure its best performance. A comparative study of harmonic effects for various load-types are introduced. The voltage regulation and THD mitigation improved the power factor and efficiency, hence, it improved the PQ of the system.

1. Introduction

Energy consumption has been dramatically increased due to industrialization outgrowth and the increased utilization of the domestic machine appliances. To satisfy this continuously increasing power demand, the world is seeking for renewable resources as alternatives to the conventional sources. Renewable power generating capacity reached its largest annual increase ever in 2017, by an added 178 GW (Giga-watts), with a total increase of 9% compared to 2016. Total renewable power installed is approximately 2,195 GW, sufficient to supply an approximately 26.5% of global electricity demand [1]. Renewable power resources like: wind, solar, wave, and tidal often form distributed generation (DG) in microgrid via power electronic system, these microgrids may be either connected to the grid; named grid connected mode or isolated; named islanded mode [2].

Distributed energy resources (DER) provide several advantages as they are secure and reliable against sudden faults. In addition, they reduce the cost of long transmission lines and offer high efficiency of energy supply. However, many challenges arise when integrating different technology-based DERs because of their different characteristics. One of the major challenges in DG system is the power quality (PQ) issue. The term PQ is referring to maintain nearly sinusoidal waveforms of voltages and currents at nominal amplitude and frequency [3].

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Harmonics, as a major PQ issue in power system, have significant negative impacts like conductor overheating, eddy current and hysteresis losses increase which lead to overheating in both transformers and motors. Furthermore, they increase the zero sequence current, increase neutral current, trip of circuit breakers, telecommunication interference, inaccurate sensors measurements, equipment malfunction and equipment lifetime reduction [4]. On the other hand, THD and power factor are closely related, therefore, codes and standard regulations like IEEE and IEC standards [5] placed the constraints on the voltage and current harmonics produced by harmonic sources like the nonlinear loads. They aim to obtain the accepted real power factor, which is represented by the displacement power factor, as well as, the distortion power factor [6].

As a result, many researchers have been interested in improving PQ, especially in microgrid system. Active power filters are generally used to improve power quality [7]. They compensate the harmonics and voltage unbalance by injecting the negative-sequence components and harmonic voltages. However, active filters cannot be installed for each microgrid as they become uneconomical. On the other hand, many types of passive filters are playing an important role in the microgrid to reduce the ripples injected into the microgrid. However, the passive filters have many disadvantages, such as mistuning, large size, instability, resonance with utility and load impedances [8,9]. The control of voltage source inverter (VSI) may involve classical linear regulators and modern control methods such as deadbeat and predictive control methods [10]. Guerrero and his colleagues proposed improvement of PQ for microgrid [11], which represents the voltage reference tracking and harmonic mitigation. Their control strategy is based on improving droop, secondary and virtual impedance with additional conventional proportional resonant (PR) controller for inner loops.

Since the use of proportional-integral (PI) controllers to follow the non-dc signals is challenging, PR compensators are most adequate to control voltages and currents in stationary frame of reference. The PR controller introduces gain at the fundamental frequency and produces almost zero gains at other frequencies [12]. The PR controller has a superior performance over the PI controller; it is simulated in a stationary reference frame, hence, there is no need for reference frame transformations. As a result, the response is faster with high computational efficiency [13,14], and that is because there is no calculations of rotational reference frame which is adopted by PI controller.

The control strategy using PR controller is discussed in [15], the author did proof that the performance of the PR controller is better than the performance of the PI controller for the steady state error and THD mitigation. The simulation results showed that the THD for the PI controller is 4.82%, while it was 2.73% for PR controller, in case of resistive load. In [16], the author proposed a four-leg inverter-based three-phase UPS to improve the performance of the output voltage control for both linear and nonlinear loads. The author adopted a control structure of proportional plus resonant filter bank and the gain parameters are tuned based on trial and error method. At linear load, the value of voltage THD was 0.7% while, at nonlinear load, the value of voltage THD was 1.8%. In [17], authors proposed a control scheme to achieve the voltage regulation and harmonic mitigation based on the non-sinusoidal PWM technique along with a PI controller. The proposed technique did improve the THD for linear load to a value of 2.8%, compared to a 7% for nonlinear load. In [18], the author applied PR controller to a microgrid-connected VSI, the overall strategy represented by droop, secondary, synchronization and hierarchical control. The inner loop controllers have a good performance, the value of voltage THD was 1.44% when suppling nonlinear load.

In [10], the authors proposed sinusoidal PWM with a deadbeat based PI controller using a heuristic tuning method for computing the PI coefficients. They aim to track the desired voltage in addition to the voltage THD minimization. The obtained simulation results were 1.53% and 2.78% for the value of voltage THD when purely resistive load and resistive plus inductive load respectively. The PQ issue was addressed in [19], where the PQ was defined as a pure sinusoidal waveforms from the source to consumer. This research proposed a control of a doubly fed induction generator using a combined nonlinear technique with a space vector algorithm. The authors aim to avoid system parameter variations that lead to a power ripple reduction and mitigation of THD based on a three-level inverter by applying sliding mode controller. The THD of the stator current is 2.98%, which guarantee a PQ improvement.

In this paper, the control strategy proposes PQ improvement using an optimized-parameters triple-action controller (TAC). The proposed TAC consists of three controllers the PR to ensure high fundamental frequency gain, selective harmonic compensator (SHC) for harmonics elimination and a current-assisted feed-forward controller to ensure minimum harmonics with faster response. Since there are so many parameters to adjust for each controller (PR, SHC and feed-forward controllers), trial and error methods will be inappropriate and time consuming. Many optimization algorithms may be utilized in this situation like Genetic Algorithm, Bee Algorithm, Ant Colony, Whale Optimization, White Shark Algorithm and Particle Swarm Optimization (PSO). The metaheuristic PSO is more robust and much simpler to implement. It has few adjustable parameters, faster convergence and shorter computation time [20,21]. PSO can generate an optimal solution within a short calculation time and more stable than other stochastic methods [22]. PSO was preferred to optimize the parameters' values taking into consideration the regulation of VSI output voltage and THD mitigation while not exceeding the allowable values of standard limitations.

This paper is organized as follows: Section 1 presents the motivations, incitement and literature review. Section 2 addresses the proportional resonant controller and the selective harmonic compensator modelling. Section 3 presents the new proposed TAC controller, PSO algorithm, and the implementation of the PSO to evaluate TAC parameters. Section 4 shows the obtained results and explains the advantages of the proposed methodology. Section 5 concludes the main paper contributions.

2. Proportional resonant controller and selective harmonic compensator

Inverters voltage and current loops are controller using the PR controller. These inner loops include proportional gain plus the transfer function (TF) term corresponds to the fundamental frequency. Other terms have been added selectively as a TF at each corresponding harmonic (i.e. 5th, 7th and 11th harmonics), at which harmonics compensation are required as shown in Fig. 1.

The ideal PR controller $G_{PR}(s)$ is represented by:

$$G_{PR}(s) = K_P + K_I \frac{S}{S^2 + \omega_0^2} \tag{1}$$

where, K_p is the proportional gain, K_I is the integral gain and ω_o is the fundamental frequency. The TF of an ideal PR controller is expressed as in Eq. (1) with an infinite gain which can cause stability problems. To avoid infinite gain issues, the PR controller could be made non-ideal by adding a damping term as expressed in Eq. (2), where, ω_c is the cut-off frequency around the resonant frequency ω_o [14].

$$G_{PR}(s) = K_P + \frac{K_I}{S^2 + 2\omega_c S + \omega_0^2} \tag{2}$$

The harmonic compensator $G_{SHC}(s)$ is represented by:

$$G_{SHC}(s) = \sum_{h=5,7,11} \frac{K_h s}{s^2 + 2(h\omega_c)s + (h\omega_o)^2} \tag{3}$$

where, K_h is the gain at the harmonic order h, and $h\omega_0$ is the harmonic frequency. The required harmonic compensator for each harmonic frequency could be added to the PR controller fundamental frequency TF to form the complete controller.

The TF $\frac{V_c(s)}{V_{ref}(s)}$ could be represented by:

$$\frac{V_c(S)}{V_{ref}(S)} = \frac{G_v(S)G_i(S)G_{PWM}(S)}{LCS^2 + CSG_i(S)G_{PWM}(S) + G_v(S)G_i(S)G_{PWM}(S) + 1} \tag{4}$$

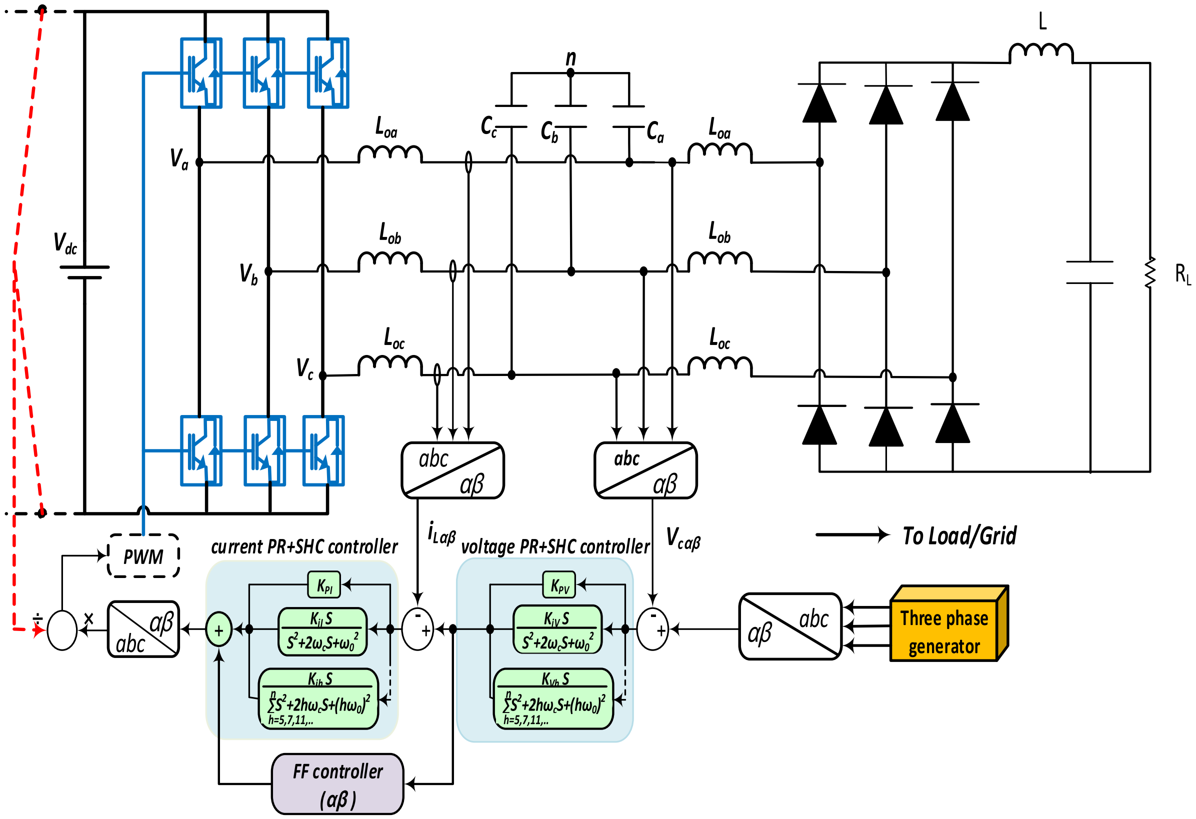

Fig. 1. Block diagram of voltage and current control loops of a three-phase VSI.

Where

$$G_v(S) = G_{PRv}(S) + G_{SHCv}(S)$$

$$G_{PRv}(S) = K_{pv} + \frac{K_{Iv}}{s^2 + 2\omega_c s + \omega_o^2}$$

$$G_{SHCv}(S) = \sum_{h=5,7,11} \frac{K_{hv} S}{S^2 + 2(h\omega_c)S + (h\omega_o)^2}$$

Similarly,

$$G_i(s) = G_{PRi}(s) + G_{SHCi}(s)$$

$$G_{PRi}(s) = K_{pi} + \frac{K_{Ii}}{s^2 + 2\omega_c s + \omega_o^2}$$

$$G_{SHCi}(s) = \sum_{h=5,7,11} \frac{K_{hi} s}{s^2 + 2(h\omega_c)s + (h\omega_o)^2}$$

$$G_{PWM}(S) = \frac{1}{1 + 1.5T_s S}$$

where, T_s is the sample time.

3. The proposed triple-action controller

In this section, a new composite TAC is proposed as shown Fig. 2. This controller is composed of the conventional PR controller with an added SHC, furthermore, a new feed forward current-assisted controller has been added to improve the system reliability and the PQ of the overall system. The feed forward controller parameters are initially selected by trial and error for preliminary testing. Hence, PSO algorithm has been adopted for the selection of TAC parameters (twelve parameters). These parameters are PR current and voltage controller parameters, as well as, the gains of 5th, 7th, and 11th harmonics (K_{pv}, K_{rv}, $K_{vh5,7,11}$, K_{pI}, K_{rI}, $K_{Ih5,7,11}$, K_α, K_β) to guarantee THD and voltage error minimization.

3.1. Particle swarm optimization

Kennedy and Eberhart proposed the PSO algorithm in 1995 [20]. It was stimulated by social behaviour of bird group or fishes, where a population of random initial, as in other population-based intelligent system. The population is formed by particles, where each particle a possible solution of the problem. The next position of each particle is governed by Eq. (5), that depends on the last position plus an updated velocity. Each particle in the swarm is treated as a valueless particle in global dimensional of search space, and it tracks its coordinates in the space associated with the best solution for becoming (weighing value) [20,21]. This value is called pbest. The overall best value in the group was tracked by an optimizer gbest. The PSO concept involves the velocity change for each particle in the swarm toward its pbest and gbest locations at each time step. For example, the j^{th} particle is represented as $x_j = (x_{j,1}, x_{j,2}, \ldots, x_{j,g})$ in the g-dimensional space. The best position of the j^{th} particle is represented as $pbest_j = (pbest_{j,1}, pbest_{j,2}, \ldots, pbest_{j,g})$ and recorded. The index of best particle between

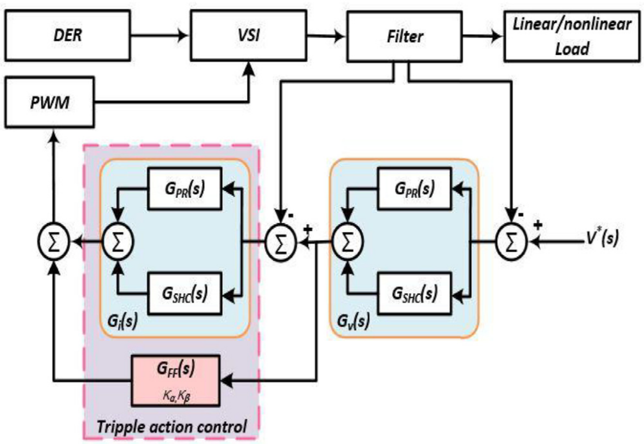

Fig. 2. Overall system block diagram illustrating the triple-action controller.

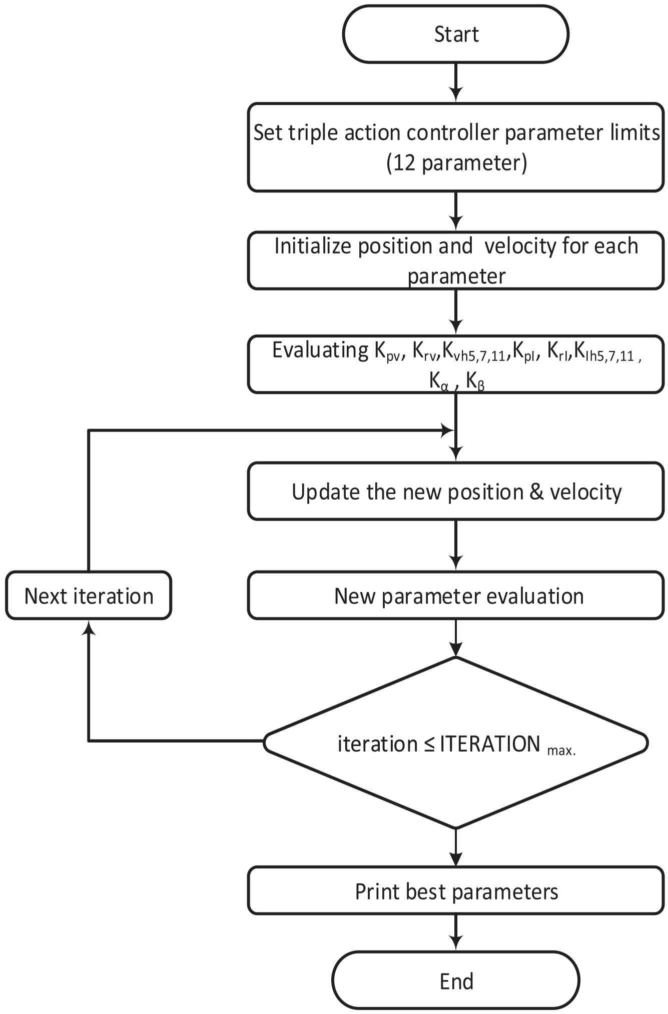

Fig. 3. Flowchart for the feed forward controller parameters' selection using PSO algorithm.

all particles in the global group is represented by the $gbest_g$ according to Eq. (6).

$$x_{j,g}^{t+1} = x_{j,g}^{t} + v_{j,g}^{t+1} \tag{5}$$

$$v_{j,g}^{t+1} = wv_{j,g}^{t} + c_1 u_1 \left(pbest_{j,g} - x_{j,g}^{t}\right) + c_2 u_2 \left(gbest_g - x_{j,g}^{t}\right) \tag{6}$$

Where

n number of particles in a group;
M number of member in a particle;
t pointer of iterations;
$v_{j,g}^{t+1}$ velocity of particle j at iteration t, $v_g^{min} \le v_{j,g}^{t} \le v_g^{max}$
w inertia weight factor;
c_1, c_2 acceleration constant;
u_1, u_2 random number between 0 and 1;
$x^{(t)}{}_{j,g}$ Current position of particle j at iteration t;
$pbest_j$ pbest of particle j;
Gbest gbest of the group

Generally, the weight of inertia (w) is set according to Eq. (7) below. Suitable selection of this weight provides a balance amongst global and local explorations, thus, requiring less iteration on the average for finding a sufficiently optimal solution

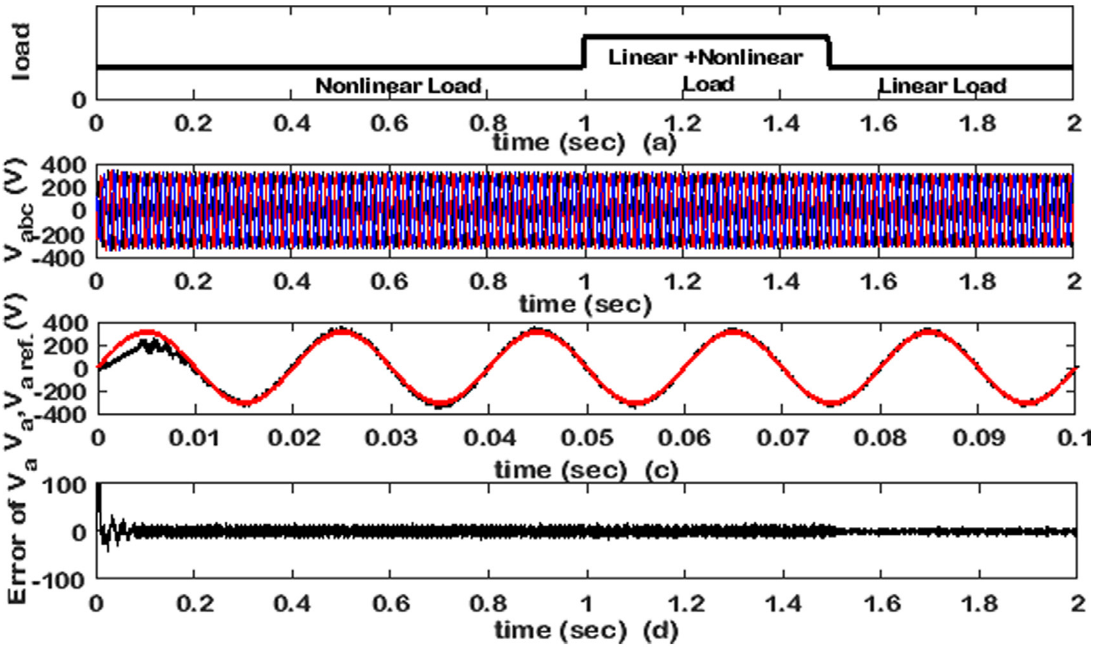

Fig. 4. Simulation results of the system three-phase voltage based on conventional controller. (a) Load curve. (b) Three-phase output voltage. (c) Reference and phase-a output. (d) Error between reference and phase-a output.

[20].

$$w = \frac{W_{max} - W_{min}}{I_{max}} I \tag{7}$$

where I_{max} is the maximum number of iterations and I is the current number of iterations.

3.2. Particle swarm optimized triple-action controller implementation

A flow chart for PSO algorithm is illustrated in Fig. 3. The use of PSO aims to obtain best parameters for the proposed TAC (twelve parameters). The proposed TAC controller offers minimum THD under varying load conditions. In this research work, a fitness function F expressed in Eq. (8), has been suggested for the PSO algorithm in order to get the optimum values for all controller parameters.

In all DER using VSI in a microgrid system, all the renewable micro sources, as well as, VSIs must be controlled to provide the required load demand keeping both voltage and frequency within the allowed limits. The voltage deviation is acceptable if it is less than ± 5% in amplitude, while the frequency deviation is acceptable if it is within ± 1.5% according to the standardization [23]. According to the proposed control strategy, VSI must be controlled efficiently. The target is to feed the load with the allowable predefined values of voltage and frequency. Moreover, their deviations should be small enough to allow for both of droop, secondary and synchronization loops to operate effectively. Therefore, the proposed multi-objective function should consider not only the error, but also the rate at which this error changes, moreover, the mean of this square error for both α and β coordinates. Furthermore, the fitness function should consider the harmonic measurements and feedforward error at the overall simulation time to satisfy minimum settling time, overshoot, undershoot, steady state error and THD_v under different load condition.

$$F = THD_{\,v}\lambda + (e_\alpha + e_\beta)\mu + \left(\Delta e_\alpha + \Delta e_\beta\right)\nu + \sum_{i=1}^{n}(e_\alpha^2 + e_\beta^2) \tag{8}$$

Where:

THD_v THD of inverter output voltage
e_α Voltage error in α coordinate
e_β Voltage error in β coordinate
Δe_α Voltage error rate in α coordinate
Δe_β Voltage error rate in β coordinate
λ, μ and ν Scaling factors reflects the priority of each term in fitness function F

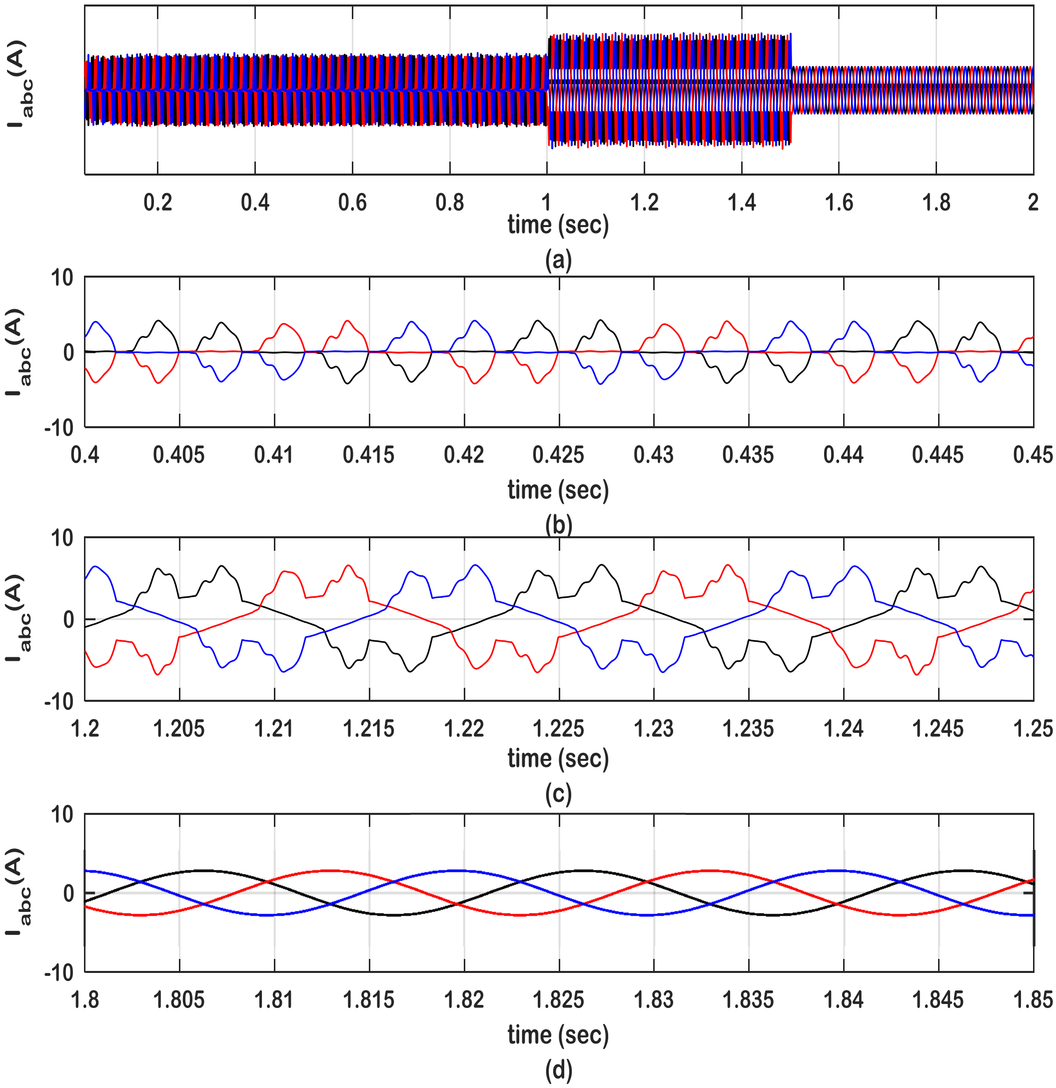

Fig. 5. Simulation results of the system three-phase current based on conventional controller. (a) Three-phase output current. (b) Zooming for nonlinear load. (c) Zooming for nonlinear plus linear load. (d) Zooming for linear load.

The PSO algorithm starts to carry out the first iteration to evaluate the voltage error and maximum THD. Hence, it repeats that process until the maximum number of iterations is reached. PSO algorithm selects the best parameters in range, at the end of the optimization process.

4. Simulation results and discussions

In this section, the PQ improvement of a microgrid-employed VSI to mitigate the exhibited THD and regulate the output voltage under various load conditions will be presented. In this case study, a 2.2KW, VSI voltage source inverter is considered, the system parameters are listed in Table 1. The configuration of the overall system is illustrated in the block diagram in Fig. 2, the PWM-VSI is loaded by linear and nonlinear load combination at different time instants during system operation. Initially the nonlinear load, as a source of harmonic generation, is connected during the time 0 to 1 s, hence, a linear load is connected along with the nonlinear load upon reaching 1.5 s then the nonlinear load is disconnected while the linear load is kept connected upon reaching 2 s of simulation time.

Fig. 4 illustrates the system response based on conventional double action controller (PR and SHC) for both voltage and current loops under different loading conditions. Fig. 4a shows the loading curve for both nonlinear and linear load combination stated above. Fig. 4b shows the dynamic response of output three-phase voltages, while Fig. 4c is magnified for phase voltage (V_a). We note that existing harmonic effect at the dynamic and steady state response on the VSI output.

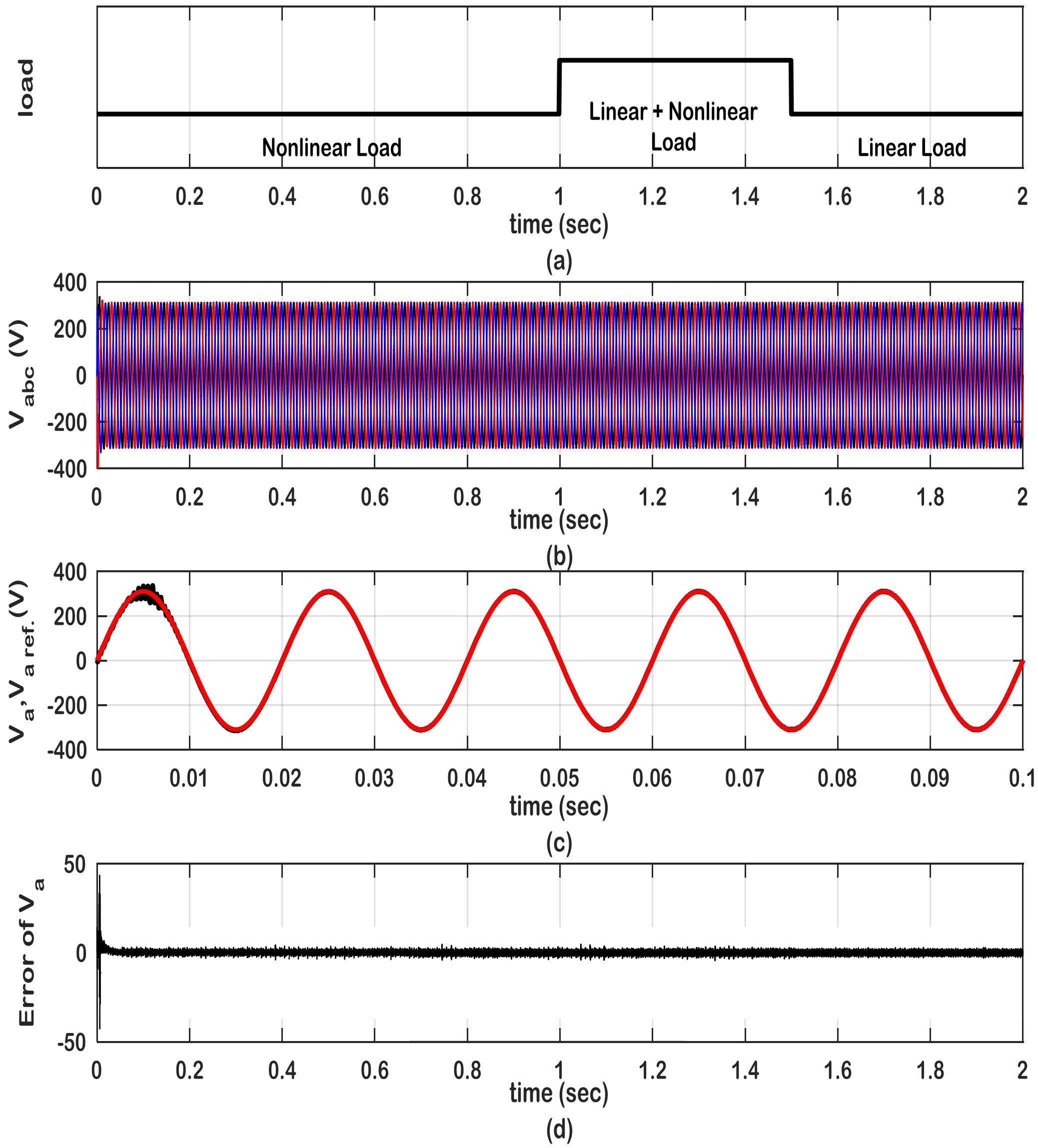

Fig. 6. Simulation result of the system three-phase voltage based on the proposed TAC. (a) Load curve. (b) Three-phase voltage output. (c) Reference and phase-a output. (d) Error between reference and phase-a output.

Table 1
Control System Parameters.

Parameter	Symbol	Value
Nominal output voltage	V_{ref}	311 V
Nominal output frequency	F	50 Hz
Switching frequency	f_s	10KHz
DC voltage	V_{dc}	650 V
Filter inductance	L_{filter}	1.8 mH
Filter capacitance	$C_{\boldsymbol{filter}}$	25 µF
load	R_L	300 Ω
Inductor of bridge filter	L_{bridge}	84 µH
Capacitor of bridge filter	$C_{\boldsymbol{bridge}}$	235 µF
Voltage-PR controller	K_{pv}, K_{rv}, $K_{vh5,7,11}$	0.5, 346, 5, 27, 12
Current-PR controller	K_{pI}, K_{rI}, $K_{Ih5,7,11}$	0.9, 80, 24, 30, 32
Feed-forward gain α, β	K_{α}, K_{β}	58.7, 7.5

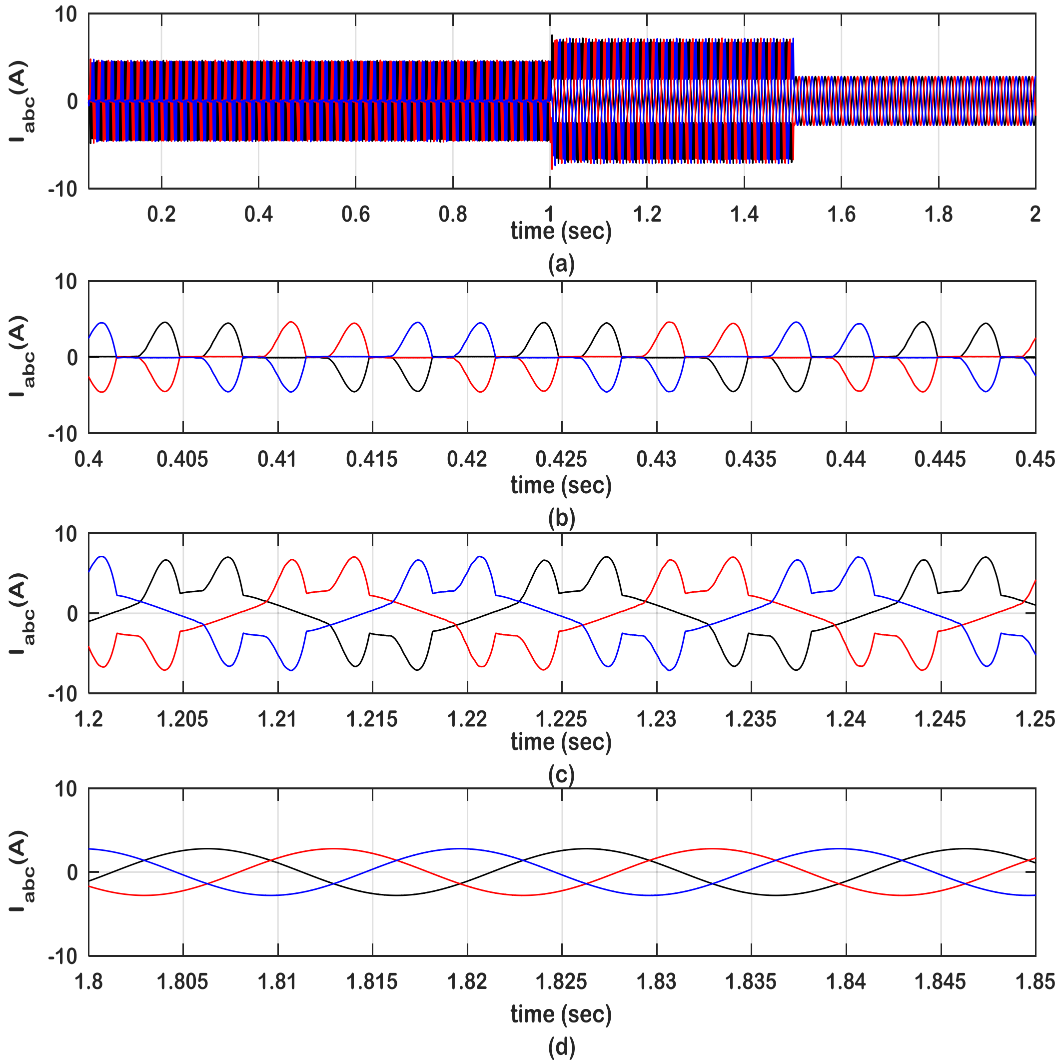

Fig. 7. Simulation result of the system three-phase current based on proposed TAC. (a) Three-phase current output. (b) Zooming for nonlinear load. (c) Zooming for nonlinear plus linear load. (d) Zooming for linear load.

The error value between the desired peak voltage and VSI output of V_a is 12 V at nonlinear loaded and 7 V at linear loaded as shown Fig. 4d.

Fig. 5 illustrates the loading effect on the three-phase currents. Fig. 5a illustrates the three-phase current waveforms with the effect of nonlinear/linear loading at the time instants 0, 1 and 1.5 s., respectively. Fig. 5b, c and d presents zoom of current waveforms for different loads. Due to existence of nonlinear loads from 0 to 1.5 s, note that the amplitude of three-phase currents are not equal leads to unbalance in electrical system and then increase in the zero-sequence current so increase the neutral current. In existence of high loads, the load current is increased leads to increase of neutral current. Increase of neutral current cause efficiency decreasing, produces damages and reduces the equipment lifetime.

After adding the new proposed feedforward current controllers, system simulation has been performed at arbitrary selected parameters for the new feedforward controllers to ensure that better results are obtained. Furthermore, PSO is used to select the optimum parameters values for the new current controllers. It has been noted that in Fig. 6, the proposed TAC was able to minimize the amplitude of voltage error of V_a and compensate the THD for dynamic and steady state response as shown Fig. 6c. The maximum amplitude voltage error between the desired voltage and VSI output does not exceed 3 V (means 2 V rms) as Fig. 6d.

After THD_v compensation, the three-phase current amplitude are almost equal. So, the neutral current is very small and therefore higher efficiency is obtained that in turn reduce damages and increase equipment lifetime as shown Fig. 7b and c.

Comparing results for conventional versus the new proposed TAC, it can be noticed that the dynamic response of the inverter output voltage (V_a) using new proposed TAC is 8 times faster than the conventional controller. The error in voltage

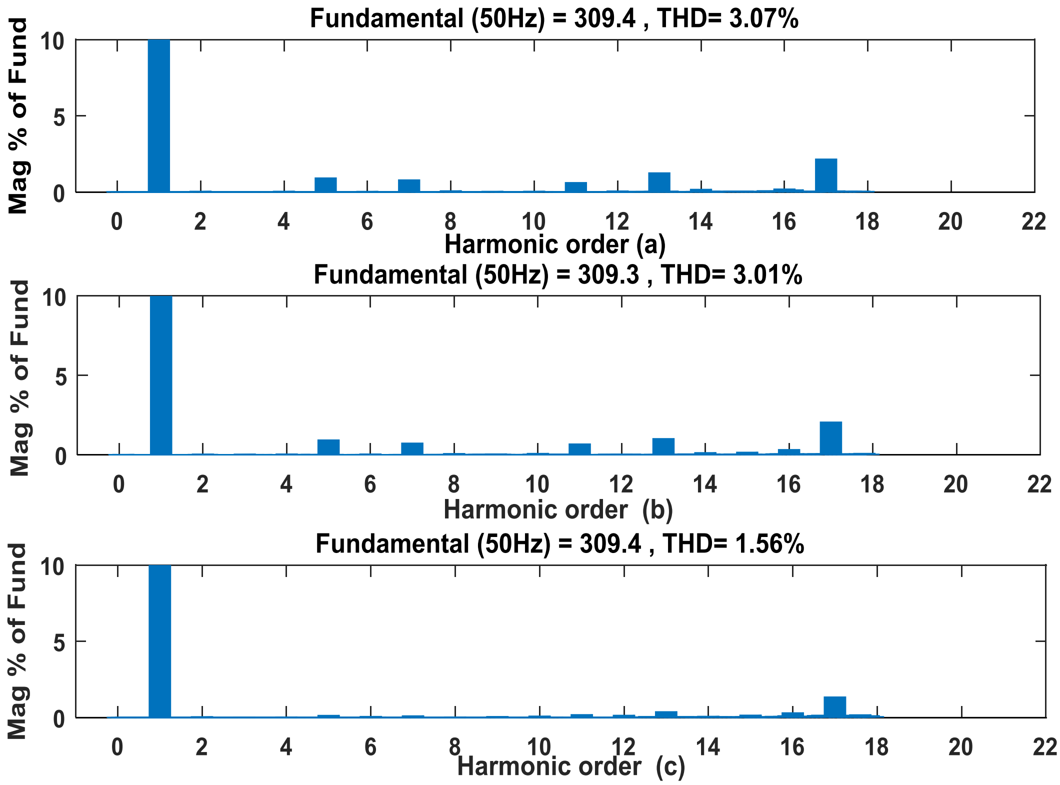

Fig. 8. THD analysis with the conventional controller. (a) THD for nonlinear load. (b) THD for nonlinear plus linear load. (c) THD for linear load.

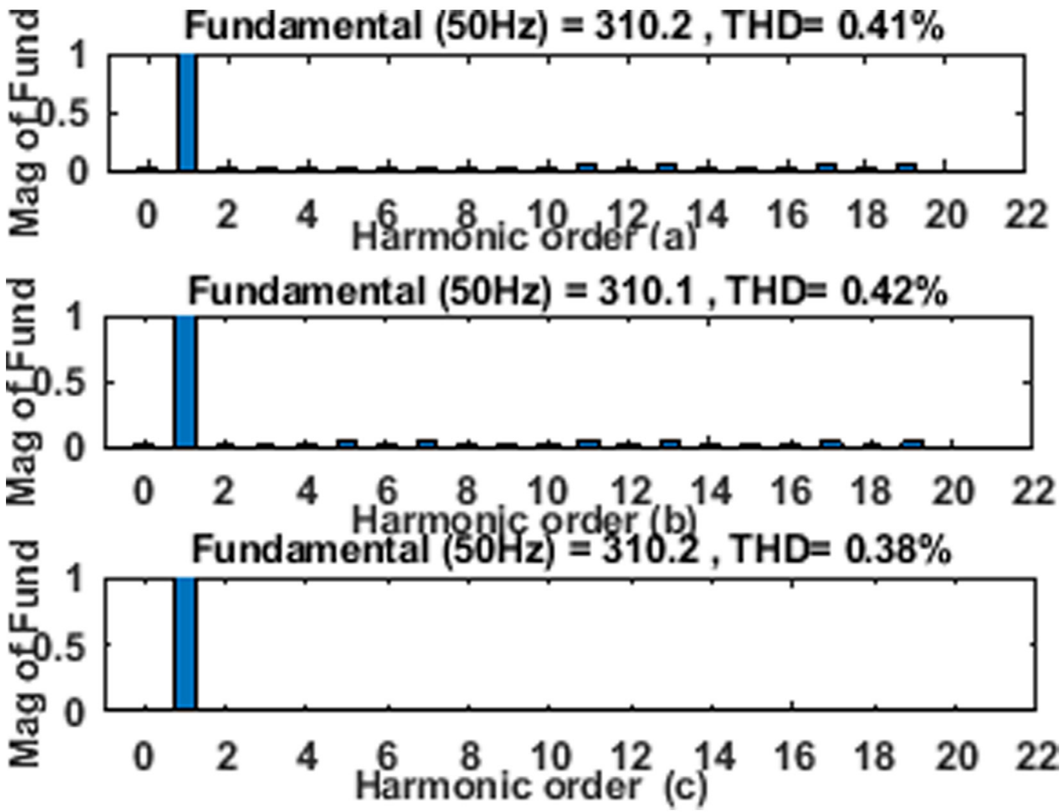

Fig. 9. THD analysis with the triple-action controller. (a) THD for nonlinear load. (b) THD for nonlinear plus linear load. (c) THD for linear load.

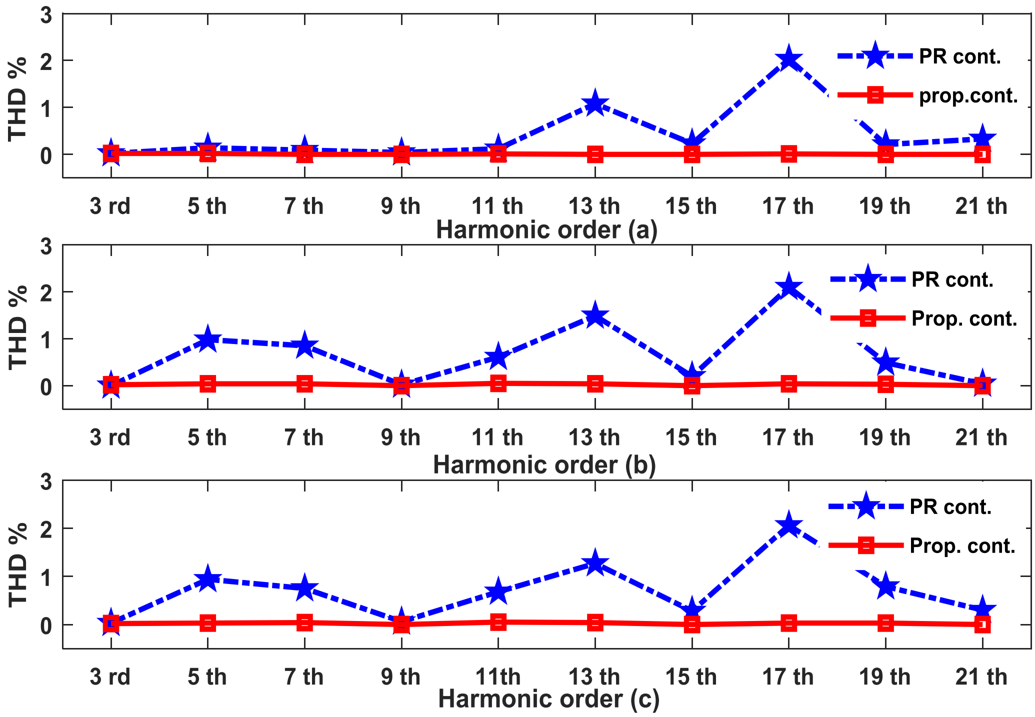

Fig. 10. Comparative graph between conventional PR controller and TAC at various loads. (a) Individual harmonic for nonlinear load. (b) Individual harmonic for nonlinear plus linear load. (c) Individual harmonic for linear load.

Table 2
Individual harmonic analysis (in percentage) for conventional and TAC at various loads.

Harmonic order	Linear		Nonlinear		Linear + Nonlinear	
	PR	NEW_FF	PR	NEW_FF	PR	NEW_FF
3^{rd}	0.02	0.02	0.03	0.02	0.03	0.02
5^{th}	0.14	0.02	0.98	0.04	0.94	0.03
7^{th}	0.09	0.00	0.85	0.04	0.75	0.04
9^{th}	0.04	0.00	0.02	0.00	0.06	0.00
11^{th}	0.12	0.01	0.61	0.05	0.68	0.05
13^{th}	1.08	0.00	1.49	0.04	1.27	0.04
15^{th}	0.23	0.00	0.2	0.00	0.28	0.00
17^{th}	2.03	0.01	2.1	0.04	2.06	0.03
19^{th}	0.21	0.00	0.49	0.03	0.79	0.03
21^{th}	0.33	0.00	0.04	0.00	0.3	0.00

V_a, with TAC, is reduced to one-half at starting and even to one-third at the steady state of the values recorded for the conventional controller regardless to the type of load. Currents are smoother with less THD in case of the new proposed TAC compared to the conventional controller.

THD and individual harmonics is shown in Figs. 8 and 9. The conventional controller analysis is shown in Fig. 8 to present the THD for 10 cycles of output voltage. The IEEE recommendations "IEEE Std 1547^{TM}-2003 (R2008)" for individual harmonic order $h < 11^{th}$ is 4% and $11^{th} < h < 17^{th}$ is 2% and $17^{th} < h < 23^{th}$ is 1.5%. While, the limit of total harmonic order is 5%.

Results of all THD and individual harmonic orders considering both conventional and new proposed TAC under various load condition is expressed in Table 2. It can be noted that the individual harmonic order $11^{th} \leq h < 17^{th}$ is out of IEEE Std. limits with nonlinear load. THD results with conventional controller are 2.3% and 2.23% for nonlinear loads and linear plus nonlinear loads respectively. On the other hand, the new proposed TAC results are reduced to 0.09% for the same load.

For the harmonic order $17^{th} \leq h < 23^{th}$, the proposed controller THD could be neglected for linear loads. While the value of THD can be 0.07% instead of 2.63% for the conventional controller driving nonlinear load. Moreover, THD value can be as low as 0.06% for linear plus nonlinear loads compared to the value of 3.15% for the conventional controller. All results are summarized in Fig. 10 that show the enhancements after adding the optimized feedforward controllers for all loading scenarios.

5. Conclusion

Since voltage source inverters are used to interface loads in any distributed generation system; for that reason, researchers paid lots of attention to achieve seamless sinusoidal output voltage. This paper introduced a procedure to design and optimize a triple-action controller using particle swarm technique to ensure almost pure sinusoidal output voltage with minimum harmonic contents. Since the conventional controller alone is like a bandpass filter that might introduce distortion to the output voltage, the proportional resonant controller, supported by the selective harmonic compensator, performed better with a total harmonic distortion within the IEEE-standard limits. Although that double-action controller exhibited individual harmonics order $11^{th} \leq h < 17^{th}$ out of IEEE Std. limits during the existence nonlinear loads. It exhibited a total harmonic distortion of 2.3% and 2.23% for nonlinear and linear plus nonlinear loads respectively. The triple-action controller proposed was able to regulate the inverter output voltage within the IEEE-standard limits under sudden change of the load types. The obtained total harmonic distortion is, as low as, 0.09% for the same loads. The harmonic orders $17^{th} \leq h < 23^{th}$, the harmonic distortion could be neglected for linear loads when using the proposed controller. For nonlinear loads, the value of total harmonic distortion reaches 0.07% instead of 2.63% for the conventional controller, while the value is 0.06% for linear plus nonlinear loads compared to the value of 3.15% for the conventional controller. These results proved that the proposed controller could increase the reliability, enhance the power factor and efficiency, hence, improve the power quality of the systems relying on renewable sources under various load conditions. This contribution made the grid connected inverter compliant to the standard regulations, hence it can be extended for microgrids utilizing renewable energy resources using voltage source inverters.

STATEMENT RAUTHO

All persons who meet authorship criteria are listed as authors, and all authors certify that they have participated sufficiently in the work to take public responsibility for the content, including participation in the concept, design, analysis, writing, or revision of the manuscript. Furthermore, each author certifies that this material or similar material has not been and will not be submitted to or published in any other publication before its appearance in the computers and electrical engineering.

Declaration of Competing Interest

The authors whose names are listed immediately below certify that they have no affiliations with or involvement in any organization or entity with any financial interest (such as honoraria; educational grants; participation in speakers' bureaus; membership, employment, consultancies, stock ownership, or other equity interest; and expert testimony or patent-licensing arrangements), or non-financial interest (such as personal or professional relationships, affiliations, knowledge or beliefs) in the subject matter or materials discussed in this manuscript.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.compeleceng.2019.106543.

CRediT authorship contribution statement

Amgad El-Sayed Salem: Conceptualization, Formal analysis, Writing - original draft, Writing - review & editing. **Omar M. Salim:** Conceptualization, Formal analysis, Writing - original draft, Writing - review & editing. **Shawky I. Arafa:** Conceptualization, Formal analysis, Writing - original draft, Writing - review & editing.

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