Three-level common emitter-current source inverter equipped with MPPT system for photovoltaic power converter

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ABSTRACT

Common emitter-current source inverter (CE-CSI) has unique features with its common emitter structure of its power switches. Hence, instead of its simpler power supply for gate drive circuits, it also allows higher switching operation because of zero gradient voltage of its power switches. One of interesting applications of current source power inverter is for photovoltaic (PV) power converter. This paper discussed the three-level CE-CSI equipped with current based incremental resistance maximum power point tracking (MPPT) system as a new alternative for PV system power converter. Test results revealed some characteristics of PV power conversion using this inverter. Moreover, in order to investigate the system performance approaching real condition, testing during partial shading condition of PV modules were also conducted. Test results verified the efficacy of the incremental resistance based MPPT algorithm implemented in the CE-CSI circuits for increasing the performance of PV power generation.

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1. INTRODUCTION

Lately, application of photovoltaic (PV) power generator has getting more popular in many countries [1]-[3]. PV are available from a small PV cell to hundreds watt capacity of a PV module. With advanced research and development, higher efficiency of PV has been developed [4]-[7]. Moreover, some governments provide incentives in the development and application of renewable energy sources such as PV. These policies have been boosting interest to apply PV in a wider and more massive usage. For many household applications, it is also very interesting to apply PV as complementary energy source. PV can be installed simply on roof top as an effective and economical technique for building and residential installations [8]-[10].

Practically, the generated power of a PV module is DC power. The output voltage and current vary regarding to environmental factors such as weather, sunlight irradiance and temperature. Power electronic converters are required to control and proceed the generated power of PV modules [11]-[13]. DC-DC power converters are employed to obtain a more stable DC voltage to be applied for DC power load system. In case of AC load system, DC-AC power converter called as power inverter is necessary to convert the generated DC power by PV into AC power [14], [15]. Using power inverter, the PV power generators can be operated in parallel with utility AC power grid in grid tied operation mode [16]-[20]. This scheme can be interesting alternative to reduce energy use from electric power utility company which are mainly generated from conventional fossil fuel power plants. Hence, it is environmentally friendly and able in reducing energy cost.

Voltage source inverter (VSI) has been popular and commercially available for PV power converter application. This kind of inverter proceed the DC output voltage of PV modules into specified AC voltage waveform. Power capacitor is mandatory for DC input side [21]-[23]. Another topology power inverter is referred as current-source-inverter (CSI). This inverter works changing DC current sources into a predetermined AC current waveform. Power inductor is obligatory for this inverter type to create DC current as input of inverter [24]-[26]. Compare to VSI, the current source inverter offers some advantages such as more immune to short circuit faults, faster response of its controller, longer lifetime of its inductor, voltage boosting capability, and better-quality AC current waveform. For a grid connected inverter of PV systems, it can be easily operated at high power factor operation [27]-[30].

A different circuit of three-level common-emitter CSI circuits has been presented in [28] by author. Moreover, multilevel circuit structure of this inverter has been also investigated in [29]. With common-emitter configuration of its controlled power switches, it is suitable to be operated in high switching operation such as for SiC power MOSFETs of power converters. Initial investigation of the three-level CE-CSI for PV energy converter has been done by author as discussed in [30]. However maximum power point tracking (MPPT) system have not been applied.

MPPT system is necessary to optimize energy capture by PV system [31]-[33]. One of popular MPPT algorithms is based on incremental resistance [34], [35]. This paper presents and discusses performance of three-level CE-CSI with different DC current generator circuits equipped with current based incremental resistance MPPT system. This new inverter introduced some features such as lower DC current ripple, better AC current and simpler circuit configuration because of its less DC current sensor and power switches. Some computer simulation testings were conducted to investigate characteristics and performance of inverter and MPPT system. The inverter system was also tested during partial shading of PV modules to explore the efficacy of the MPPT system.

2. PROPOSED PHOTOVOLTAIC SYSTEM

Figure 1 shows power circuit of the three-level common-emitter CSI. The inverter circuits consist of four unidirectional controlled semiconductor switches Q_1, Q_2, Q_3, and Q_4 linked at common emitter configuration. Combination operation of these power switches will produce a three-level AC current signal +I, 0, and –I levels as shown in Table 1. Coupled inductors L_1 and L_2 are used to generate two DC current sources as input of inverter circuits. The power switch Q_c is used to control the current flowing thru the inductors L_1 and L_2 working as DC input current sources. In this research, the power source V_{dc} was replaced by a PV system. The diode D_f is a free-wheeling diode to maintain continuous current path of inductor currents. Capacitor filter C_f is connected at inverter's output terminal to remove harmonics components of PWM AC current waveform.

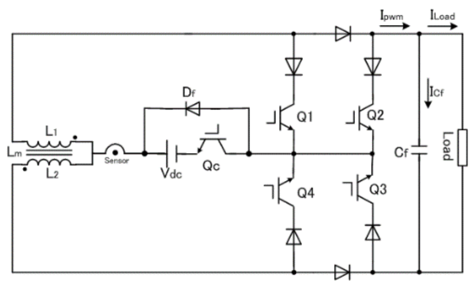


Figure 1. Three-level CE-CSI circuit [28]

Table 1. Switching operation [29]

Switching state				Output current
Q_1	Q_2	Q_3	Q_4	
OFF	OFF	ON	ON	+I
ON	OFF	OFF	ON	0
ON	ON	OFF	OFF	-I

In this research, the inverter circuit was connected to 1,000 watt-peak (1 kWp) PV system consist of ten PV modules with configuration as shown in Figure 2. Table 2 presents parameters of the PV module. Five

PV modules were connected in parallel to obtain higher current from the PV system. Two parallel PV systems were connected in series to produce higher DC voltage of PV system as in Figure 2. Table 3 lists the parameters of inverter circuits applying two coupled windings with single iron core as power inductors L_1 and L_2 of inverter circuits. The switching of power inverter was chosen as 20 kHz for power MOSFET switching operation. Characteristic of output power versus voltage, and output voltage versus current of PV system for different irradiance levels are presented in Figures 3(a) and (b).

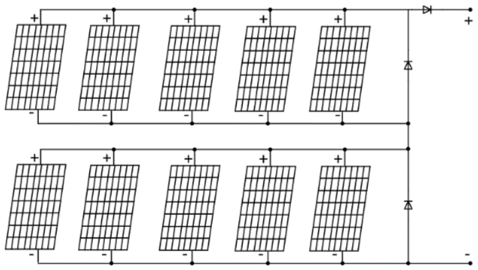


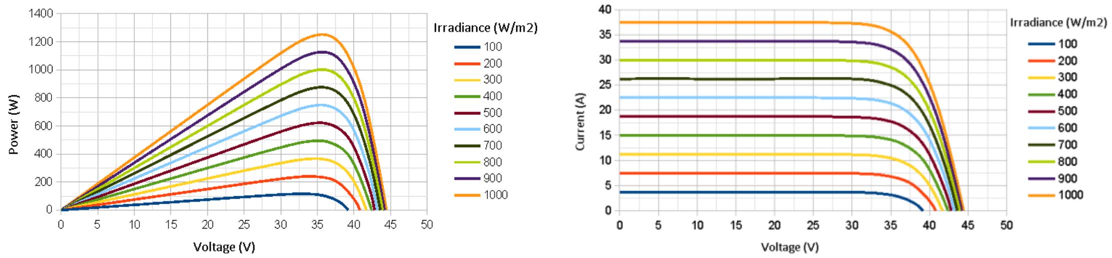
Figure 2. Configuration of PV system

Table 2. Parameters of PV module

Parameters	Values
Peak power (P_{max})	100 W
Voltage at peak power (V_{mpp})	17.46 V
Voltage (V_{oc})	21.97 V
Peak current (I_m)	5.73 A
Short circuit current (I_{sc})	6.07 A
Efficiency	12.88%

Table 3. Parameters of inverter circuits

Parameters	Values
Inductance of first inductor L_1	0.01 H
Inductance of second inductor L_2	0.01 H
Resistance of first inductor L_1	0.1 Ω
Resistance of second inductor L_2	0.1 Ω
Magnetizing inductance of inductor L_m	0.5 H
Switching frequency of inverter switches	20 kHz



(a) (b)

Figure 3. Characteristic of; (a) power versus voltage of PV system and (b) output voltage versus current of PV

Energy harvest using PV system depends on solar light intensity and weather condition. Hence, in order to optimize the sun light energy conversion, MPPT system was employed to the PV energy converter system. In this research, the applied MPPT system is the current based incremental resistance algorithm. Figure 4 shows the flowchart of the current based incremental resistance algorithm MPPT system implemented in CE-CSI circuits. The incremental resistance algorithm works detecting the ramp of the P–V curve, and the MPP is achieved by tracing the peak of the P–V curve. This MPPT method utilizes the instantaneous resistance *V/I* and the incremental resistance *dv/di* for MPPT [34], [35]. It depends on the values of voltage and current change as expressed in (1)-(3). Based on these conditions, the maximum operation point of the PV module can be determined from the characteristic of P-V. It will output maximum power. In (2) and (3) indicate the left and right flank operation of the maximum power from the P-V curve, successively.

$$dv/di = -V/I \quad (1)$$

$$dv/di > -V/I \quad (2)$$

$$dv/di < -V/I \quad (3)$$

These three equations are attained from the concept wherein the ramp of the P–V curve at MPP condition is equal to zero (4):

$$dp/dv = 0 \quad (4)$$

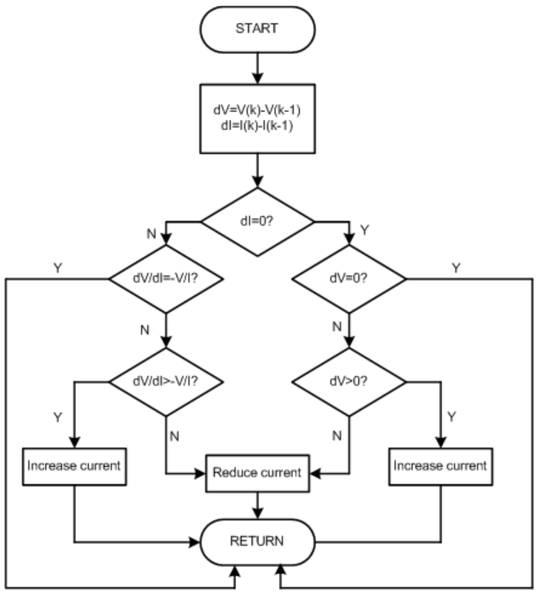


Figure 4. Flowchart of MPPT system

Based on (5) is obtained from (4),

$$I + V\frac{di}{dv} = 0 \quad (5)$$

The voltage and current of the PV modules are detected and gauged by the MPPT system as shown in Figure 5. If (1) is satisfied, the duty cycle of the power converter will be reduced, and conversely if (2) is satisfied, whereas no change on the duty cycle if (3) is satisfied. The PI controller and triangle carrier signal will adjust this duty cycle after comparing them in the comparator circuit. The output of this comparator is the gating signal of the switch Q_c of inverter circuits. Moreover, the gating signal of inverter switches Q_1, Q_2, Q_3, and Q_4 were generated by sinusoidal pulse width modulation method.

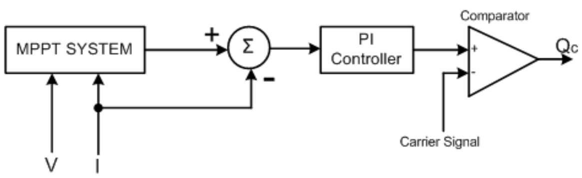
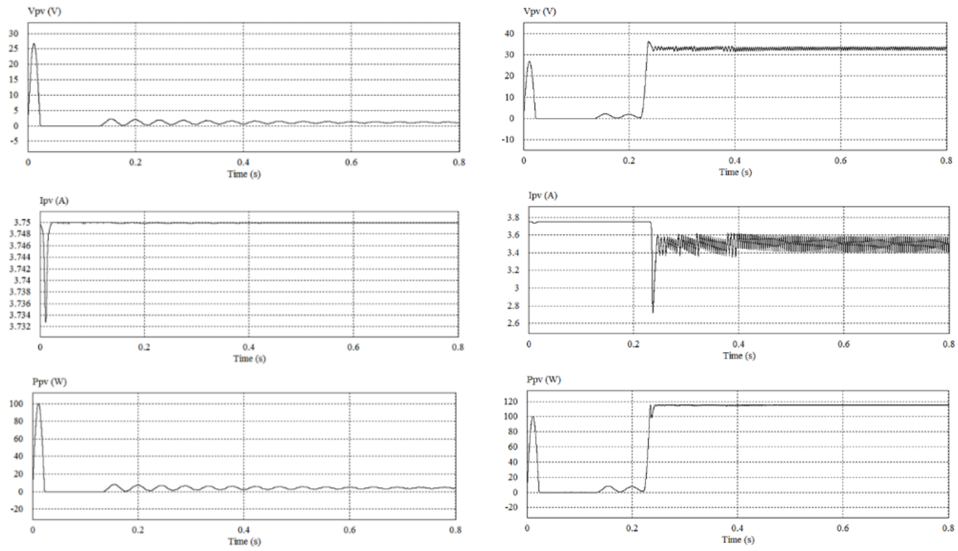


Figure 5. MPPT system

3. RESULTS AND DISCUSSION

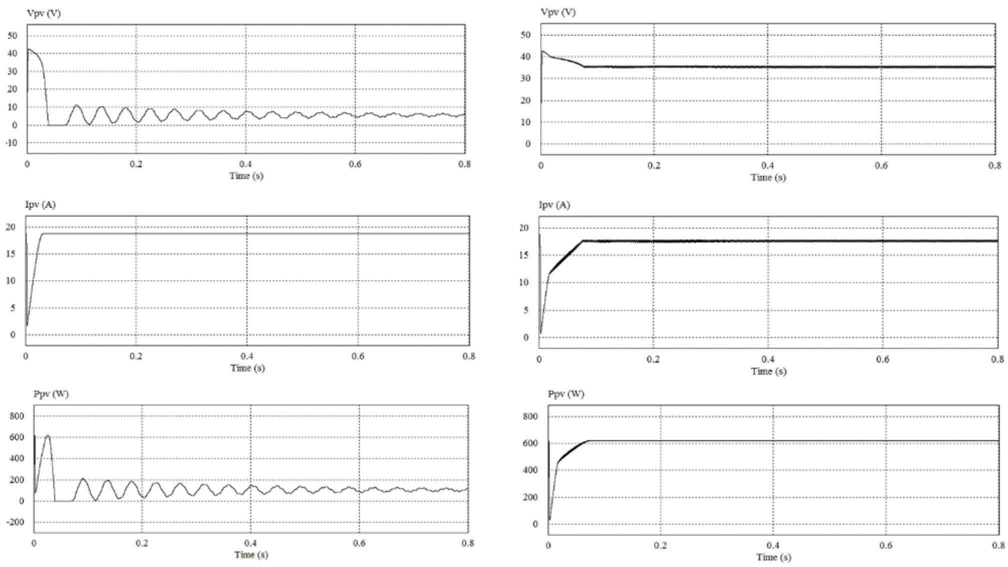
The PV-inverter system with MPPT were tested using computer simulations to obtain the performance characteristic of inverter circuits equipped with MPPT. The test was carried out at different irradiance levels, i.e., 100 W/m^2, 500 W/m^2, and 1,000 W/m^2. The results are shown as follow in Figures 6(a) and (b). Figure 6(a) presents the characteristics of output voltage (V_{pv}), output current I_{pv} and output power of PV in case of the inverter equipped with MPPT system. While Figure 6(b) shows the characteristics without MPPT system in the inverter system. As can be seen in these 100 W/m^2 irradiance levels the output power was relatively small. However, if MPPT was added to inverter, the output power was larger than the inverter without MPPT.



(a) (b)

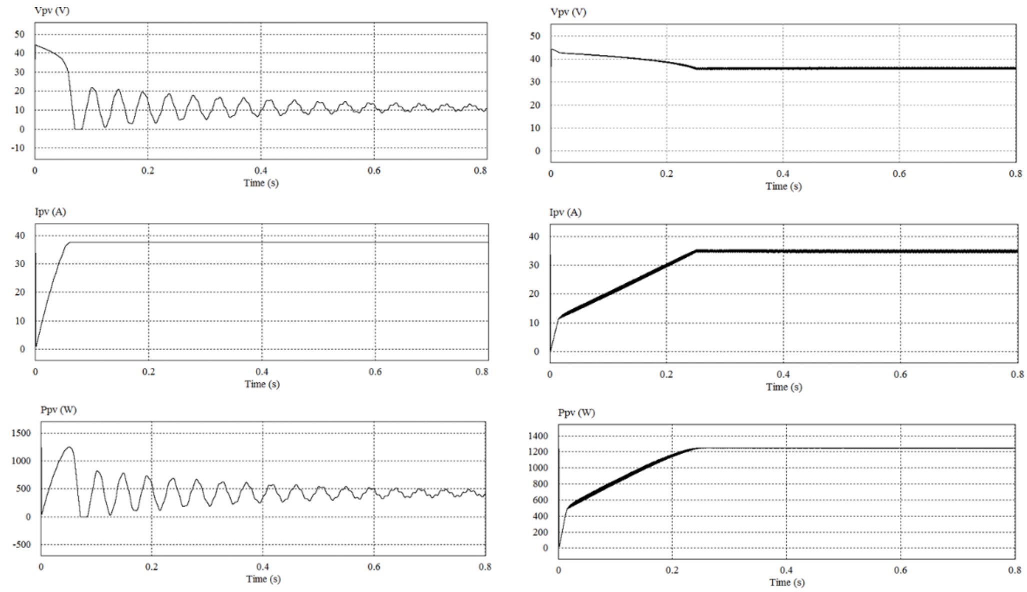
Figure 6. Comparison of output voltage, current and power of PV system: (a) without MPPT and (b) with MPPT system at irradiance 100 W/m^2

Moreover, the test results of photovoltaic output voltage (V_{pv}), photovoltaic current (I_{pv}) and PV output power for irradiance 500 W/m^2 in case of without and with MPPT are shown in Figures 7(a) and (b), respectively. An optimum output power at about 600 W was generated by the PV with MPPT system. The test results for irradiance level 1,000 W/m^2 of inverter system without MPPT was presented in Figure 8(a). Moreover, the test results when the inverter was equipped with MPPT was shown in Figure 8(b). Applying MPPT system, an optimum power of PV system about 1,200 W was generated.



(a) (b)

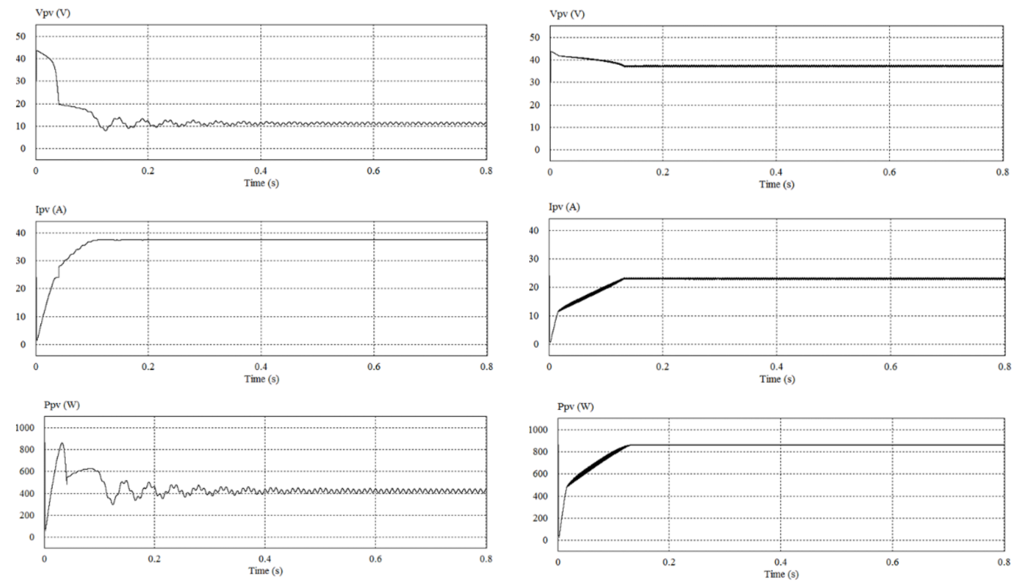
Figure 7. Comparison of output voltage, current and power of PV system: (a) without MPPT system and (b) with MPPT system at irradiance 500 W/m^2



(a) (b)

Figure 8. Comparison of output voltage, current and power of PV system: (a) without MPPT system and (b) with MPPT system at irradiance 1,000 W/m^2

A comparison of output voltage, current and power of PV system with and without MPPT system when two PV modules in shading condition is depicted in Figures 9(a) and (b). The MPPT system worked well even two PV modules were in shading condition as depicted in Figure 9(b). Furthermore, the output power of PV system without and with MPPT for different power loads if two PV modules in shading condition are shown in Figure 10. The MPPT worked keeping maximum power generated by PV system. The results confirm the effectiveness of MPPT proposed to be applied in the CE-CSI circuits as PV power converter in icreasing the efficiency of power conversion. Moreover, the inverter output current before filtering (I_{PWM}) and after filtering (I_{Load}) are shown in Figure 11. The inverter generated a sinusoidal load current waveform with small waveform distortion, i.e., low harmonics component <1%.



(a) (b)

Figure 9. Comparison of output voltage, current and power of PV system: (a) without MPPT system and (b) with MPPT system when two PV modules in shading condition

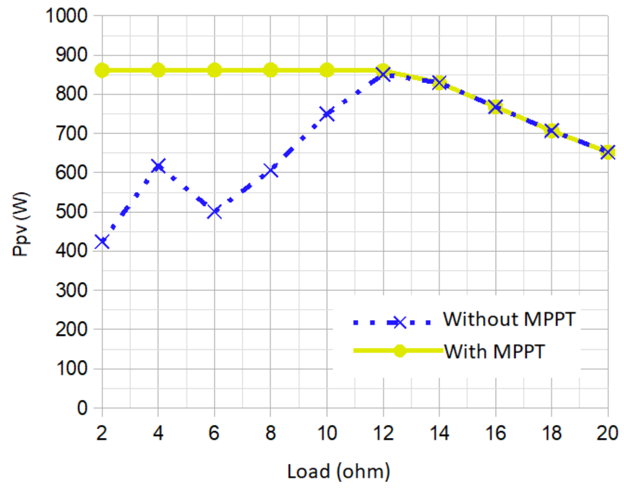


Figure 10. PV output power for different load with two PV modules in shading condition

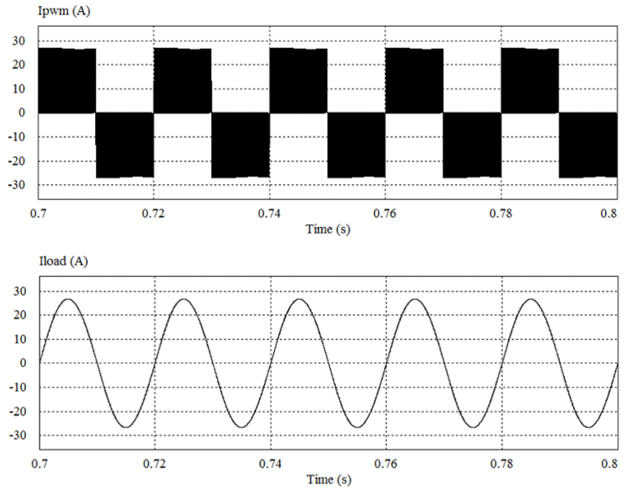


Figure 11. PWM and load current waveforms of inverter

4. CONCLUSION

This paper presented an application of incremental resistance based MPPT system in the three-level common-emitter CSI as PV power converter. The inverter worked converting the DC power of PV system into a predetermined three-level PWM AC current. The test results showed a much better performance of the inverter system equipped with MPPT system as PV power conditioner if compared to system with no MPPT. The test during shading condition of PV modules also gave a good performance of the inverter system as solar energy conversion system.

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