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Direct Power Control of an Under-damped Grid Connected Boost Inverter

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ABSTRACT

This paper presents a simple and direct power control approach to control a single-phase grid-connected boost inverter (*GCBI*) for renewable energy applications. A *DC* voltage source and a single-phase single-stage boost inverter that is connected to the grid by an *L* filter form the power injection system (*PIS*). Unlike the conventional voltage source inverters (*VSIs*), the boost inverter can generate an *AC* output voltage with amplitude larger than the *DC* input one, only in a single stage. In comparison with multi-stage power c0.onversion systems, the aforementioned inverter has less number of devices and components which results in low cost and higher efficiency. Nevertheless, the boost inverter suffers from undesirable dynamic behavior and extreme fluctuation response that makes it difficult to control. Thus, the proposed power injection control system consists of two parts. First, a proper state-feedback control scheme is designed to increase damping and also improve the stability of the closed-loop system. Then, the direct power control strategy is employed to control and track the desired powers that should be injected into the grid. Simulation results are presented to validate the effectiveness of the proposed control strategy.

Article Info

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Boost inverter, Direct power control approach, Power injection system (*PIS*), Damping of the system, Renewable energy.

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I. INTRODUCTION

The high cost of fossil fuels and their destructive effects on the environment are the current concerns of modern society. Renewable energy resources, such as solar, wind, fuel cells, and geothermal and etc. are faced with better conditions to generate electrical power [1]. One of the most important parts of grid-connected systems is control unit. There are various control structures depend on the configuration of renewable energy systems as well as their power conversion stage topology.

Besides conventional two-stage grid-connected inverters (*GCIs*) have inevitable drawbacks, such as being bulky, costly, and inefficient. Accordingly, a single-stage *DC-AC* boost inverter has been proposed, which naturally generates an *AC* output voltage whose peak value is larger than the *DC* input one, depending on the instantaneous duty cycle [2]. Few electronic components, smaller bulk, lower total harmonic distortion (*THD*) of the output voltage and output current, lower cost, higher efficiency, as well as higher reliability are some of the advantages of the boost inverter compared with a two-stage one.

In addition to choosing a proper *DC-AC* inverter, the control of power electronic inverters has always been considered as a challenging control issue. In [3] and [4], the grid-connected boost inverter (*GCBI*) is presented, but the references of the cascade control are obtained from an external loop based on the active and reactive power control. A double-loop control scheme is proposed for a grid-connected single-stage boost inverter (*SSBI*) in [5], which can be used in a *UPS*, photovoltaic systems, etc. but the stability of the double-loop regulation scheme cannot be completely guaranteed under the possible occurrence of operational conditions. A non-linear control approach based on sliding mode control is used [6] to control the *SSBI* that it involves complex theory, variable switching frequency and also involves current mode control in addition to voltage mode. An adaptive control design, in addition to fix the variable switching frequency problem, improves the system response even in the case of variation in output load [7]. A controller based on energy shaping theory [8] is proposed

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which is complex too. A dynamic sliding mode control for the boost inverter topology is proposed in [9]. The drawback of the controller is the steady-state error caused by the proportional-integral (*PI*) controller and the existence of chattering phenomenon due to the presence of dynamic sliding mode controller (*DSMC*). The current control of the boost inverter is proposed in [10] to control the output power independent of the load variations. A control strategy to control output current with only one closed control loop is presented in [11] for a *GCBI*, where identical control structure is employed for its two *DC-DC* boost converters. A hybrid control scheme is applied [12] to an *SSBI* for photovoltaic and Nano-grid residential applications. This method includes one cycle control and adaptive Neuro fuzzy inference system.

In general, the common control method in the grid-connected micro-inverters is to control the output current directly [13, 14]; the real and reactive references power are applied to generate the reference value of injected current into the grid. Accordingly, a new control strategy based on direct power control has been presented in [15] for a grid-connected full-bridge voltage source inverter with a *DC* input voltage source. The main advantage of this method compared to the current mode control is its simplicity and also even if there is a sudden change in the grid voltage, it can be independently compensated and fed desired powers into the grid. In this paper, the proposed controller is based on the direct power control concept.

The remaining of this paper is organized as follows. In section II, the linearized state-space model of the *PIS* is obtained and an internal feedback controller based on state-feedback method is designed in section III. Then, the controller design to inject desired power into the grid is detailed in section IV. The simulation results are presented in section V. Finally, conclusions are summarized in section VI.

II. System Configuration

A. Description and Modelling of the System

Fig. 1 shows the schematic of the single-phase *GCBI*, which consists of two conventional boost converters. The two converter outputs are connected differentially in series with the grid voltage V_g through the inductor *L*.

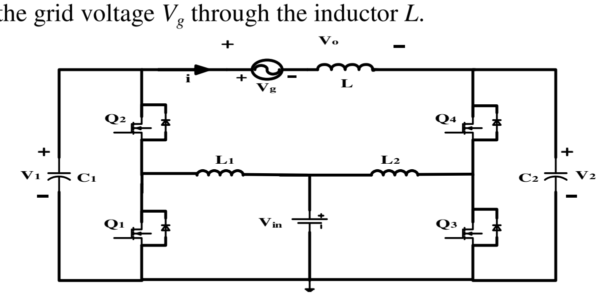


Fig.1. Schematic of grid-connected single-stage boost *DC-AC* inverter.

B. Averaged Nonlinear Model

To model the system, suppose that all the circuit components are ideal and the *SSBI* operates in a continuous conduction mode. Each side of the boost converter operates based on individual duty cycles d and d', respectively. The switching circuit scheme of the *GCBI* is illustrated in Fig. 2.

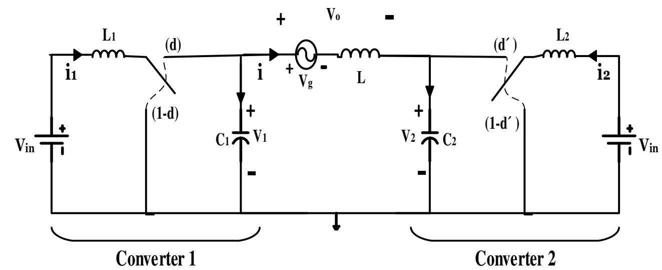


Fig.2. Switching circuit diagram of the *GCBI*.

From Fig. 2, the average model of the *GCBI* is expressed as follows:

$$\begin{aligned}
&L_1\frac{di_1}{dt} = v_{in} - d(t)v_1\\
&C_1\frac{dv_1}{dt} = d(t)i_1 - i\\
&L_2\frac{di_2}{dt} = v_{in} - d'(t)v_2\\
&C_2\frac{dv_2}{dt} = d'(t)i_2 + i\\
&L\frac{di}{dt} = v_1 - v_2 - v_g
\end{aligned} \tag{1}$$

where i_1, i_2 and i are the inductors and output currents, respectively; v_1, v_2 and v_g are the capacitors and grid voltages, respectively; v_{in} is the *DC* input voltage and d and d' are the duty cycles of two converters.

C. Linear Model and Transient Behavior Analysis

To evaluate the transient behavior of the system, by using the Taylor expansion, the nonlinear dynamic Equ. (1) are linearized around the operating point. Assume:

$$\begin{aligned}
&i_1(t) = \tilde{i}_1(t) + I_1, i_2(t) = \tilde{i}_2(t) + I_2,\\
&i(t) = \tilde{i}(t) + I_2,\ v_1(t) = \tilde{v}_1(t) + V_1\ ,\\
&v_2(t) = \tilde{v}_2(t) + V_2,\ d(t) = D + \tilde{d}(t),\\
&d'(t) = D' + \tilde{d}'(t)
\end{aligned} \tag{2}$$

By considering the Equ. (1) in the steady state mode, one can obtain the quiescent values of the capacitor voltages and inductor currents as follows:

$$V_1 = \frac{V_{in}}{D}, V_2 = \frac{V_{in}}{D'}\ , I_1 = \frac{I}{D}\ , I_2 = \frac{I}{D'}\ , I = \frac{V_o \sin\delta}{L\omega} \tag{3}$$

Assuming that the ac variations are much smaller than the quiescent values, so the linearized equations in the state space form are as follows:

$$\begin{cases}\dot{X}(t) = AX(t) + BU(t)\\ \quad y(t) = CX(t)\end{cases} \tag{4}$$

$$X(t)=\begin{bmatrix}\tilde{\imath}_1(t)\\ \tilde{v}_1(t)\\ \tilde{\imath}_2(t)\\ \tilde{v}_2(t)\\ \tilde{\imath}(t)\end{bmatrix},U(t)=\begin{bmatrix}\tilde{d}(t)\\ \tilde{d}'(t)\end{bmatrix}$$

where

$$A=\begin{bmatrix}0 & \frac{-D}{L_1} & 0 & 0 & 0\\ \frac{D}{C_1} & 0 & 0 & 0 & \frac{-1}{C_1}\\ 0 & 0 & 0 & \frac{-D'}{L_2} & 0\\ 0 & 0 & \frac{D'}{C_2} & 0 & \frac{1}{C_2}\\ 0 & \frac{1}{L} & 0 & \frac{-1}{L} & 0\end{bmatrix},B=\begin{bmatrix}\frac{-V_1}{L_1} & 0\\ \frac{I_1}{C_1} & 0\\ 0 & \frac{-V_2}{L_2}\\ 0 & \frac{I_2}{C_2}\end{bmatrix},$$

$$C=[0\quad 1\quad 0\quad -1\quad 0]$$

Note that for having the boost inverter output voltage (V_o) equal to $V_o = V_{ac}\ sin\ (\omega t)$, the converter output voltages (V_1 and V_2) should be set according to Equ. (3). To this end, duty cycles rated values (D and D') can be computed as:

$$D(t)=\frac{1}{a\sin(\omega t)+b},D'(t)=\frac{1}{-a\sin(\omega t)+b} \tag{5}$$

thus:

$$V_o=V_1-V_2=\left(\frac{1}{D}-\frac{1}{D'}\right)V_{in}= \\ =[(a\sin(\omega t)+b)-(-a\sin(\omega t)+b)]V_{in} \\ =2a\sin(\omega t)V_{in} \tag{6}$$

To survey the system transient behavior, suppose that the alternative output voltage is V_o=*311sin (100πt) (220v (rms) 50Hz)*. According to the *DC* input voltage and steady state capacitor voltage values, the steady-state duty cycles of two converters are obtained as follows:

$$\begin{cases} V_1=\frac{V_{in}}{D} \\ V_2=\frac{V_{in}}{D'} \\ V_{in}=100 \\ V_o(t)=311\sin(100\pi t)\end{cases} \Rightarrow \tag{7}$$

$$D(t)=\frac{1}{1.55\sin(\omega t)+2.55},$$

$$D'(t)=\frac{1}{-1.55\sin(\omega t)+2.55}$$

D. Stability Analysis

Since the switching frequency is much higher than the change rate of duty cycle, therefore, we can take it constant in the stability analysis.

By using the linearized model, the root locus of the open-loop system for various values of *D(t)* and *D΄(t)* in the interval of [0 1] is shown in Fig. 3. One can see that the system is on the boundary of instability. The corresponding output voltage waveform is visible in Fig. 8(a), which shows weak damping and extreme oscillations on the output voltage signal.

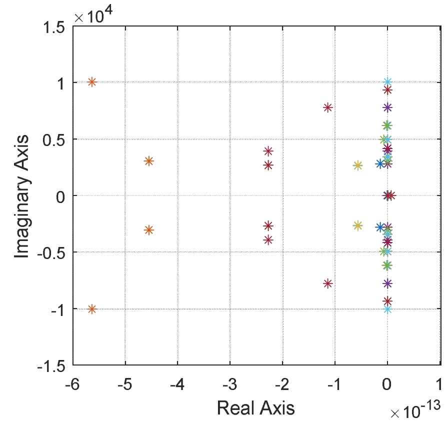


Fig.3. Root Locus of the open-loop system for various values of *D(t)* and *D΄(t)* in the interval of [0 1].

A control approach based on state-feedback will be proposed to improve system behavior regarding to damping and oscillation.

III. Improvement of System Dynamic Behavior Based on State Feedback Control

Here, the controller design objects are aimed at increasing damping and closed-loop stability. To design the state-feedback controller, the controllability should be checked at first as follow:

$$\rho(\varphi_c)=\rho[B\quad AB\quad A^2B\quad A^3B\quad A^4B])=4=m<5=n \tag{8}$$

where φ_c is the controllability matrix and Equ. (8) states that the controllability matrix rank is four. Therefore, the system is not fully controllable. Accordingly, the system has four controllable states and one uncontrollable state. Actually, one can see in the circuit of the system (Fig. 2), there is an inductive loop. It means that $\tilde{\imath}(t)$ cannot be controlled independently, but since the $\tilde{\imath}(t)$ is depended on $\tilde{\imath}_1(t)$ and $\tilde{\imath}_2(t)$, by independently controlling of $\tilde{\imath}_1(t)$ and $\tilde{\imath}_2(t)$, the desired output current ($\tilde{\imath}(t)$) is achieved. Consequently, the system is decomposed into two controllable and uncontrollable sub-spaces in which the controllable sub-space of this system corresponds to the state variables $\begin{bmatrix}\tilde{\imath}_1(t)\\ \tilde{v}_1(t)\\ \tilde{\imath}_2(t)\\ \tilde{v}_2(t)\end{bmatrix}$. As aresult, the state-feedback gain matrix can be expressed as follow:

$$U(t) = -KX(t) \quad \longrightarrow \quad U(t) = \begin{bmatrix} \tilde{d}(t) \\ \tilde{d}'(t) \end{bmatrix} =$$

$$= -\begin{bmatrix} k_{11} & k_{12} & k_{13} & k_{14} \\ k_{21} & k_{22} & k_{23} & k_{24} \end{bmatrix} \begin{bmatrix} \tilde{i}_1(t) \\ \tilde{v}_1(t) \\ \tilde{i}_2(t) \\ \tilde{v}_2(t) \end{bmatrix} \tag{9}$$

by substituting (9) into state equations (4), results:

$$\begin{cases} \dot{X}(t) = (A - BK)X(t) \\ y(t) = CX(t) \end{cases} \tag{10}$$

By considering the desired closed-loop poles by trial and error method at *-499±9902i* and *-3110±104i*, the state-feedback controller gain matrix is obtained as follow:

$$K = \begin{bmatrix} -0.001 & 0.0003 & 0 & 0 \\ 0 & 0 & -0.001 & 0.0003 \end{bmatrix} \tag{11}$$

Fig. 4 shows the location of closed-loop system poles for the various values of *D(t)* and *D´(t)* in the interval of [0 1].

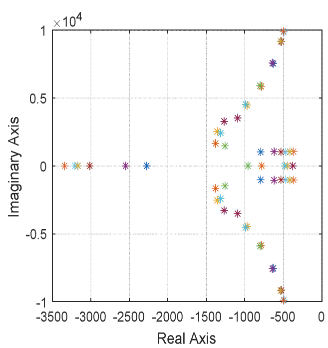


Fig.4. Root Locus of the closed-loop system for various values of *D(t)* and *D´(t)* in the interval of [0 1].

One can see (in Fig. 4) that the closed-loop system poles have been transferred to the left-hand side of the imaginary axis by applying the designed controller to *GCBI* system. Fig. 8(b) demonstrates the dynamic behavior improvement of the system applying proposed controller.

IV. Power Injection Controller Design

The general control scheme for desired power injected into the grid through the single-phase *SSBI* is illustrated in Fig. 5. In this paper, our goal is to control the system such that the desired power references can be injected into the grid.

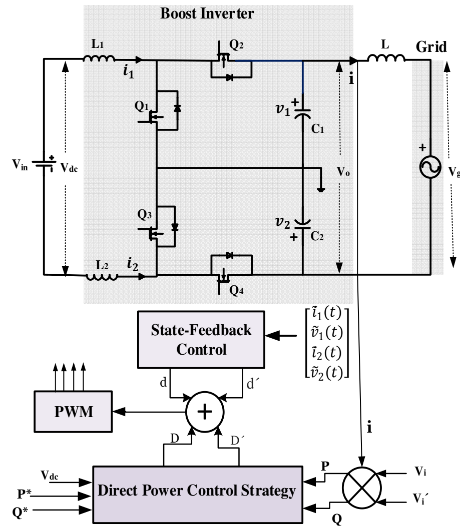


Fig.5. General Diagram of proposed control scheme.

As can be seen in Fig.5, the proposed power injection control scheme is divided into two stages: the first stage consists of state-feedback control method in which transient behavior improvement and closed-loop stability of *PIS* is achieved (as mentioned in the previous section). Then, the direct power control concept is employed.

A. Power Injection Using Direct Power Control Concept

The goal is to control and inject the specified powers into the grid by controlling the *SSBI* based on the direct power control approach. Note that we use the modified *GCBI* model (see in section. III) to design the power injection controller. The direct power control strategy is applied in this paper which active and reactive desired powers are being directly used as a tracking reference values. Fig. 6 illustrates the equivalent circuit of the grid-connected boost inverter system via an *L* filter. The boost inverter output voltage is indicated as v_o and v_g is the grid voltage. From this figure, we have:

$$v_o(t) = L\frac{di}{dt} + v_g(t) \tag{12}$$

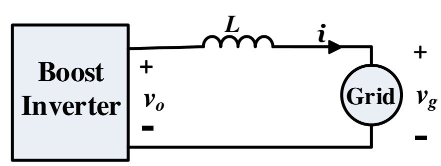


Fig.6. Equivalent circuit of the *GCBI* system.

Let define the virtual boost inverter voltage as [15]:

$$v_i(t) = v_o(t) + Ri(t) \tag{13}$$

where $v_i(t)$ is the virtual boost inverter voltage and *R* is a positive value and represents a virtual resistance in series with *L*. In fact, this virtual resistance ensures the stability of the power injection control system [15]. The block diagram of the control strategy is shown in Fig. 7.

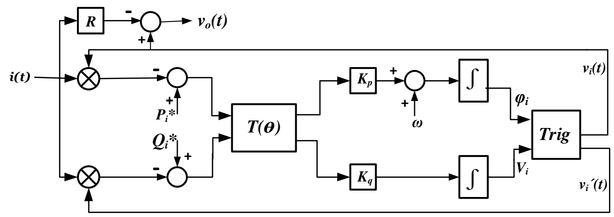


Fig.7. Block diagram of the power injection control approach [15].

According to the Equ. (13), the boost inverter output voltage can be rewritten as:

$$v_o(t) = v_i(t) - Ri(t) = V_i(t)\cos\big(\emptyset_i(t)\big) - Ri(t) \tag{14}$$

where $\emptyset_i(t) = \omega t + \delta(t)$ in which ω is the system's frequency, δ and V_i are the phase angle and peak value of virtual boost inverter voltage, respectively. The virtual active and reactive powers can be computed as:

$$P_i = \frac{V_i}{2Z}[V_i\, cos\theta - V_g \cos(\delta+\theta)] \tag{15}$$

$$Q_i = \frac{V_i}{2Z}[V_i\, sin\theta - V_g \sin(\delta+\theta)] \tag{16}$$

where

$$\vec{Z} = R + jX = R + jL\omega = Ze^{j\theta}$$

Note that the active and reactive powers are completely coupled, results in calculations and controller design will become more complicated. By applying transformation $T(\theta)$, the active and reactive powers will be decoupled. The transformation $T(\theta)$ is considered as follow:

$$T(\theta) = \begin{pmatrix} sin\theta & -cos\theta \\ cos\theta & sin\theta \end{pmatrix} \tag{17}$$

Now, the transformed virtual active and reactive powers are obtained as follows:

$$\begin{pmatrix} P_i' \\ Q_i' \end{pmatrix} = T(\theta)\begin{pmatrix} P_i \\ Q_i \end{pmatrix} = \frac{V_iV_g}{2Z}\begin{pmatrix} sin\delta \\ \dfrac{V_i - V_g cos\delta}{V_g} \end{pmatrix} \tag{18}$$

Actually, the angle δ and the voltage difference ration $(V_i - V_g)/V_g$ are not large and, thus, P_i' can chiefly be controlled by δ while Q_i' can be controlled by V_i. Based on this fact, and assuming that P_i^* and Q_i^* are the reference values of those powers, a control algorithm can be proposed as:

$$\frac{d}{dt}\begin{pmatrix} \delta(t) \\ V_i(t) \end{pmatrix} = \begin{pmatrix} k_p & 0 \\ 0 & k_q \end{pmatrix} T(\theta)\begin{pmatrix} P_i^* - p_i(t) \\ Q_i^* - q_i(t) \end{pmatrix} \tag{19}$$

where k_p and k_q are the real positive constants. The $p_i(t)$ and $q_i(t)$ are the virtual instantaneous powers and defined as:

$$p_i(t) = v_i(t)i(t) \tag{20}$$

$$q_i(t) = v_i'(t)i(t) \tag{21}$$

where $v_i'(t)$ is the 90° phase shifted version of $v_i(t)$, that "Trig" block computes $v_i(t)$ and $v_i'(t)$ as follow:

$$\begin{pmatrix} v_i(t) \\ v_i'(t) \end{pmatrix} = \begin{pmatrix} V_i\cos(\emptyset_i) \\ V_i\sin(\emptyset_i) \end{pmatrix} \tag{22}$$

Generally, Equ. (19) describes the basis of the direct power control approach for grid-connected operation. Hence, assuming that the peak grid voltage (V_g), its frequency (ω) and the inductance L are the given parameters; then, R, k_p and k_q will be designed as follow [15]:

First, select $\alpha > 0$, that α^{-1} corresponds to the time-constant of the response. Afterward, the virtual resistance (R) can be obtained from:

$$R = 3\alpha L \tag{23}$$

Then, k is calculated as:

$$k = \frac{2}{3}R\omega \tag{24}$$

Finally the controller's parameters will be determined as:

$$k_p = \frac{k}{V_g^2} \tag{25}$$

$$k_q = \frac{k}{V_g} \tag{26}$$

Therefore, this proposed power injection control approach (as Fig.7. shows) determines the desired boost inverter output voltage (V_o) based on aforementioned procedure, which its amplitude and phase angle correspond to the desired values of δ and V_i that are required for controlling and injecting the real and reactive references power. For this reason, the desired boost inverter output voltage is substituted in equation (7) in section II. (C) and based on the *DC* input voltage and steady state capacitor voltage values, the duty cycles rated values ($D(t)$ and $D'(t)$) are determined as follows:

$$\begin{cases} V_o(t) = V_{om}\sin(\omega t+\varphi) = V_1 - V_2 = 2a\sin(\omega t+\varphi)V_{in} \\ \quad V_2 = \dfrac{V_{in}}{D'} = (a\sin(\omega t+\varphi) + b)V_{in} \\ \quad V_1 = \dfrac{V_{in}}{D} = (-a\sin(\omega t+\varphi) + b)V_{in} \end{cases} \Rightarrow$$

$$a = \frac{V_{om}}{2V_{in}} \quad , \quad b = \left(\frac{V_1+V_2}{2}\right)\frac{1}{V_{in}} = \frac{V_{dc}}{V_{in}} \Rightarrow$$

$$D(t) = \frac{1}{\frac{V_{om}}{2V_{in}}\sin(\omega t+\varphi) + \frac{V_{dc}}{V_{in}}} \quad ,$$

$$D'(t) = \frac{1}{-\frac{V_{om}}{2V_{in}}\sin(\omega t+\varphi) + \frac{V_{dc}}{V_{in}}} \tag{27}$$

Thereby, the proposed power injection control system is completely designed.

V. Simulation Results

In order to validate the performance of the proposed control strategy, the grid-connected single-stage boost inverter is simulated using MATLAB/Simulink software. The active and reactive power references are assumed to be 1.5 kW and 0 Var, respectively. In fact, our goal is to control and inject desired powers into the grid. The simulation parameters are given in Table I.

TABLE I
Simulation Parameters

Parameter	Description	Value
V_{in}	*DC* input Voltage	100 [V]
L_1, L_2	Boost inverter inductors	100 [μH]
C_1, C_2	Boost inverter capacitors	100 [μF]
V_g	Grid voltage	220 [V_{rms}]
f	Grid frequency	50 [Hz]
L	Grid inductance filter	10 [mH]
f_s	switching frequency	10 [KHz]

Fig. 8(a) shows the output voltage of open-loop *GCBI*. One can see that the output voltage has an extreme fluctuations due to weak stability and damping of the open-loop system. Fig. 8(b) shows the output voltage of the closed-loop system. In fact, by applying the proposed state-feedback control, the output voltage oscillations have been significantly decreased and the damping ratio of the system increased.

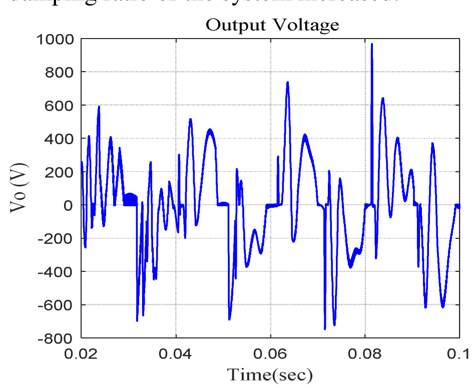


Fig.8 (a)

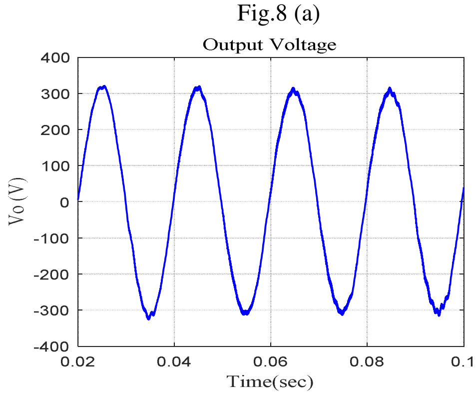


Fig.8 (b)

Fig.8. Output voltage of (a) open-loop *GCBI* system; (b) closed-loop *GCBI* system.

Next, the proposed power injection controller (section. IV) is applied to this modified *GCBI* (section. III). The performance of the controller is depicted in Fig. 9. One can see that the injected powers reach to their final values before 0.4 seconds and the steady state error can be ignored.

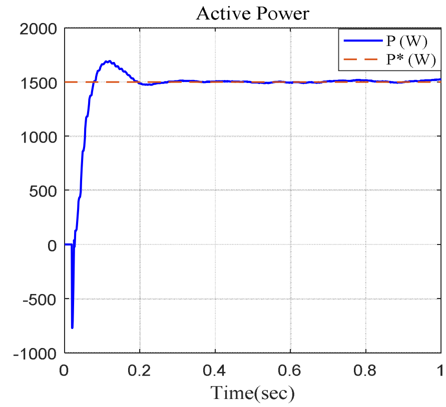


Fig.9 (a)

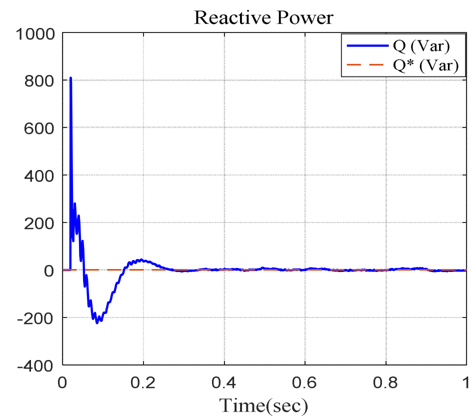


Fig.9 (b)

Fig.9. Injected(a) real power;(b) reactive power.

Fig. 10 shows the output current and grid voltage. Note that for greater clarity, the grid voltage amplitude has become 10 times smaller. From this figure, one can see that the output current is in phase synchrony with the grid voltage and thereby the power injected into the grid is purely active. In other words, the power factor is unity.

The fast fourier transform analysis (*FFT*) of the grid side current is shown in Fig. 11, in which the corresponding *THD* is attained about 4.52%. Although, this *THD* is in the standard interval (based on requirement of *IEEE 1547* standard (*THD*<5%)), but, it is some how high. The main reason is that the system is nonlinear and this high *THD* is the consequence of nonlinearity. To decrease *THD*, a nonlinear controller is required.

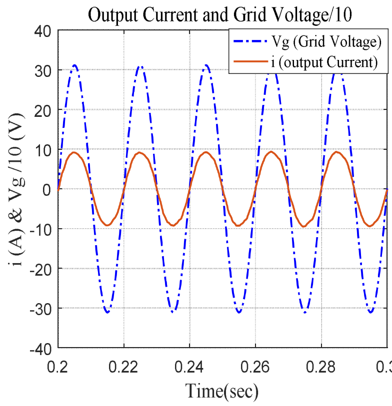


Fig.10. Grid voltage and output current by applying proposed power injection control approach.

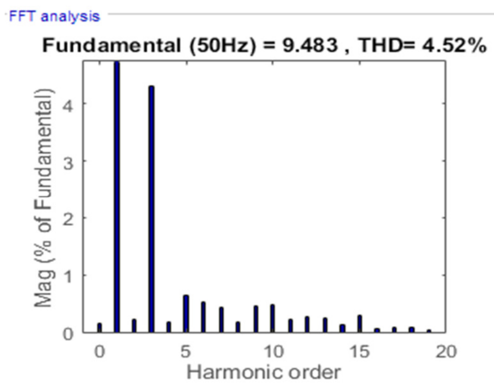


Fig.11. *THD* of output current by applying proposed power injection control approach.

The boost inverter output voltage (V_o) and the capacitor voltages (V_1 and V_2) waveforms are also shown in Fig. 12 (a) and (b), that indicates while operating the proposed power injection controller, the output voltage has a good waveform quality, in which, the *THD* is less than 3% (see Fig. 13). From this figure, one can see that the amplitudes of capacitor voltages are the same, while they are in anti-phase.

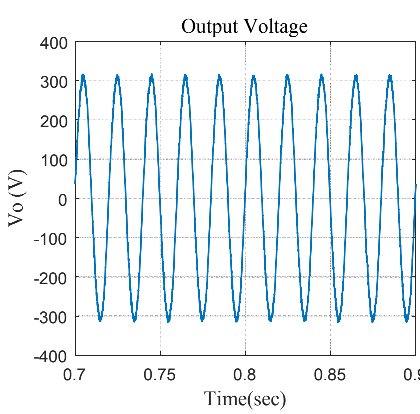
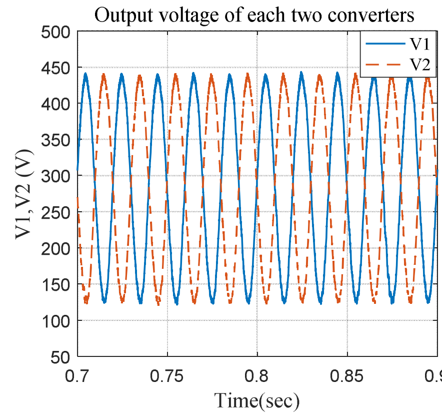


Fig.12. (a) Output voltage of *GCBI*;



(b)

Fig.12. (b) output voltage of each two converters during operating proposed power injection controller.

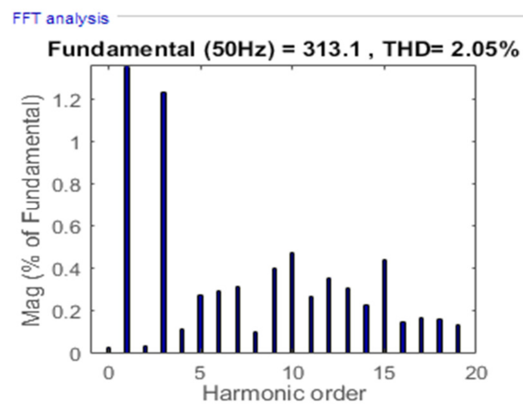


Fig.13. *THD* of output voltage by applying proposed power injection control approach.

Moreover, the desired boundary limitation of duty cycle (which is in the interval of [0 1]) waveforms of each corresponding boost converter have been properly maintained during the applying the proposed direct power control strategy, which is shown in Fig 14.

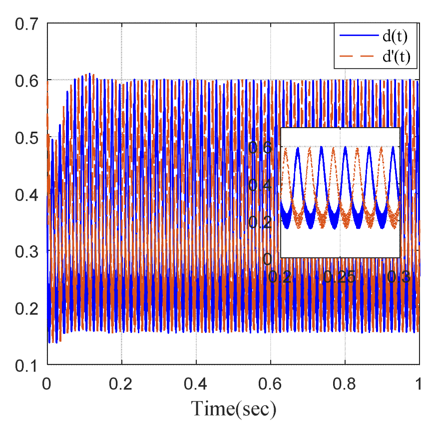


Fig.14. Duty cycle waveforms of the *GCBI* during operating proposed power injection controller.

VI. CONCLUSIONS

The goal of this paper was to present a method to control a single-phase single power stage grid-connected system based on boost inverter topology, for injecting the desired specified powers into the grid. Despite the different advantages such as a single power conversion stage with high efficiency, simplified topology, low cost and as well as high reliability, the *GCBI* is marginally stable and has a weak damping. Accordingly, a modified *GCBI* was established through a state-feedback control which improves the system dynamic behavior and stabilize closed-loop system. In this regard, the linearized state-space model of system has been developed. The direct power control framework was applied to modified model of the system for power injection control. A remarkable feature of the proposed controller is that, unlike the current control methods for power injection systems, it does not depend on the output current and uses active and reactive desired powers directly in controller design process that makes it robust under grid voltage variations. Furthermore, in proposed power injection control scheme, controlling of the active and reactive powers have been decoupled from each other by adopting a simple transformation. Therefore, these features allow to obtain a simple control structure with high quality power references tracking. Simulation results confirm the effectiveness and desirable performance of the proposed controller for grid-connected applications.

REFERENCES

[1] M. Monfared, and S. Golestan, "Control strategies for single-phase grid integration of small-scale renewable energy sources: A review," *Renewable and Sustainable Energy Reviews*, Vol. 16, No. 7, pp. 4982-4993,Sep. 2012.

[2] R. Caceres, and I. Barbi, "A Boost DC-AC converter: operation, analysis, control and experimentation," *Industrial Electronics, Control, and Instrumentation, 1995., Proceedings of the 1995 IEEE IECON 21st International Conference on*, Vol. 1, pp. 546-551, Nov. 1995.

[3] M. Jang, M. Ciobotaru, and V. G. Agelidis, "A single-phase grid-connected fuel cell system based on a boost-inverter," *IEEE transactions on power electronics,*Vol. 28, No. 1, pp. 279-288, Jan. 2013.

[4] D. B. W. Abeywardana, B. Hredzak, and V. G. Agelidis, "A rule-based controller to mitigate DC-side second-order harmonic current in a single-phase boost inverter," *IEEE Transactions on Power Electronics,*Vol. 31, No. 2, pp. 1665-1679, Feb. 2016.

[5] P. Sanchis, A. Ursæa, E.Gubia, and L. Marroyo, "Boost DC-AC inverter: a new control strategy," *IEEE Transactions on power electronics*, Vol. 20, No. 2, pp. 343-353, Mar. 2005.

[6] F. Flores-Bahamonde, H. Valderrama-Blavi, J. M. Bosque-Moncusi, G. García, and L. Martínez-Salamero, "Using the sliding-mode control approach for analysis and design of the boost inverter," *IET Power Electronics,*Vol. 9, No. 8, pp. 1625-1634, June. 2016.

[7] C. Albea, F. Gordillo, and C. Canudas-de-Wit, "Adaptive control design for a boost inverter," *Control Engineering Practice,*Vol. 19, No. 1, pp. 32-44, Jan. 2011.

[8] C. Albea, and F. Gordillo, "Control of the boost DC-AC converter with RL load by energy shaping," *In Decision and Control, 2007 46th conference on IEEE*, pp. 2417-2422, Dec. 2007.

[9] D. Cortes, N. Vázquez, and J. Alvarez-Gallegos, "Dynamical sliding-mode control of the boost inverter," *IEEE Transactions on Industrial Electronics,*Vol. 56, No. 9, pp. 3467-3476, Sep. 2009.

[10] W. Zhao, D. D.-C. Lu, and V. G. Agelidis, "Current control of grid-connected boost inverter with zero steady-state error," *IEEE Transactions on Power Electronics,*Vol. 26, No. 10, pp. 2825-2834, Oct. 2011.

[11] S. Huang, F. Tang, Z. Xin, Q. Xiao, and P. C. Loh, "High performance current control strategy for grid-connected boost DC-AC inverter,"*Control and Modeling for Power Electronics (COMPEL) 2017 IEEE*, pp. 1-8, Jul. 2017.

[12] S. Annapoorani, and R. Jayaparvathy, "An efficient single stage boost inverter with one cycle control for PV applications,"*International Workshop on Integrated Power Packaging (IWIPP)*, pp. 1-5, April. 2017.

[13] A. Timbus, M. Liserre, R. Teodorescu, P. Rodriguez, and F. Blaabjerg, "Evaluation of current controllers for distributed power generation systems," *IEEE Transactions on power electronics,*Vol. 24, No. 3, pp. 654-664, Mar. 2009.

[14] Y. A. R. I.Mohamed, and R.Seethapathy,"Robust line-voltage sensorless control and synchronization of LCL-filtered distributed generation inverters for high power quality grid connection,"*IEEE Transactions on Power Electronics*, Vol. 27, No. 1, pp. 87-98, Jan. 2012.

[15] M. Karimi-Ghartemani, "universal integrated synchronization and control for single-phase DC/AC converters," *IEEE Transactions on Power Electronics,*Vol. 30, No. 3, pp. 1544-1557, March. 2015.

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