International Journal of Science, Engineering and Technology Research (IJSETR), Volume 4, Issue 12, December 2015

POWER QUALITY IMPROVEMENT IN GRID-CONNECTED PV SYSTEM BASED ON DOUBLE TUNED RESONANT FILTER

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Abstract— **In proposed system the single stage converter used with a double tuned resonant filter circuit. The system utilizes transformer-less single-stage conversion for tracking the maximum power point and interfacing the photovoltaic array to the grid. The maximum power point is maintained with a fuzzy logic controller. A proportional-resonant controller is used to control the current injected into the grid. To improve the power quality and system efficiency, a double-tuned parallel resonant circuit is proposed to attenuate the second- and fourth- order harmonics at the inverter dc side. A modified carrier based modulation technique for the current source inverter is proposed to magnetize the dc-link inductor by shorting one of the bridge converter legs after every active switching cycle.**

Index Terms— Doubled tuned resonant filter, Fuzzy Logic Controller, Current Source Inverter.

I. INTRODUCTION

High initial investment and limited life span of a photo-voltaic (PV) array makes it necessary for the user to ex- tract maximum power from the PV system. The nonlinear i–v characteristics of the PV array [1] and the rotation and revolution of the earth around the sun, further necessitate the application of maximum power point tracking (MPPT) [2] to the system. In this context, grid connected PV systems have become very popular because they do not need battery back-ups to en- sure MPPT. Stand-alone systems can also achieve MPPT, but they would need suitable battery back-ups for this purpose.

Though, multistage systems [1] have been reported for certain applications, grid connected PV systems usually employ two stages [3]–[7] to appropriately condition the avail- able solar power for feeding into the grid. While the first stage is used to boost the PV array voltage and track the maximum solar power, the second stage inverts this dc power into high quality ac power. Typically, the first stage comprises of a boost or buck-boost type dc–dc converter topology. Such two-stage configurations are time tested and work well, but have drawbacks such as higher part count, lower efficiency, lower reliability, higher cost and larger size. Adding a transformer (corresponding to the grid frequency) will add to the bulk and cost of the system, be- sides adding losses. On the other hand, a PV array with large dc voltage suffers from drawbacks such as hot-spots during partial shading of the array, reduced safety and increased probability of leakage current through the parasitic capacitance between the panel and the system ground. Further, in both the options, the inverter must take care of the MPPT.

In view of the ongoing discussion, it is reasonable to conclude that the best option is to have only a single power electronic stage between the PV array and the grid to achieve all the functions—namely the electrical MPPT, boosting and in- version leading to a compact system. Such com- pact systems are also in line with the modern day need to have highly integrated systems built into modules having high reliability, high performance (e.g., intelligence, protection, low electromagnetic interference (EMI), etc.), reduced weight and low cost. Lesser is the number of (power) stages, easier is the module integration. Also, the number of devices in a power stage should also be minimized. In other words, a complete circuit optimization is required.

An ac current loop is essential in the grid connected application in order to limit the current and quickly recover the grid current variation during varying weather conditions. A dynamic model and control structure for a single-stage three-phase grid-connected PV system using a CSI is proposed. The current injected into the grid has a low THD and unity power factor under various weather conditions.

II. SYSTEM DESCRIPTION

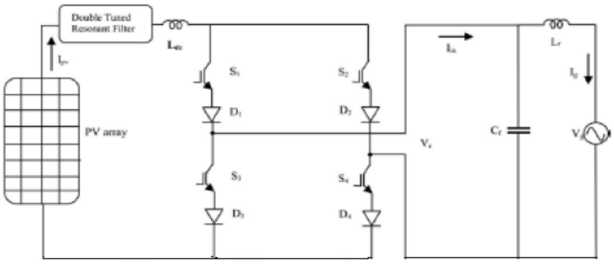

Fig 1 Single-phase grid connected current source inverter.

A grid-connected PV system using a single-phase CSI is shown in Fig.1.The inverter has four insulated-gate bipolar transistors (IGBTs) (S1–S4) and four diodes (D1–D4). Each diode is connected in series with an IGBT switch for reverse blocking capability. A doubled-tuned parallel resonant circuit in series with dc-link inductor L_{dc} is employed for

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ISSN: 2278 – 7798

smoothing the dc link current. To eliminate the switching harmonics, a *C–L* filter is connected into the inverter ac side.

III. DOUBLE-TUNED RESONANT FILTER

In a single-phase CSI, the pulsating instantaneous power of twice the system frequency generates even harmonics in the dc-link current. These harmonics reflect onto the ac side as low order odd harmonics in the current and voltage. Undesirably, these even harmonics affect MPPT in PV system applications and reduce the PV lifetime. In order to mitigate the impact of these dc-side harmonics on the ac side and on the PV, the dc link inductance must be large enough to suppress the dc-link current ripple produced by these harmonics. Practically, large dc-link inductance is not acceptable, because of its cost, size, weight, and the fact that it slows MPPT transient response. To reduce the necessary dc-link inductance, a parallel resonant circuit tuned to the second-order harmonic is employed in series with the dc-link inductor. The filter is capable of smoothing the dc-link current by using relatively small inductances. Even though the impact of the second-order harmonic is significant in the dc-link current, the fourth-order harmonic can also affect the dc-link current, especially when the CSI operates at high modulation indices. Therefore, in an attempt to improve the parallel resonant circuit, this paper proposes a double-tuned parallel resonant circuit tuned at the second- and fourth-order harmonics, as shown in Fig. 2

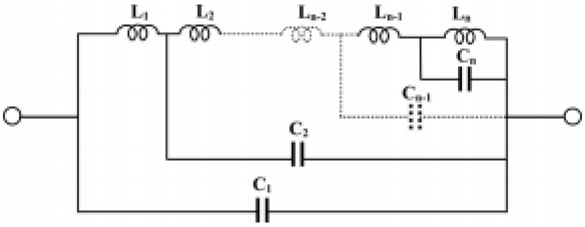


Fig 2. Proposed double-tuned resonant filter r for eliminating n harmonics.

IV. OPEARATION DESCRIPTION

The proposed circuit model has the major parameters like as PV array, CSI and fuzzy logic controller strategy is required. In this output power is influenced with the fuzzy logic controllers with the sinusoidal pulse width modulation techniques are used to compensate the harmonics in the grid side and the inverter side of the generated output voltage. The calculation of currents in the grid side and inverter side and the transfer function and the stability analysis corresponding functions are calculated and listed below

$$I_{g,peak}=\mathrm{M}I_{pv}$$

$$V_{pv}=\frac{1}{2}\mathrm{M}V_{g,peak}\mathrm{s}$$

$$\Delta p = P(K) - P(K-1)$$

$$\Delta I_{pv} = I_{pv}(K) - I_{pv}(K-1)$$

$$\mathrm{Z(S)}= K_i\,\frac{s}{s^2+\omega_0^2}\mathrm{e(S)}$$

$$\frac{dZ(t)}{dt} = K_i\,e - \omega(t)$$

$$\mathrm{Y}=K_p e(t) + Z(t)$$

$$\mathrm{W(K+1)=W(K)+}\,T_s\omega_0^2 Z(K)$$

$$\mathrm{Z(K+1)}= Z(K) + T_s(K_i\,e(K)\text{-}\mathrm{W(K+1)})$$

$$\mathrm{Y(K+1)}= K_p e(K) + Z(K+1)$$

V. PROPOSED SYSTEM CONTROL TECHNIQUE

To design a grid-connected PV system using a CSI, the relationship between the PV output voltage and the grid voltage is derived as follows. By neglecting inverter losses, the PV output power is equal to the grid power

$$V_{\mathrm{PV}}I_{\mathrm{PV}} = \tfrac{1}{2}I_{g,\mathrm{peak}}V_{g,\mathrm{peak}}\cos\theta$$

where θ is the phase angle, V_{PV} and I_{PV} are the PV output voltage and current, respectively, while $V_{g,peak}$ and $I_{g,peak}$ are the grid peak voltage and current, respectively. The grid current is equal to the PV output current multiplied by the inverter modulation index M

$$I_{g,\mathrm{peak}} = MI_{\mathrm{PV}}.$$

assuming unity power factor, the equation describing the relationship between the PV output voltage and the grid voltage is

$$V_{\mathrm{PV}} = \frac{1}{2}MV_{g,\mathrm{peak}}.$$

Therefore, in order to interface the PV system to the grid using a CSI, the PV voltage should not exceed half the grid peak voltage. The CSI is utilized to track the PV MPP and to interface the PV system to the grid. In order to achieve these requirements, three control loops are employed, namely MPPT, an ac current loop, and a voltage loop. To operate the PV at the MPP, MPPT is used to identify the optimum grid current peak value. Any conventional MPPT technique can be used. However, to prevent significant losses in power, the tracking technique should be fast enough to handle any variation in load or weather conditions. Therefore, a fuzzy logic controller (FLC) is used to quickly locate the MPP.

The inputs of the FLC are

$$\Delta P = P(k) - P(k-1)$$

$$\Delta I_{\mathrm{PV}} = I_{\mathrm{PV}}(k) - I_{\mathrm{PV}}(k - \text{‘}1)$$

and the output equation is

$$\Delta I_{g,\mathrm{ref}} = I_{g,\mathrm{ref}}(k) - I_{g,\mathrm{ref}}(k-1)$$

where ΔP and ΔI_{PV} are the PV array output power and current change, $\Delta I_{g,ref}$ is the grid current amplitude change reference, $\Delta I_{g,ref}$ is the grid current reference, and k is the sample instant. The variable inputs and output are divided into four fuzzy subsets: PB (Positive Big), PS (Positive Small), NB (Negative Big), and NS (Negative Small). Therefore, the fuzzy algorithm requires 16 fuzzy control rules; these rules are based on the regulation of the hill climbing algorithm, where the fuzzy rules are shown in Table II. To operate the fuzzy combination, Mamdani's method with Max–Min is used.

From the behavior of the controller inputs and output, the shapes and fuzzy subset partitions of the membership function in both the inputs and output are shown in Fig. 8. A center of area algorithm (COA) is used in the defuzzification stage to convert the fuzzy subset duty cycle changes into real numbers.

To ensure synchronization between the grid current and voltage, a sinusoidal signal generated by a phase-locked-loop (PLL) is multiplied by the MPPT output. Fig. 3 shows a block diagram of the MPPT structure.

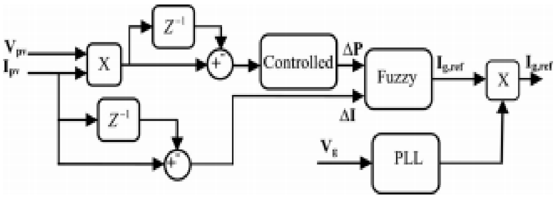


Fig 3. Block diagram of the FLC-based MPPT.

For precise control of the single-phase inverter, proportional resonant (PR) control is employed in the voltage and current loop controllers. The basic principle of the PR controller is to introduce an infinite gain at a selected resonant frequency in order to eliminate steady-state error at that frequency.

VI. FUZZY LOGIC CONTROL METHOD

Artificial intelligence is a new trend to improve MPPT operation of PV. Fuzzy logic control (FLC) is one of these artificial intelligence controls. FLC uses two inputs are the error (E) and the change in error (CE) at a sample time (k). The output of FLC generates the direct duty cycle value (D). MPPT is achieved when FLC adjusts D value of PWM unit to generate accurate pulses for switching device (IGBT) of current source inverter.

$$E(k) = \frac{P(k) - P(k-1)}{V(k) - V(k-1)}$$

$$CE(k) = E(k) - E(k-1)$$

FLC is divided into four categories, which include fuzzification, inference, rule based and defuzzification as shown in Fig.4. During the fuzzification block, any numerical input variables are converted to linguistic variables based on the membership functions.

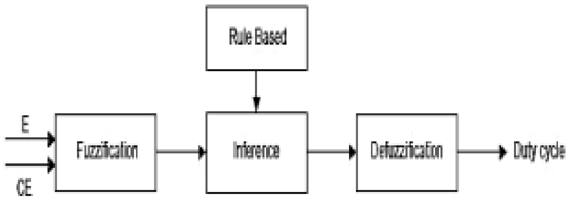


Fig 4. Block diagram of FLC method

After E and CE are calculated, these inputs are converted into linguistic variable, then by looking up in the rule base table of FLC that is used to track MPP of PV.it is easy now to find the required rule where all the rules are based on this relation "If X and Y, Then Z". To determine the output of FLC, the inference block is used. There are many methods for inference but the popular one is called Mamdani. The output of FLC is converted back to numerical variable from linguistic variable during defuzzification block. The most common method used for this defuzzification is called centroid. Centroid method has good averaging properties and more accurate results [5]. There are five proposed linguistic variables for making FLC rules that used to determine MPPT of PV panels. These variables are called as follow: N (Negative), ZE (Zero), PS (Positive small), P (Positive), and PB (Positive big). Fig.5 shows FLC membership functions for changing of the output power (ΔP), changing of the output voltage (ΔV) from the PV panels and the generated value of duty cycle (ΔD).

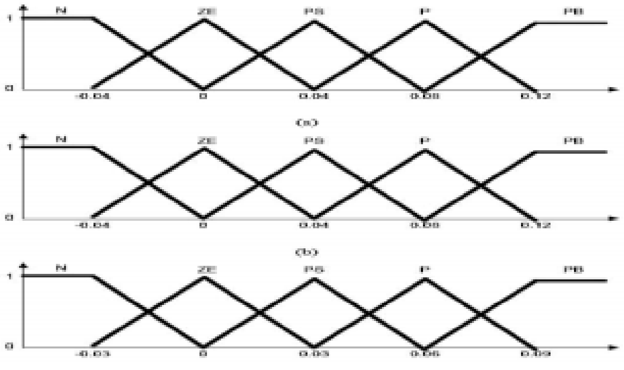


Fig 5. FLC Membership Functions for (a) ΔP,
(b) ΔV and (c) ΔD.

After ΔP and ΔV are calculated, they are converted into linguistic variables to use them as input inside FLC. The output is ΔD that is generated by using inference block and FLC rules as shown in Table I. Finally; the defuzzification block operates to convert the generated value of ΔD from linguistic variable to numerical variable again to be used inside PWM unit to be able to generate the input signal for (IGBT) switch of dc-dc boost converter that will find the accurate MPPT of PV.

ΔP\ΔV	N	ZE	PS	P	PB
N	**ZE**	**PS**	**P**	**PB**	**PB**
ZE	**ZE**	**ZE**	**PS**	**P**	**PB**
PS	**N**	**ZE**	**ZE**	**PS**	**P**
P	**N**	**N**	**ZE**	**ZE**	**PS**
PB	**N**	**N**	**N**	**ZE**	**ZE**

Table I. FLC Rules for producing MPPT of PV panels

VII. SIMULATION RESULTS AND DISCUSSIONS

In this work, the selected PV module is called Sun Power (SPR 305W). Its type is mono crystalline PV module. Table II shows the detailed parameters of (SPR 305 W) PV module at Standard Testing Condition (STC). These parameters are used to build a PV array by using MATLAB-Simulink as shown in Fig.6. The most significance parameters are the open-circuit voltage and the short-circuit current. The photo current is the short circuit current value of PV panels and the open circuit voltage is determined by assuming the output current is zero. PV panels are categorized to be with good quality and high efficiency if its fill factor almost equal one.

Item	value
PV open circuit voltage, V_{oc} (V)	80
PV short circuit current, I_{sc} (A)	15
PV array rated power, P_R (W)	500
Resonant filter inductor, L_1 (mH)	10
Resonant filter inductor, L_2 (mH)	5
Resonant filter capacitor, C_1 (μF)	125
Resonant filter capacitor, C_2 (μF)	250
dc link inductor, L_{dc} (mH)	5
Switching frequency, f_s (kHz)	4
AC line inductor, L (mH)	1
AC line capacitor, C (μF)	20
Grid voltage, $V_{g,rms}$ (V)	110

Table II. Design specifications and circuit parameter

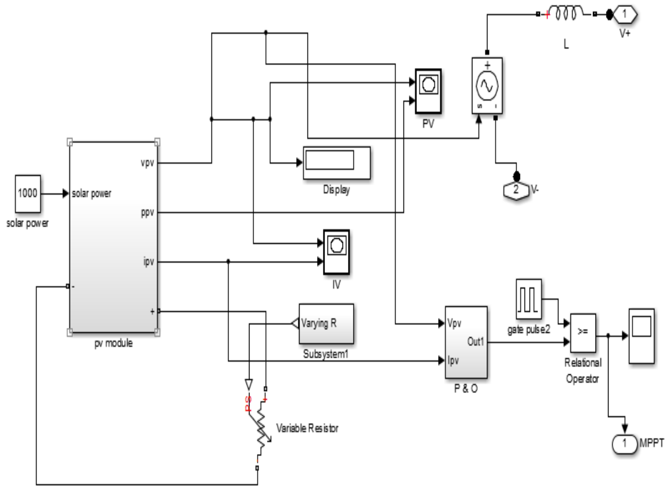


Fig 6. PV Array Structure in Matlab-Simulink.

VIII. SIMULATION OF GRID CONNECTED PV PLANT

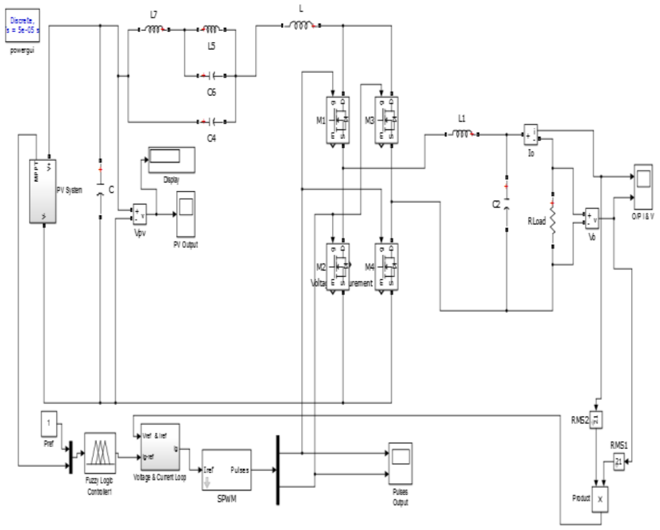


Fig 7. Schematic diagram for grid connected PV plant

The simulated PV array is connected to the Double tuned resonant filter which mitigates the DC side harmonics. The regulated dc power from PV side is fed into special type of inverters is called “on grid inverter” to convert it from dc power to ac power. The MPPT of this PV plant is controlled by using different control schemes. The first one uses FLC control method, the second uses SPWM method and the third uses the combination of SPWM and FLC methods.

The PV array is simulated by using matlab/simulink environment. The P-V and V-I curves of PV array at different temperatures and different irradiances are shown in figures. The curves depicts that as the irradiance is increased by making temperature constant the output power of PV array is increased. P-V curves also depicts that if temperature is increased the output power decreases.

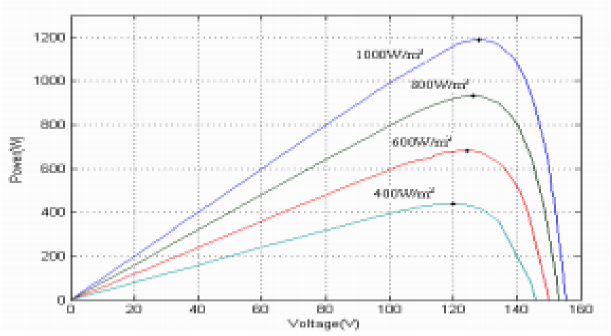


Fig. 8. P-V Curve of solar array for different irradiations and constant temperature of 25°C.

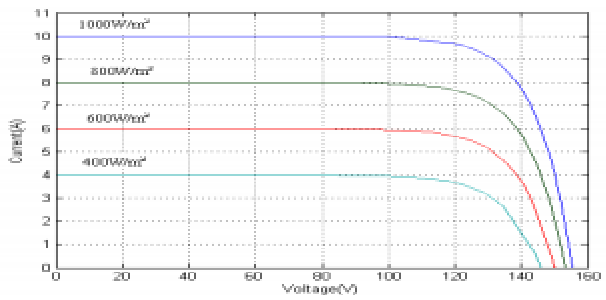


Fig 9. V-I Curve of solar array for different irradiations and constant temperature of 2

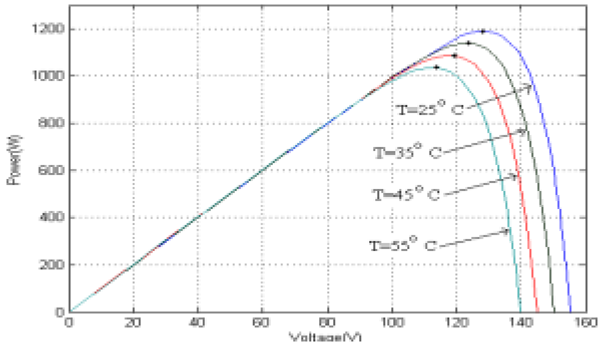


Fig 10. P-V Curve of solar array for different temperatures Constant irradiance of 1000W/m2.

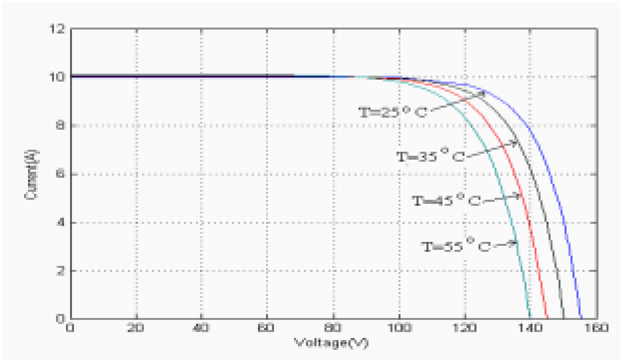


Fig 11. V-I Curve of solar array for different temperatures Constant irradiance of 1000W/m2.

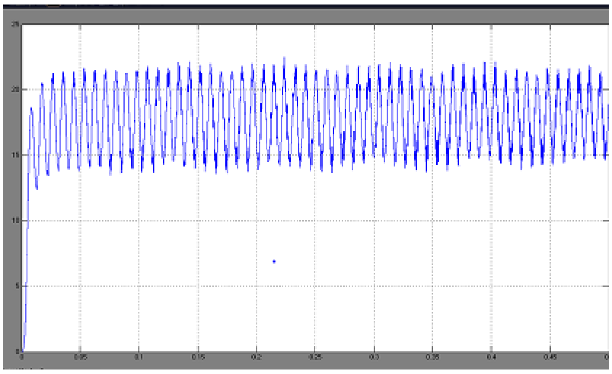


Fig 12. PV array output

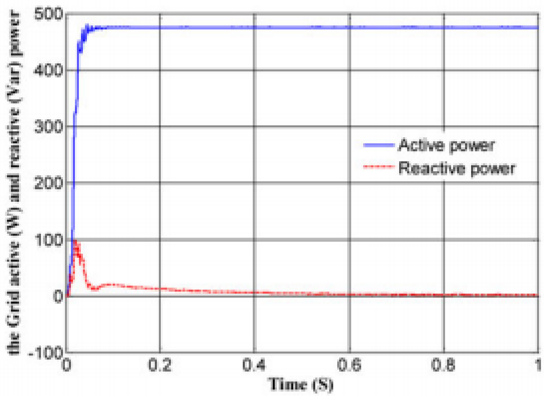
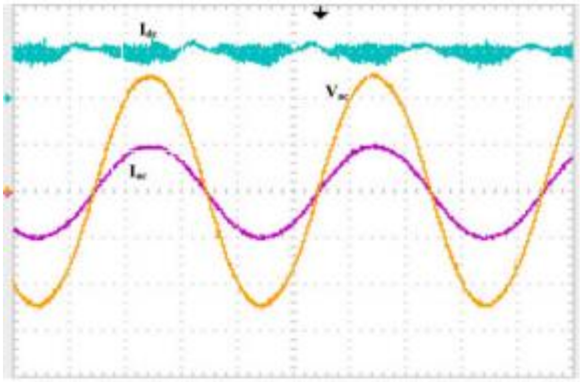


Fig 13. Grid active and reactive power.



5s/div, V_{ac}: 30 *V/div*, I_{ac}: 2 *A/div*, I_{dc}: 1 *A/div*

Fig 14. Experimental results of the proposed grid connected system.

IX. CONCLUSION

A single-stage single-phase grid-connected PV system using a CSI has been proposed that can meet the grid requirements without using a high dc voltage or a bulky transformer. The control structure of the proposed system consists of MPPT, a current loop, and a voltage loop to improve system performance during normal and varying weather conditions. Since the system consists of a single-stage, the PV power is delivered to the grid with high efficiency, low cost, and small footprint. A modified carrier-based modulation technique has been proposed to provide a short circuit current path on the dc side to magnetize the inductor after every conduction mode. Moreover, a double-tuned resonant filter has been proposed to suppress the second- and fourth-order harmonics on the dc side with relatively small inductance. The THD of the grid-injected current was 1.5% in the simulation and around 2% practically. The feasibility and effectiveness of the proposed system has been successfully evaluated with various simulation studies and practical implementation.

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