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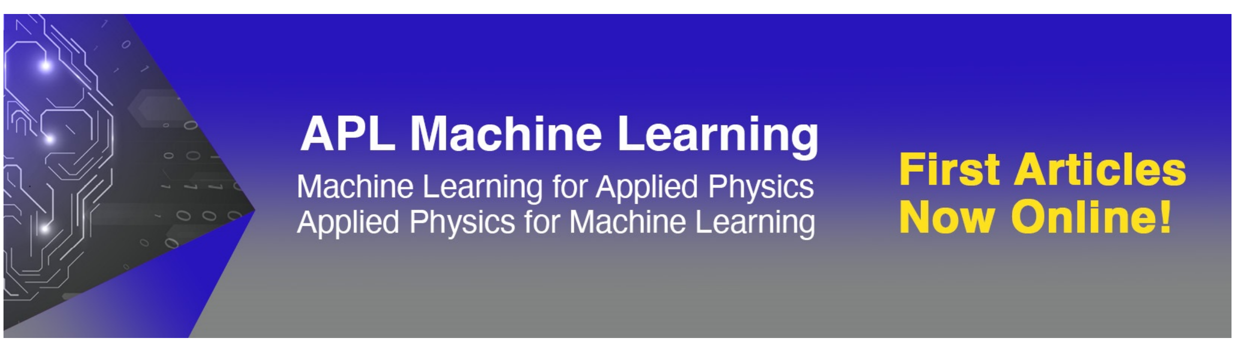

Characteristics of DC Current Component Injection in Grid Tied H-Bridge CSI with Transformer

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Abstract. Grid tied operation is a working scheme of photovoltaic power system operating together with utility power grid to supply electric power to the load. In a grid connected photovoltaic system, the energy management can be applied to optimize energy utilization of photovoltaic system while keeping high reliability of power supply to the power load. Compared to voltage source inverter system, the grid connected photovoltaic system using current source inverter offers some merits such as higher quality of AC current, higher reliability of inverter, and high power factor operation. This paper discusses and analyzes characteristics of DC current component injection in a grid tied photovoltaic system using H-bridge current source inverter and transformer. Some data were presented and discussed to explore the characteristics of DC current injection of a grid connected H-bridge CSI.

INTRODUCTION

Recently, utilization of renewable energy sources has been increasing rapidly around the world. This trend is bolstered by environmental problems introduced by conventional fossil fuel based energy sources. One reason is that the fossil energy sources produce pollutant gases that cause serious environmental problems such as glass house effect, and climate change phenomenon in the world. Moreover, the pollutant gasses generated by conventional combustion engine are also harmful for human health [1], [2]. Renewable energy sources do not generate pollutant gasses as produced by fossil energy. They are more environmentally friendly. Hence it has attracted many countries to develop and apply renewable energy sources in higher portion and in a wider application.

In most of tropical countries, the solar energy is plentifully available. The solar energy can be in the form of solar thermal and solar light. Solar thermal can be alternative heat source to generate steam required by steam turbine to drive generator machine. The solar light energy can be converted into electrical energy by using photovoltaic modules. Since electrical loads are commonly AC load system, and the generated power by photovoltaic system is in the form of DC power, power inverter is needed to meet this condition [3], [4]. The photovoltaic modules are available from few watt power into hundreds watt power capacity per module. To increase capacity of solar modules, it can be easily attained by connecting some photovoltaic modules in series and parallel. Series connection is suitable when higher voltage is needed, while parallel connection is applied when high output current is required [5-8].

Basically, photovoltaic system can be operated in stand-alone or grid tied operations. In a stand-alone scheme, the photovoltaic system supply energy to the load. This scheme can be a solution when there is no utility power supply available. It is commonly interesting to be applied in a remote and isolated area where the power load can be DC or AC system. In addition, in a grid connected photovoltaic system, the photovoltaic works concurrently with utility power supply to give electric power to the load [9-11]. As a result, it can reduce the energy consumption and energy cost that should be paid to utility power company by consumers.

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Practically, harmonics are appeared in the AC current generated by inverter. It can be caused by some factors such as improper work of controller, errors of modulation circuits, and also the presence of voltage drop in circuit components [12]. Low order of harmonics and DC current components can cause serious problems such as overheat of power load, components, and premature saturation of power transformer in the system [13-16]. This paper presents and discusses characteristics of generated DC current component by H-bridge current source inverter operated in grid connected operation. The characteristics was compared with the off-grid operation. The system was examined by computer simulations tests.

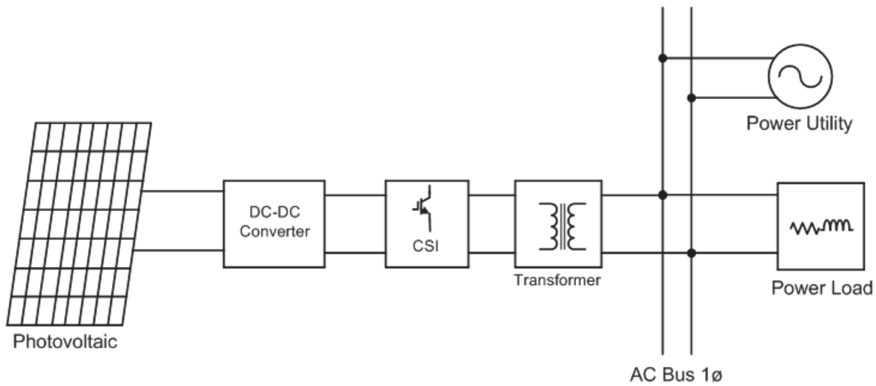

FIGURE 1. Grid connected photovoltaic system using inverter and power transformer

PROPOSED SYSTEM

Fig. 1 shows a configuration of grid connected photovoltaic system by using power inverter, dc-dc converter and power transformer. Technically, to connect photovoltaic system to power grid, a power inverter is required as interface and power conditioner. The power inverter will work to convert the DC power of photovoltaic system into AC power to meet the voltage level and frequency of AC power grid. These power inverters can be voltage source power inverter or current source one [17-19]. The voltage source inverters have been widely used and commercially available in the market. They are available in low power range for single phase configuration, and higher power in kilo-watts order for three phase inverter circuits. The current source inverter is relatively new inverter circuit. It has some advantages such as higher reliability from short circuit faults, better quality of AC current, and easy to be operated in high power factor operation. It can be new alternative of photovoltaic inverter [20].

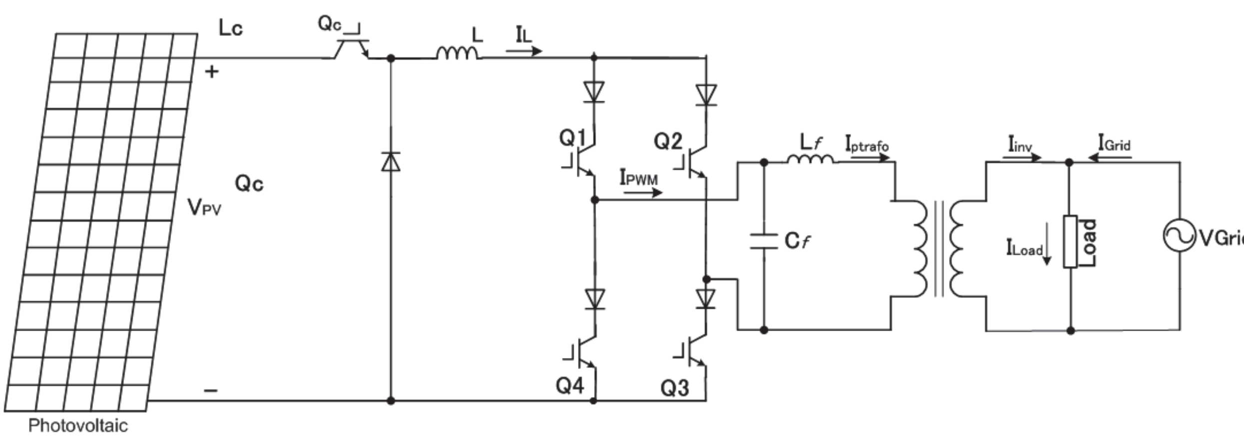

FIGURE 2. Proposed grid connected photovoltaic system

Fig. 2 presents configuration of grid connected photovoltaic system applying H-bridge current source inverter and power transformer. The current source inverter works converting DC current of photovoltaic system into AC current suitable with power grid frequency. The inductor L is used to obtain DC current source for inverter circuits from the operation of power switch Q_c. Capacitor and inductor filters, i.e. C_f and L_f, are implemented to obtain a sinusoidal output current of inverter circuits.

Table 1 lists the circuit parameters of the system. The power inductor size is 2.2 mH, filter capacitor 100 µF. The output voltage of photovoltaic system is 49.7 V. The inverter was operated in sinusoidal pulse width modulation mode to deliver closely sinusoidal AC output current. The switching frequency of inverter power switches was determined at 22 kHz. It is suitable for IGBTs power switches employed to construct inverter circuits. The IGBTs power switches were connected in series with high speed power diodes to achieve unidirectional current power switches. To meet the voltage level of power grid, a power transformer was applied with winding ratio between primary and secondary sides 1:6. The output terminal of transformer was connected to 220 V 50 Hz AC power grid system. The inverter and utility power grid supply a common power load, i.e. resistor 8 Ω, inductor 6 mH. To govern the output current of inverter, a PI current controller was implemented.

TABLE 1 Circuit parameters

Parameters	Values
DC inductor	2.2 mH
Voltage of PV system	± 49.7 V
Grid voltage	220 V, 50 Hz
Switching frequency	22 kHz
Modulation index	0.9
Capacitor filter	100 µF
Load	R = 8 , L =6 mH
Main frequency	50 Hz
Power transformer ratio	1:6

RESULTS AND ANALYSIS

The proposed photovoltaic and inverter system with parameters as described in Table 1 was tested by computer simulations. Some test results are explained as follow:

Off-Grid Operation Test

Output waveforms of the system during off-grid operation is depicted in Fig. 3. The output current of photovoltaic (I_{pv}), inverter current before filtering (I_{pwm}), and inverter current at primary side of transformer (I_{ptrafo}) can be observed in this figure. The measured RMS value of I_{ptrafo} was 16,623 A. Three-level PWM current and sinusoidal output currents were produced by inverter circuits. The THD value of I_{ptrafo} was 3.481 %.

A measured magnitude of DC current in the inverter output current (I_{DC}) was 0.063 A or 0.234 % of RMS inverter current. Fig. 4 presents a characteristic of DC current component in the inverter output current during off-grid operation for different modulation index values. From the obtained data, the largest percentage of I_{DC} was happened at modulation index 0.2. The largest value of DC current component compared to the RMS value of AC output current was 29.57%. While the minimum percentage of DC component was achieved at modulation index 1 with its value was 0.195%.

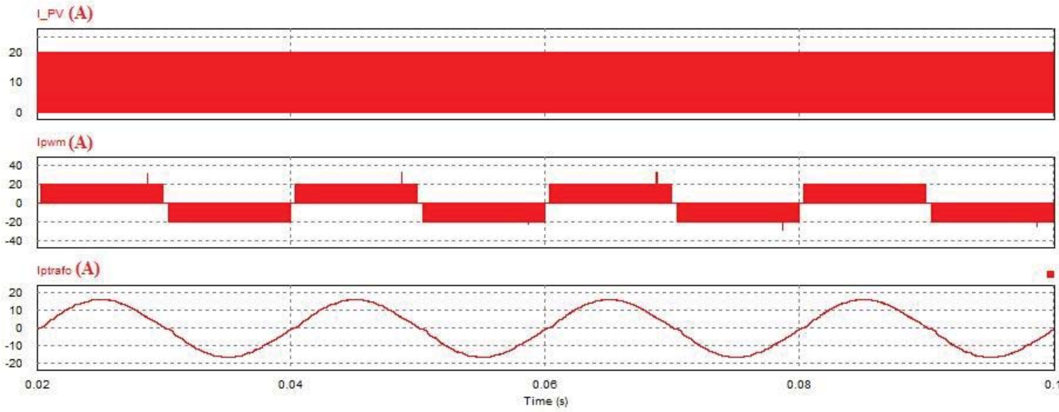

FIGURE 3. Photovoltaic current, three-level PWM current and primary side of transformer currents.

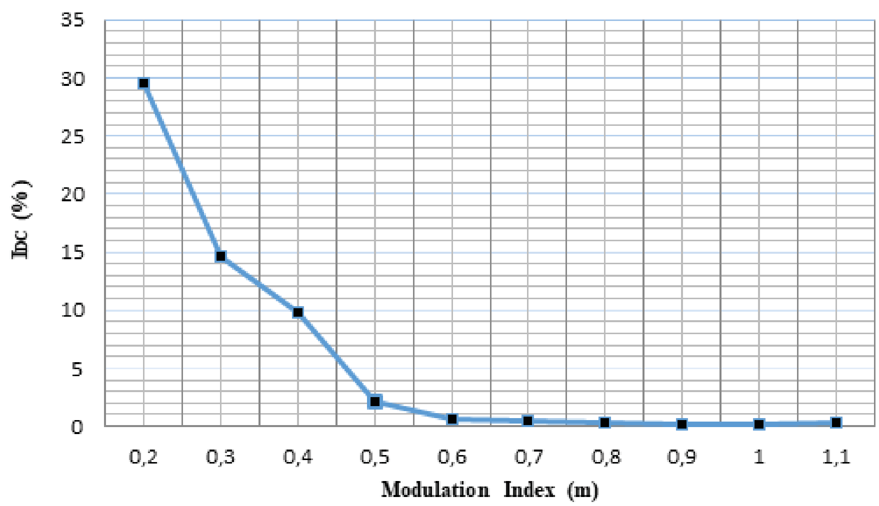

FIGURE 4. Characteristic of dc current component during off-grid operation.

On-Grid Operation Test

The photovoltaic system of Fig. 2 was connected to AC 220 V 50 Hz power grid. Fig. 5 present the measured waveforms of photovoltaic output current (I_{pv}), PWM current (I_{pwm}) and transformer primary side current (I_{ptrafo}). The measured THD value of transformer primary side current (I_{ptrafo}) was 9.034 %. It was worse than the result of off-grid operation test. High frequency ripple appear in the inverter output current. It is caused by the power grid that behave as disturbance to the inverter control system.

A DC current component characteristics of the inverter output current for different modulation indexes is depicted in Fig. 6. The maximum percentage of DC current was occurred at modulation index 0.2 with its value was 18.5%. While the minimum percentage of DC current component was obtained at modulation index 1, i.e. 0.072%. Comparison of percentage DC current component during off-grid and on-grid systems was shown in Fig. 7. The percentage of DC current component was lower during grid connected operation of inverter system.

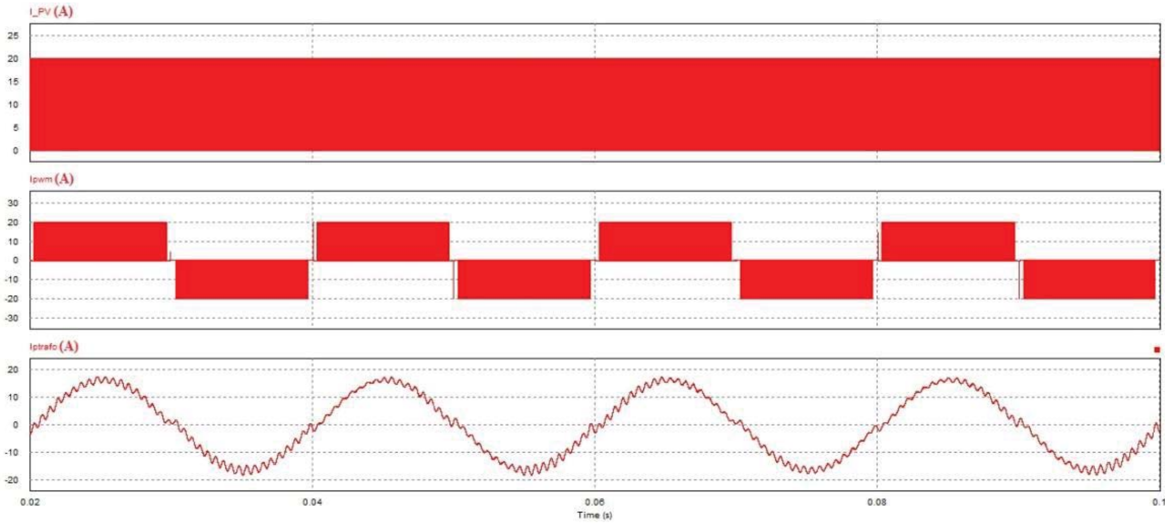

FIGURE 5. Current waveform during grid connected operation.

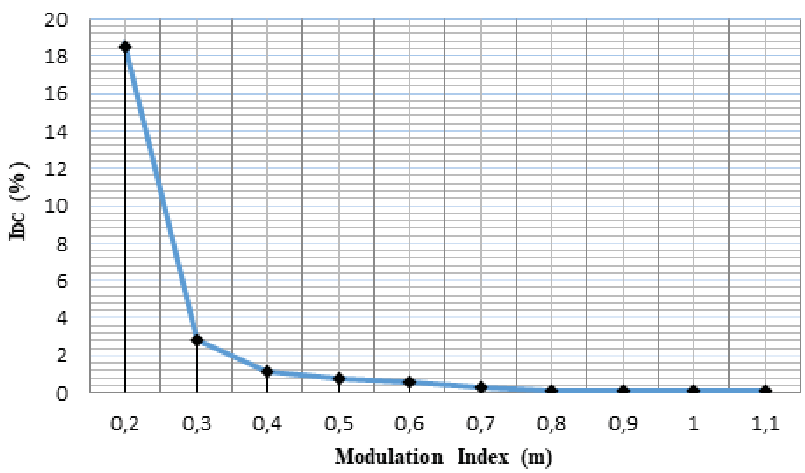

FIGURE 6. Characteristic of DC current component for different modulation index.

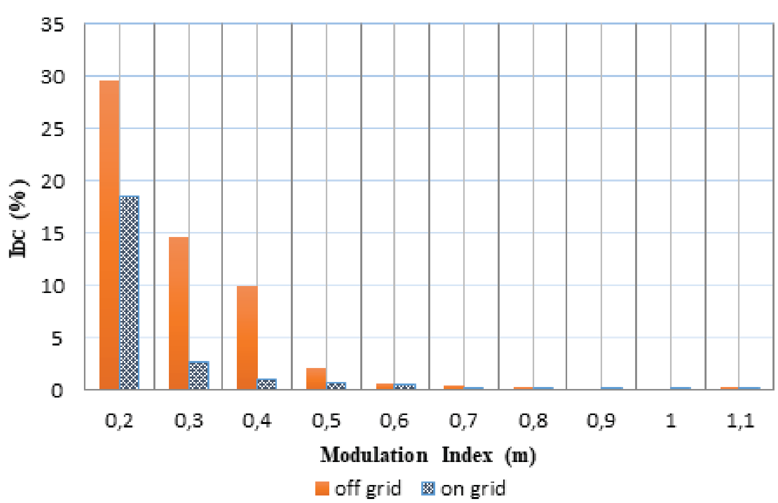

FIGURE 7. Comparison of DC current component during off-grid and on-grid operations.

CONCLUSIONS

A grid tied photovoltaic system applying H-bridge CSI and transformer has been presented and discussed in this paper, focusing on characteristics of DC current component of the inverter output current. The data showed that the percentage of DC current component will decrease as modulation index getting higher with minimum value achieved at modulation index 1. Comparison between off-grid and on-grid operation showed that the percentage of DC current component was lower when the inverter operated as grid tied operation. The DC current component of inverter output current should be minimized to reduce its effects to system component performance.

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