A PV Micro-Inverter System Using Repetitive Current Control

Lenisha Vincent Chirayath,**R.NarcissStarbell**

Abstract—Thisproject work proposes a grid-connected photovoltaic (PV) micro-inverter system and its control implementations. A dc-dc converter is used to interface the low-voltage PV module with load. A full-bridge pulse width-modulated inverter is cascaded and injects synchronized sinusoidal current to the grid. A plug-in repetitive current controller is proposed to regulate the grid current. Repetitive controller (RC) is suitable to eliminate periodic errors in a nonlinear dynamical system. In order to achieve high accuracy in the presence of periodic uncertainties, RC can be employed to remove the line side current harmonics in this work. High power factor and very low total harmonic distortions are guaranteed under varying load conditions. The model of the proposed scheme employing a repetitive current control in PV micro-inverter has been built using MATLAB/Simulink.

Keywords-: Boost Converter, grid-connected photovoltaic (PV) system, photovoltaic micro-inverter, repetitive current control.

I. INTRODUCTION

The concept of micro-inverter (also known as module integrated converter/inverter) has become a future trend for single-phase grid-connected photovoltaic (PV) power systems for its removal of energy yield mismatches among PV modules, possibility of individual PV-module-oriented optimal design and independent maximum power point tracking(MPPT). In general, a PV micro-inverter system is often supplied by a low-voltage solar panel, which requires a high-voltage step-up ratio to produce desired output ac voltage. Hence, a dc–dc converter cascaded by an inverter is the most popular topology. In this work, the boost converter is incorporated as the dc–dc conversion stage for the grid-connected PV micro-inverter system. A full-bridge PWM inverter with an output *LCL* filter is incorporated to inject synchronized sinusoidal current to the grid. In general, its performance is evaluated by the output current total harmonic distortions (THDs), power factor, anddynamic response. Repetitive control (RC) is known as aneffective solution for elimination of periodic harmonic errors.An IIR filter is incorporatedin RC to obtain very high system open-loop gains at a large number of harmonic frequencies such that the harmonic rejection capability is greatly enhanced. In this work, a plug-in repetitive current controller is proposed. It is composed of a proportional part and an RC part, to which the IIR filter is accommodated. The proposed current controller exhibits the following superior features:

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1) High power factor is obtained;
2) Current harmonic distortions (up to the 13th-order) causedby the grid voltage nonideality are minimized;
3) Outstanding current regulation is guaranteed within a widerange of load conditions;
4) Fast dynamic response is achieved during the transients ofload or solar irradiance change.

II. BOOST CONVERTER PV MICRO-INVERTER

The boost converterconverts an input voltage to a higher output voltage.It is a class of switching-mode power supply containing at least two semiconductor switches (a diode and a transistor) and at least one energy storage element. Filters made of capacitors are normally added to the output of the converter to reduce output voltage ripple.

The key principle that drives the boost converter is the tendency of an inductor to resist changes in current When being charged it acts as a load and absorbs energy and when being discharged it acts as an energy source.DC/DC converter helps to reduce the undesired effects on the output PV power and draw its maximum power. These converters are normally named as maximum power point trackers (MPPTs). The maximum power point tracking is basically a load matching problem. In order to get the maximum power of PV panel adjust the duty cycle of boost converter.

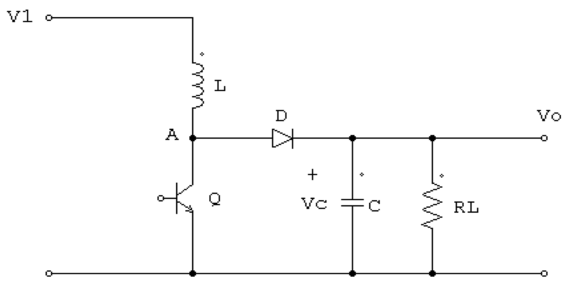

Fig 1 A Boost Converter

A. *Design Parameters*

The following assumptions are taken for design of boost switching regulator.

Switching frequency f_{sw} = 21.6 KHz.

Input voltage ,V_{in} =41.3V

Output voltage, V_o=370V

Output power, P_o=210W

$$I_0 = \frac{P_o}{V_o} = 0.567A \qquad (1)$$

where I_o is the output current

1) Design of Inductor

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$$L=\frac{2.5V_{in}D_r(1-D_r)}{I_0 f_{sw}}=890\mu\text{H} \quad (2)$$

Duty Ratio D_r can be calculated as

$$D_r = 1 - \frac{V_{in}}{V_0} = 0.883 \quad (3)$$

2) Design of capacitor

The peak-peak output ripple ΔV_0= 0.05V

$$C = \frac{I_0 D_r}{f_{sw}\Delta V_0} = 462\text{uF} \quad (4)$$

III. SYSTEM CONTROL DESCRIPTION

A digital approach is adopted for the control of the PV micro-inverter system, as shown in Fig. 2. The PV voltage V_{PV} and current I_{PV} are both sensed for calculation of the instantaneous PV power P_{PV}. At the inverter side, the grid voltage V_g is sensed to extract the instantaneous sinusoidal angle θ_g, which is commonly known as the phase lock loop. The inverter output current I_{inv} is prefiltered by a first-order low-pass filter on the sensing circuitry to eliminate the HF noises. The filter output I_{inv} is then fed back to the plug-in repetitive controller for the inner loop regulation. V_{dc} can be sensed which is used as a reference voltage for tracking of the grid voltage. The grid current and the dc voltage references are represented by $I_{inv}*$ and $V_{dc}*$, respectively.

In order to achieve fast dynamic responses of the grid current as well as the dc voltage, a current reference feed forward,I_{invff} is added in correspondence to the input PV power P_{PV}. The magnitude of the current feed forward is expressed as follows:

$$Iinvff = \frac{2Ppv}{Vg} (5)$$

where$|Vg|$ is the magnitude of the grid voltage and can be calculated by

$$|Vg| = \frac{1}{2}\int_0^{\pi} Vg\, d\theta g \quad (6)$$

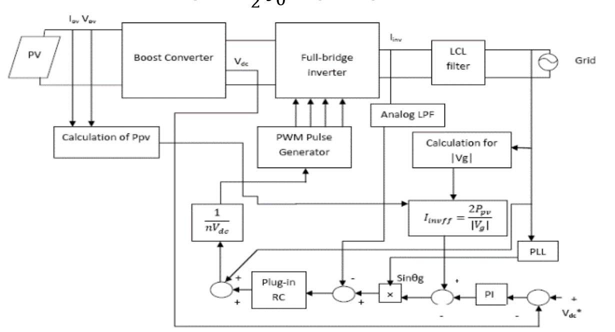

Fig 2. Control circuit of PV micro-inverter system

IV. PLUG-IN REPETITIVE CURRENT CONTROLLER

Using an LCL filter in a grid-connected inverter system has been recognized as an attractive solution to reduce current harmonics around the switching frequency, improve the system dynamic response, and reduce the total size and cost. An undampedLCL filter exhibits a sharp LC resonance peak, which indicates a potential stability issue for the current regulator design. Hence, either passive damping or active damping techniques can be adopted to attenuate the resonance peak below 0 dB. On the other hand, a current regulator without introducing any damping method can also be stabilized, as long as the LCL parameters and the current sensor location are properly selected. The current sensor is placed at the inverter side instead of the grid side. As a result no damping techniques are needed such that the current control is much simplified.

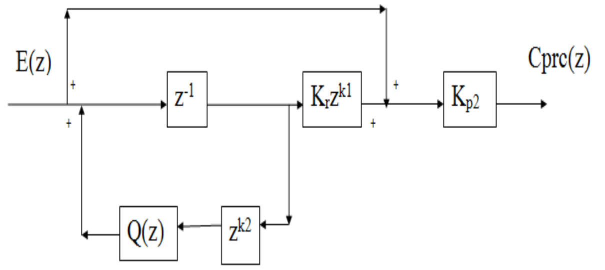

Fig 3 Block diagram of the proposed plug-in repetitive controller

The plug-in digital repetitive controller is designed, as shown in Fig. 3 .The conventional proportional controller with a gain of K_{p2} is used to obtain fast dynamics. The RC is then plugged in and operates in parallel with the proportional controller. e(z) and d(z) represent the tracking error and the repetitive disturbances, respectively.

The modified internal model, which is denoted by the positive feedback loop inside the RC, plays the most critical role in the proposed current regulator. $z^{-N}$is the time delay unit, where N denotes the number of samples in one fundamental period. In an ideal RC, a unity gain is along the positive feedback path such that all the repetitive errors based on the fundamental period are completely eliminated when the system reaches equilibrium. However, in order to obtain a sufficient stability margin, a zero-phase low-pass filter is often incorporated rather than the unity gain. This can be realized by cascading a linear-phase low pass filter Q (z) and a phase lead compensator $z^{k2}.z^{k1}$ is another phase lead unit, which compensates the phase lag of inverter at HFs. Here k_1 and $k_2$both stand for the number of sampling periods. $K_r$is the constant gain unit that determines the weight of the RC in the whole control system.

From Fig. 3, the transfer function of the entire plug-in RC current regulator can be described as follows:

$$Cprc(z) = \frac{K_r K_{p2} z^{-N} z^{k1}}{1-Q(z)z^{k2}z^{-N}} + Kp2 (7)$$

A. Analysis and Design of the Plug-In RC

The proportional controller modifies the transient response and steady state error. It produces an output signal proportional to error signal, and amplifies the error signal to increases the loop gain of the system. In this work, K_{p2} = 50,is chosen to increase the loop gain.It is noticeable that larger K_{p2} will result in a smaller tracking error during the transient.

Let

$$|H(z)|_{z=e^{jwT_{sw2}}} = \left[\left\| Q(z)z^{k2} - \frac{K_r K_{p2} z^{k1} G_{inv}(z)}{1+K_{p2}G_{inv}(z)} \right\|\right], w\epsilon \left[0, \frac{\pi}{Tsw2}\right]$$

in which T_{sw2} is also the sampling period, w is sampling frequency . A sufficient condition to meet the stability requirement is

$$|H(e^{jwTsw2})| < 1 \quad (8)$$

At the fundamental and harmonic frequencies, $z^{-N}$is simply equal to unity

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The general design criteria of $Q(z)$ for obtaining a good stability as well as a small steady-state error can be summarized as: 1) $Q(z)$ must have sufficient attenuation at HFs; 2) $Q(z)$ must be close to unity in a frequency range, which covers a large number of harmonics; and 3)$Q(z)z^{k2}$ must have a zero phase when $Q(z)$ is close to unity.

In a fourth-order linear-phase IIR filter has been synthesize for the repetitive voltage controller for UPS systems. Compared with the conventional linear-phase finite impulse response filters used for RC, the linear-phase IIR filter exhibits a flat gain in the pass band.Hence, it is a good candidate for the repetitive current controller .

In practice, $Q(z)$ is synthesized by cascading a second-order elliptic filter $Qe(z)$ and a second-order all-pass phase equalizer $Qa(z)$. $Q(z)$, $Qe(z)$, and $Qa(z)$ are expressed by the following equations

$$Q(z) = Qe(z)Qa(z) \quad (9)$$

$$Qe(z) = \frac{0.1385 + 0.2564\,z^{-1} + 0.1385z^{-2}}{1 - 0.7599z^{-1} + 0.2971z^{-2}} \quad (10)$$

$$Qa(z) = \frac{0.1019 - 0.6151z^{-1} + z^{-2}}{1 - 0.6151z^{-1} + 0.1019z^{-2}} \quad (11)$$

V. SIMULATION

The tools used for computer simulation is MATLAB R2009b/Simulink Steps involved in simulation are

1. PV panel is simulated together with boost converter and measured current (I), voltage (V) and Power (P) output of PV panel.
2. Duty ratio generated for maximum power is given to boost converter.
3. Full Bridge Inverter with its control circuit (Repetitive current control) is simulated and the results are obtained.

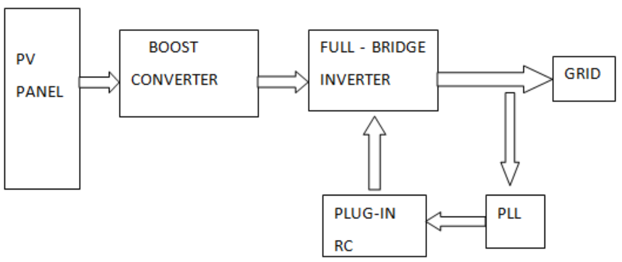

Fig 4 Block diagram of entire system

The entire block diagram of system is shown in fig. 4. Voltage and current from the PV panel is measured using voltage and current measurement block and given to Boost converter whose duty cycle is adjusted to get maximum power. The output of boost converter is given to full bridge inverter.PWM pulses for controlling the switching of inverter is done using plug-in RC with PI controller for voltage and current regulation.

By using equivalent circuit mentioned, a 210W solar panel is modeled based on the following values. The value of resistor and current source is adjusted such that it attains the required short circuit current and open circuit voltage of panel.

Maximum power Pmax	210
Voltage at Pmax	41.3
Current at Pmax	5.09
Open-circuit voltage Voc	50.9
Short-circuit current Isc	5.57
Shunt resistance Rsh	1000
Series resistance Rs	0.012
Short circuit current Isc0	5.57
Saturation current Is0	6.33e-010
Temperature coefficient CT	0.00195

Table 1 Specification of PV panel

A boost converter act as a power conditioning circuit between the panel and the microinverter**.**The output of the microinverter is regulated and given to grid.

Input voltage	370V
Switching frequency	10.8kHz
Sampling frequency	10.8kHz
Output power	210W
Grid voltage	180V
Grid line frequency	50Hz
Filter inductor(L1,L2)	8.5mH
Filter capacitor	330nF

Table 2 Full bridge Inverter parameters

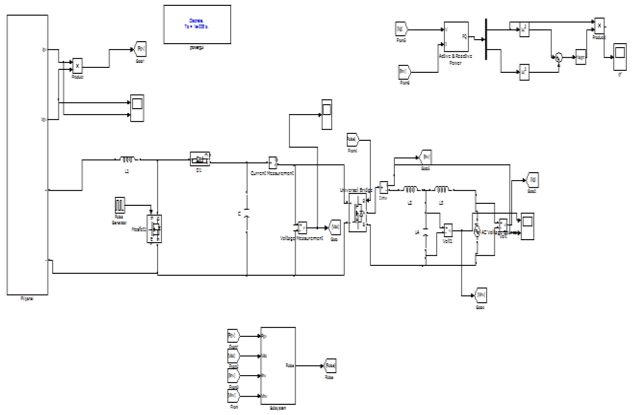

Fig. 5 Simulink model of the overall circuit

VI. SIMULATION RESULTS AND ANALYSIS

The proposed plug-in RC achieves a voltage THD as low as 1.51% and current THD of 1.76% and 0.99 power factor. The proportional part in the plug-in RC enables the controller to respond to the abrupt reference change promptly. Meanwhile, RC part cancels the harmonic distortions in several fundamental cycles

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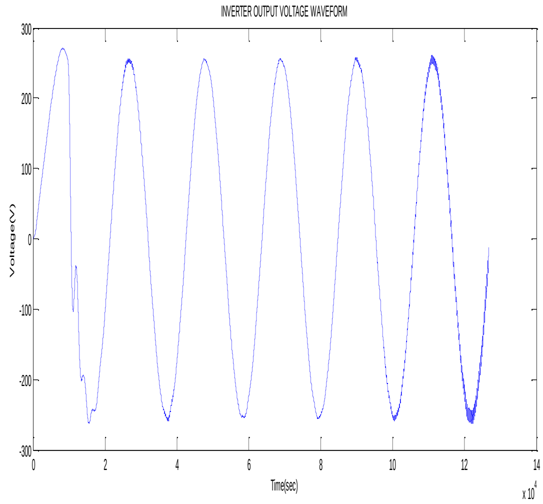

Fig 6 Output voltage waveform ofmicroinverter

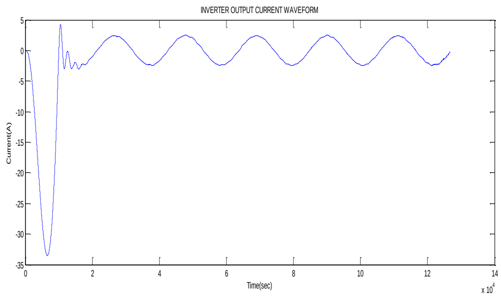

Fig 7.Output current waveform of microinverter

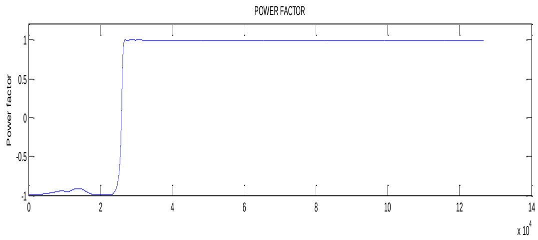

Fig 8 Power factor

VII. CONCLUSION

The conventional energy resources are not enough to fulfill the needs of society, that's the reason for going alternative energy sources like renewable energy sources. Renewable energy is the energy generated from natural resources like solar, wind and tidal etc. Solar energy is the radiant light and heat from the sun, which can be converted directly into electrical energy by using photovoltaic effect. As the temperature and insolation changes the output power will change. In this project a micro-inverter for grid-connected PV systems has been presented. A plug-in repetitive current controller was proposed and illustrated. Simulation of Repetitive current controller used as a control circuit for micro-inverter has been carried out. Simulation of proposed system is done by using MATLAB/Simulink. Performance metrics is taken as THD and power factor. The current injected to the grid is regulated precisely and stiffly. High power factor (>0.99) and low THD (0.9%–2.87%) are obtained As a result, the proposed PV micro-inverter system with its advanced control implementation will be a competitive candidate for grid-connected PV applications.

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