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Research Paper

Enhancement of Power Quality in Grid Integrated System using DC-link Voltage PI Controlled VSC based STATCOM

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Abstract: This paper demonstrates an enhancement of power quality in grid integrated systems with the help of the proposed control strategy for voltage source converter based active power filters. The Shunt Active Power filters (SAPF) are extensively utilized in modern grid integrated systems to diminish the power quality concerns associated with it. The SAPF is one of the various power filters, which has better dynamic performance. The SAPF requires an accurate control strategy that provides robust performance under source and loads unbalance conditions. The proposed control scheme is responsible for generating the gate signals to activate the operation of Voltage Source Converter (VSC) based Active Power Filter. Thus, the performance of mitigation of harmonics of source current principally depends on the adopted algorithm. The present paper represents a performance study of a control scheme to mitigate power quality issues in the grid integrated system. The proposed system is modelled and simulated in MATLAB-Simulink in Simpower system block set.

Keywords: Voltage Source Converter (VSC), Active Power Filter (APF), Power quality Issues, Control strategy, Performance analysis, Total Harmonic Distortion (THD).

1 Introduction

THE modern distribution system facing severe power quality concerns, enlarged utilization of power electronic-based loads such as electric Arc furnace uninterrupted power supply (UPS), Computer power supply and adjustable speed drives (ASD) etc.

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These Power Electronics based loads inject the current harmonics into the system, which affects the lifespan and performance of the proposed system [1-13]. To nullify the injected harmonics, it is needed to install the harmonic filters at the point of common coupling in the proposed test model.There are several proven technical options available to nullify the power quality issues in the system; the shunt connected active filters have proved to provide better dynamic performance [1, 3-15]. The effective performance of voltage source converter based shunt active filter depends on the applied control scheme for the creation of gate signals for SAPF. Few control strategies mentioned in [11, 6, 14] providing good performance for balanced load conditions, for unbalanced load conditions that performance is not satisfactory. The proposed control strategies in [7, 8] can solve this particular problem in the projected system. This paper demonstrates a study of the proposed control strategy to nullify the power quality problems in the proposed integrated system.

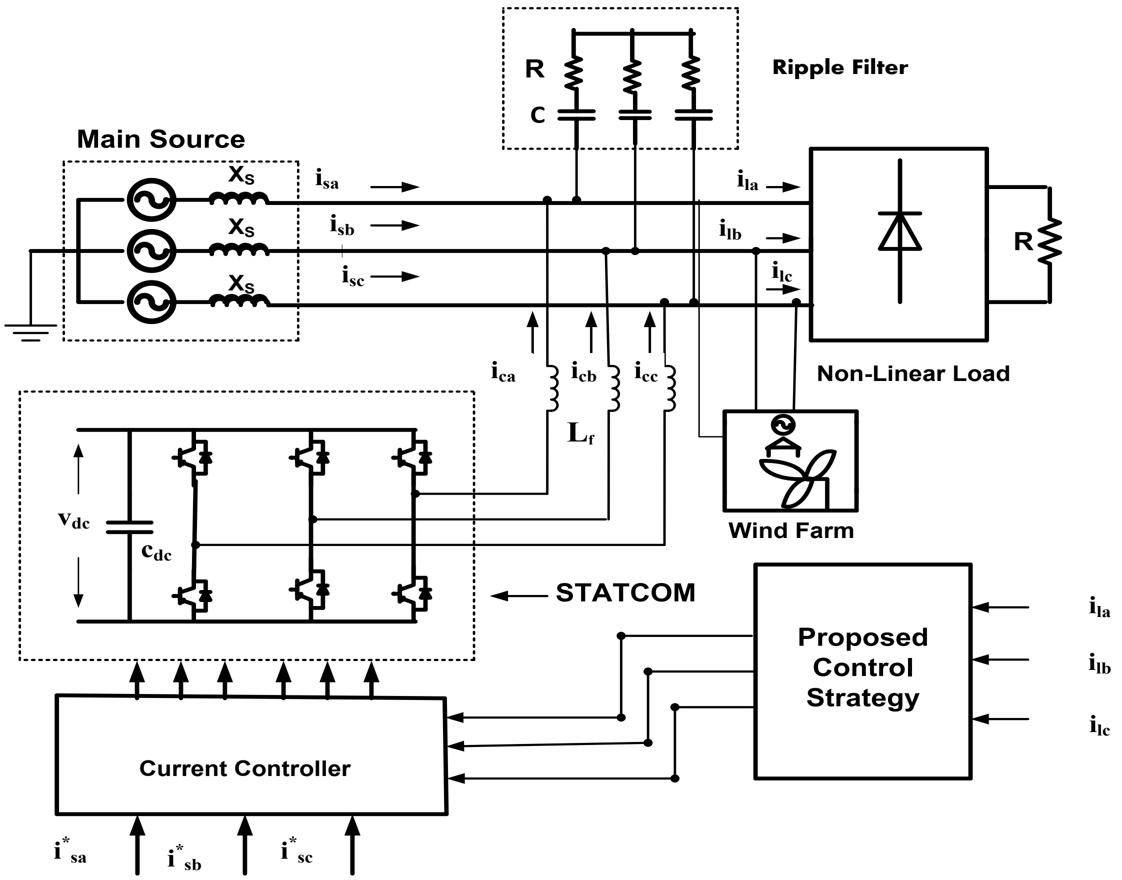

Fig. 1 The basic test model for harmonic mitigation in a grid-tie system.

This paper managed as follows section 2 presents current harmonics mitigation schemes along with the description of the proposed test model section 3 demonstrates the control strategies for the generation of gate current signals, Section 4 and 5 indicates the result analysis and conclusion parts respectively.

2 Test Model for Harmonic Compensation

The proposed test model for harmonic compensation as depicted in Fig. 1 consists of the main power circuits and DC link voltage control unit. The Voltage source control based active filter for harmonic compensation is connected in shunt with a grid integrated system. Because of their dynamic characteristics, the shunt active power filters are the featured trend for harmonic mitigation in the proposed electrical distribution system.

The shunt active power filter consists of the DC bus capacitor and interfacing inductor injection compensating current with desired magnitude and phase shift for the mitigation of current harmonics in the grid integrated proposed system. The relation between main current, load current and compensation current is given as follows:

$$I_L = I_S + I_{Com} \tag{1}$$
$$I_{Com} = I_L - I_S \tag{2}$$

The injected Complex power by the shunt active filter in the grid-tie system can be expressed as follows:

$$S_{Com} = V_L I_{Com}^* \tag{3}$$

The interfacing inductor and DC bus capacitor can be designed with the help of the following equation for harmonic compensation.

$$L_f = \frac{\sqrt{3} m V_{dc}}{12 m a f_s i_{crpp}} \tag{4}$$

L_f is interfacing inductor, f_s switching frequency, i_{crpp} is ripple current, m is modulation index and a is overloading factor.

$$\frac{1}{2} C_{dc}\{(V_{dc}^2 - V_{dc1}^2)\} = K\{3V_{ph}(aI_{ph})t\} \tag{5}$$

In this proposed research work, the shunt active filter is acting as a current injector for mitigation of the current harmonics developed by the nonlinear load [1, 3, 12, and 16] in the grid integrated system with the help of the control strategy the active filter is improving the load factor.

3 Control Strategy for Reference Current Generation

It is very important that the generation of gate signals in the proposed work, which activates the dynamic operation of an active filter in the grid integrated system. The DC link voltage PI controller is responsible for the generation of the gate signals. The DC Bus capacitor which is located on the DC side of the VSC is utilized as an energy storage element for both supplying required reactive power the load and voltage regulation at PCC [4, 6, and 8]. In grid tie test model. For normal operation no power will pass through to the power converter, hence an average DC voltage of the converter DC capacitor is kept as a constant value [12].

During abnormal operation (power unbalance), an error power can be injected by the active filter, which creates voltage fluctuations at the DC link capacitor. Now it is clear that the flow of active power in the system can be done based on the average value of the DC capacitor voltage. Fig. 2 depicts the complete internal structure of the DC link voltage PI control circuit.

The proposed control scheme consists of a three-phase sine wave generator and PI controller for the generation of gate signals to activate the operation of the active filter [1, 5, and 7]. The actual capacitor voltage is compared with the reference voltage values. The peak value of supply current is obtained from the PI controller and later multiplies with the unit vector in face unit vector in phase with respective source voltage for the voltage for generation of voltage generation reference currents [1, 9, 10, and 13]. The generated reference currents and actual currents are compared at the hysteresis band for generations of gate signals [17, 18, and 19]. To Keep DC link voltage as a constant value for effective harmonic compensation, the PI controller is utilized effectively. The PI controller error voltage is computed as:

$$V_{err} = V_{dc} - V_{dc-ref} \tag{6}$$

The reference currents for three phases can be computed as:

$$I_{sa}^{*} = I\ U_{sa} \tag{7}$$

$$I_{sb}^{*} = IU_{sb} \tag{8}$$

$$I_{sc}^{*} = I.U_{sc} \tag{9}$$

where the unit vector for phases *a*, *b* and *c* can be computed [1, 3, and 12] as follows:

$$U_{sa} = \frac{V_{sa}}{V_{sm}} \tag{10}$$

$$U_{sb} = \frac{V_{sb}}{V_{sm}} \tag{11}$$

$$U_{sc} = \frac{V_{sc}}{V_{sm}} \tag{12}$$

where V_{sm}, Va, Vb and Vc are given as follows:

$$V_{sm} = \{(V_{sa}^2 + V_{sb}^2 + V_{sc}^2)\}^{1/2} \tag{13}$$

$$Va = VmSin(\omega t) \tag{14}$$

$$Vb = VmSin\left(\omega t - \frac{2\pi}{3}\right) \tag{15}$$

$$Vc = VmSin\left(\omega t + \frac{2\pi}{3}\right) \tag{16}$$

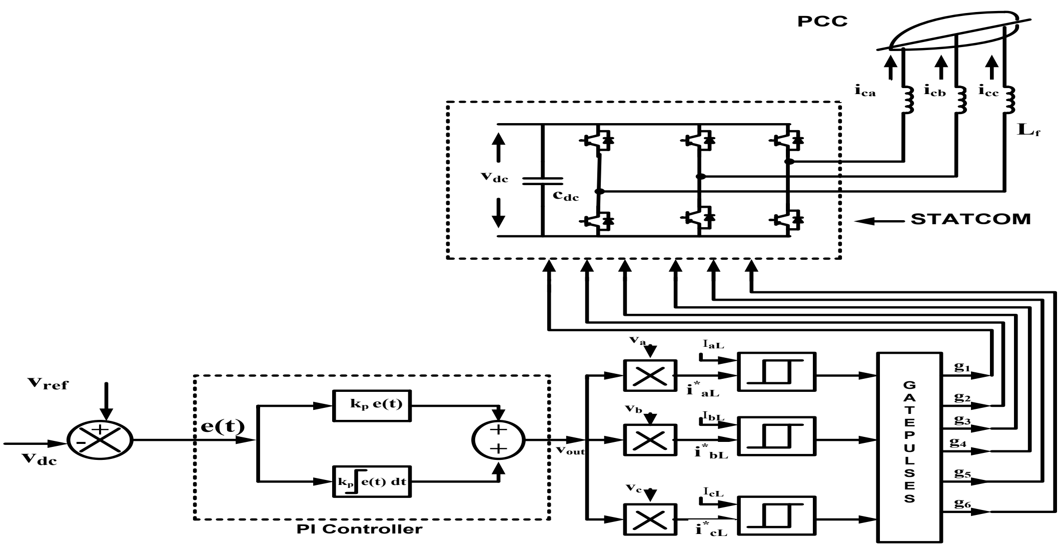

Fig. 2 Block diagram representation for proposed control scheme.

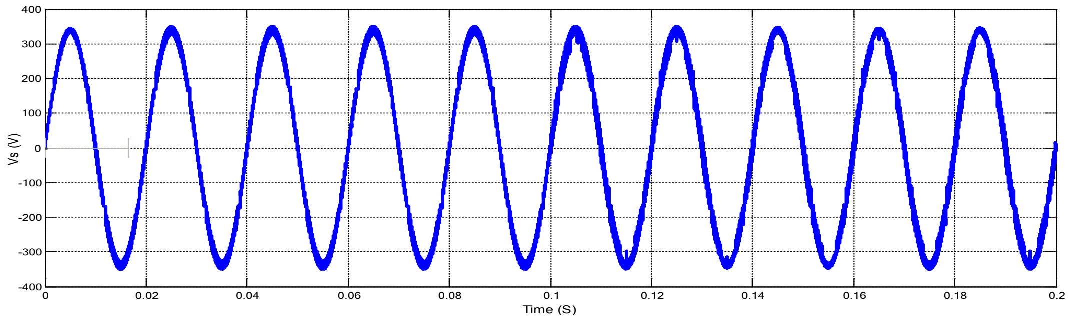

Fig. 3 Source voltage for phase-*a* in three-phase *abc* system.

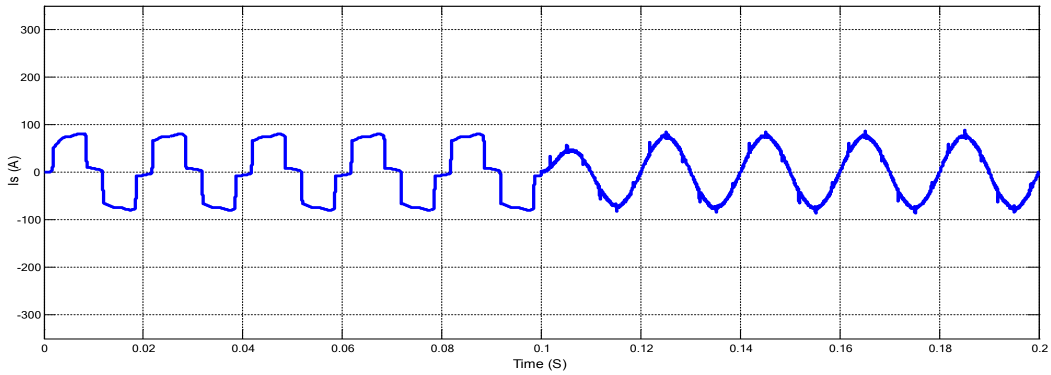

Fig. 4 Source current for phase-*a* in three-phase *abc* system with & without STATCOM.

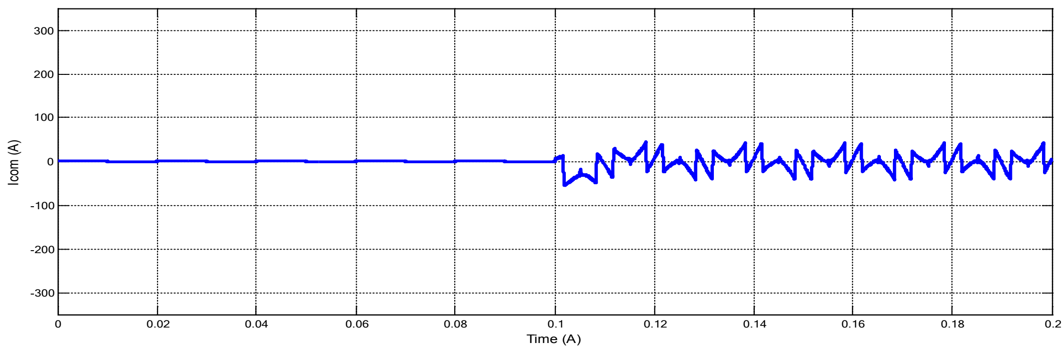

Fig. 5 Compensating current for phase-*a* in three-phase *abc* system for mitigation of harmonics.

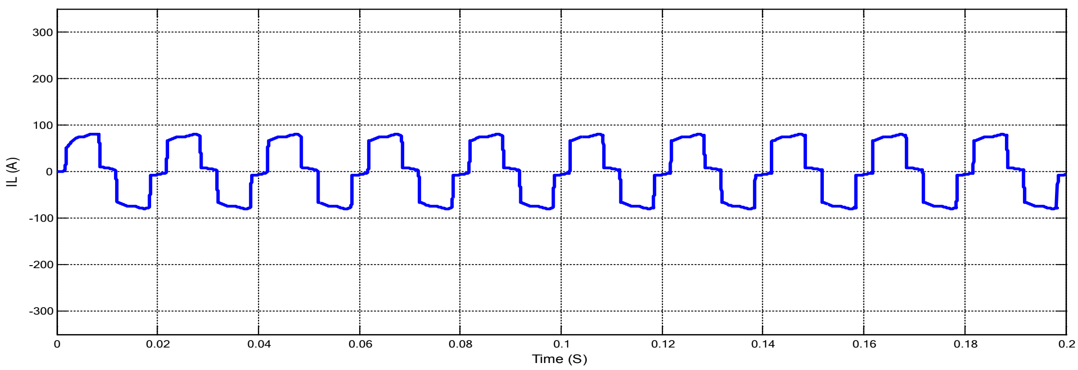

Fig. 6 Nonlinear load current for phase-*a* in three-phase *abc* system.

4 Simulation Result Analysis

This segment indicates the MATLAB simulation results of a proposed test model for power quality enhancement using an active filter. To reach the capital load demand the current is supplied from both the main grid source and green energy source called wind form as shown in Fig. 1. The generated current harmonics by the nonlinear load will be completely mitigated by the shunt active filter in the grid integrated system. Table 1 indicates that the various parameter values considered for the MATLAB simulation study for nullification of current harmonics in the proposed research work. The single-phase source voltage (Vs) is indicated in Fig. 3.

Fig. 4 and Fig. 5 depicts the simulation results of source current and compensator current respectively. The active filter is allowed to operate from 0.1s as shown in Fig. 5 for mitigation of current harmonics generated by the nonlinear load. From Fig.4 It is clear that before time t=0.1s am (an active filter Turned Off) the source current is affected by harmonic current and from time t= 0.1s the source current is free from harmonics. The Active filter is injecting the desired compensating currents from 0.1s onwards. Show that the current harmonics are completely mitigated from 0.1s as shown in Fig. 4 in the grid-tie system.

Fig. 6 indicates the MATLAB simulation results of load current. Because of its nonlinear characteristics always the load draws the nonlinear current. Fig. 7 indicates the MATLAB simulation results of a wind generator which is connected with a grid-tie system to reach the load demand. Fig. 8 depicts the phase relationship between the source voltage and source current. It is clear that before 0.1s there is no desire phase relation between the source voltage and source current.

From 0.1s onwards both *Vs* and *Is* have desired phase relation with the help of active operation of shunt connected active filter. So that PF is improved from lagging PF to Unity PF. The THD value is reduced from 27% to 4% which is within the *IEEE* Standard level. The following Table 2 indicates the performance analysis of Active Filter in the grid-connected system.

Table 1 System parameter specification.

S. No.	Parameter	Specifications
1	Source Voltage	415 V, 50 Hz
2	Line Parameters	R= 0.1 Ω, L_r = 0.05 m H
3	Wind Generator	3.30 kVA, 415 V, 50 Hz, N=1500 rpm, P= 4, R_r= 20Ω, L_r= 0.06 H
4	DC Bus Capacitor	V_{dc}= 750 V, C_{dc} = 10 *mF*.
5	Interfacing inductor (L_f)	L_f=1.25 mH.
6	Distorting Load	10 Ω, 12 mH.

Table 2 performance analysis of STATCOM.

Measuring Factor	Without STATCOM	With Statcom
% THD in Source Current	27%	4%
Power Factor (PF)	0.9 (Lagging PF)	1.0 (Unity PF)

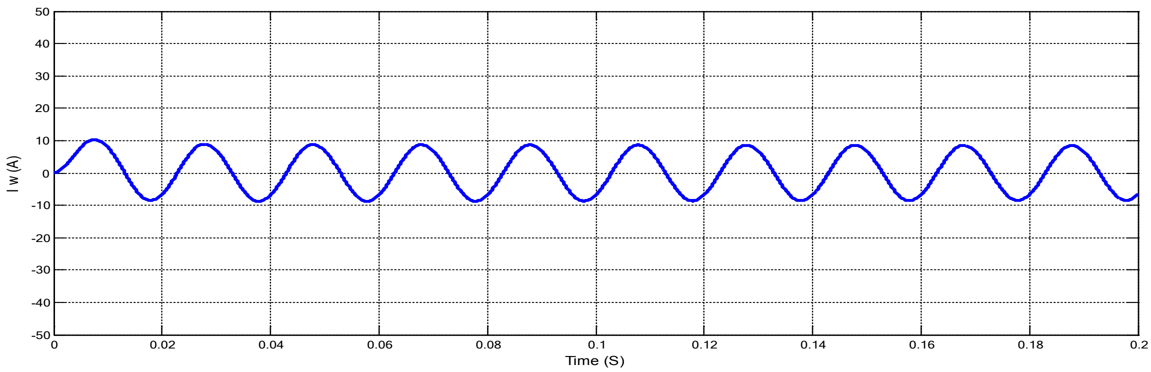

Fig. 7 Wind generator current for phase-*a* in three-phase *abc* system.

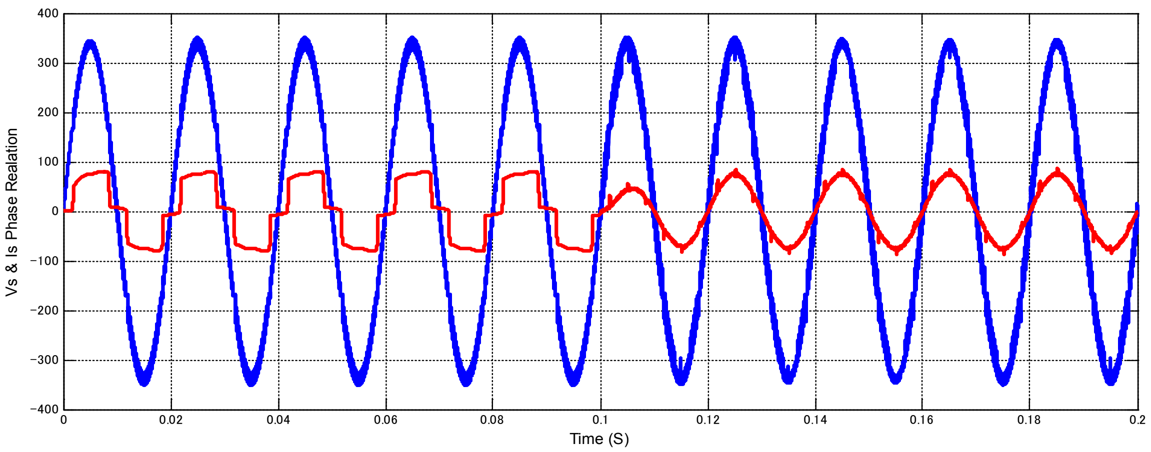

Fig. 8 The phase relationship between source voltage & source current for phase-*a* in three-phase *abc* system with & without STATCOM.

5 Conclusion

This paper indicates the dynamic operation of a shunt connected active filter for elimination of current harmonics in the source current due to nonlinear load. The harmonic distortion is one of the major power quality issues which is associated with PE-based loads (nonlinear loads), which draws non-sinusoidal current and creates power quality problems in the grid-tie system. The proposed active filter completely mitigated the current harmonics with the help of a DC link voltage controller. It is confirmed that the DC link voltage PI controller is the superior one and can obtain the desire THD value for source currents. The proposed control strategy has been stimulated to demonstrate the effectiveness of the shunt connected active filter using the MATLAB Simulink platform.

Intellectual Property

The authors confirm that they have given due consideration to the protection of intellectual property associated with this work and that there are no impediments to publication, including the timing to publication, with respect to intellectual property.

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Credit Authorship Contribution Statement

P. Lakshman Naik: Idea & Conceptualization, Research & Investigation, Data Curation, Analysis, Methodology, Project Administration, Software and Simulation, Verification, Original Draft Preparation, Revise & Editing. **H. Jafari:** Idea & Conceptualization, Research & Investigation, Data Curation, Project Administration, Software and Simulation, Supervision, Verification, Revise & Editing. **T. Sudhakar Babu:** Research & Investigation, Analysis, Methodology, Software and Simulation, Supervision, Revise & Editing. **A. Anil:** Research & Investigation, Analysis, Methodology, Supervision, Revise & Editing. **S. Venkata Padmavathi:** Idea & Conceptualization, Research & Investigation, Methodology, Project Administration, Verification, Original Draft Preparation, Revise & Editing. **D. Nazarpour:** Research & Investigation, Analysis, Methodology, Supervision, Revise & Editing.

Declaration of Competing Interest

The authors hereby confirm that the submitted manuscript is an original work and has not been published so far, is not under consideration for publication by any other journal and will not be submitted to any other journal until the decision will be made by this journal. All authors have approved the manuscript and agree with its submission to "Iranian Journal of Electrical and Electronic Engineering".

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