Performance and electromagnetic interference mitigation of DC-DC converter connected to photovoltaic panel

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Abstract

Renewable energy has been rapidly increased in terms of installed capacity. However, the electronic components inside such a system can cause a serious threat such as Electromagnetic Interference (EMI) to nearby sensitive devices/equipment. This paper aims to study on performance of DC-DC boost converter connected to photovoltaic panel and how to reduce EMI emissions issued in the system. A passive EMI low-pass filtering is one of various mitigation techniques. The designed converter connected to photovoltaic panel and EMI filter are tested in both simulation software and field testing by using EN55022 standard as a reference.

Keywords: Converter, Electromagnetic interference, Renewable energy, Performance analysis

1. Introduction

In recent decade, renewable energy has gained significant role in energy and environment issue, especially the solar power. The reason is a support from government with incentive policy, reduction in installation cost and rapid increase in private sector investment. Data from International Energy Agency (IEA) indicated the rapid increase in solar power penetration level [1]. Photovoltaic (PV) electricity generation is 37 TWh or 0.2% share of global electricity generation in 2010 and its target will be 4,572 TWh or 10.8%, share of global electricity generation in 2050. This results in massive PV installation, thus increasing the various technical issues, such as power quality, electromagnetic interference (EMI). The photovoltaic system requires integrated operation between electronic devices and controlling technique in order to achieve maximum power transfer in energy conversion process with high efficient output [2]-[3].

One of the components in photovoltaic system is a converter used to convert or adjust the voltage and/or current level to load or end user. It increases and regulates voltage on the required level in order to operate equipment or device. However, the operation of DC-DC boost converter can generate electromagnetic interference (EMI) from the switching devices inside electronic components. This noise signals may interrupt other sensitive electronic devices or communication in the system [4]. High speed switching power converters are significant for the more electric aircraft, the work [5] proposed the high frequency EMI attenuation technique for designing ACPI converter, it was shown that reducing the main gate resistor value is an effectively way to reduce EMI causing lower power losses.

The EMI mitigation methodology must be implemented in order to limit this value within standard. Many researches and studied regarding the novel EMI mitigation have been reviewed [6]-[9]. The common mode noise reduction in boost converter has been proposed using current cancellation circuit [7]. The switching frequency modulation circuit to limit EMI generated from PWM frequency modulationbased switching power supply has been discussed [8]. The PFM and PSM hybrid modulation control method implemented with spread spectrum technique has been introduced in [9] to mitigate EMI in LLC resonance power converter. The LED driver is no longer working on a fixed frequency, a spread spectrum method in [10] is also one of various ways are used to overcome the EMI in LED system. EMI filter for

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electronic device design has been described in Caponet and et al. research [11]. The Line Impedance Stabilization Network (LISN) is a main part to determine EMI in any electrical/electronic system, such as in power converter [12]-[13]. The Ferrite chokes are normally applied in the system as a filter to suppress EMI, the improved RLC model of the chokes has been studied in [14] by parameter determination technique. From the researches and studies mentioned above, it can be seen that EMI is the main issue in converter including the one that is part of photovoltaic system. The mitigation methodology must be taken into account to meet the Electromagnetic Compatibility (EMC) of the whole system.

This paper proposes a design of DC-DC boost converter in photovoltaic system. The performance and its effect in terms of EMI are addressed using EN55022 standard as a reference. The EMI mitigation methodology using low-pass EMI filter is also presented. The proposed methodology has been testing in field test with photovoltaic panel. The designed circuit and EMI mitigation method can be applied to various electrical/electronic devices that cause EMI issue.

2. Conducted EMI in PV System

The solar power generation system consists of a photo voltaic panel as the DC power source, sensors, controllers and DC-DC converter to matching and maintaining the voltage level to the load. In the DC conversion can easily introduce or form to high-frequency noise, also called Electromagnetic interference (EMI). The disturbance caused by EMI may degrade the overall performance of the circuit in term of the data interruption and losses of data. The problem of EMI also related to system efficiency by generated the high order power losses in the form of heat, sensitive electromagnetic interference (150 kHz - 30 MHz) and radiated electromagnetic interference (30 MHz - 1000 MHz). In PV system operation is focused on the conducted emission, which is divided into two components; common mode (CM) and differential mode (DM) interference depends on the path of noise delivered in the system. The CM mode the noise conducted on line and neutral in the same direction to the load and flow to reference ground thru the generated parasitic capacitor. The DM mode, noise is conducted on the signal line and ground in opposite direction to each other.

3. Simulation

3.1. Modelling



Fig. 1. DC-DC boost converter circuit with load variation

In this study, a boost converter for the photovoltaic system has been designed and investigated in terms of power quality and EMI issues. The designed DC-DC boost converter using PROTEUS software is

shown in Fig. 1. The circuit operation can be described as follows: MOSFET usually functions as switching device in boost converter, controlled by voltage difference between gate and source terminal. The voltage regulation with negative feedback requires a duty cycle of PWM as input data to adjust the output voltage of boost converter, starting from voltage divider to separate the voltage level determining the reference voltage to microcontroller 16F877. If the input voltage is excessive, microcontroller will command the MOSFET to switch lower PWM duty cycle. In the other hand, below expected voltage level, MOSFET will switch higher PWM duty cycle; this aims to remain the output voltage of boost converter to 24 V.

The Line Impedance Stabilization Network (LISN) as illustrated in Fig. 2 was implemented to system. Its role is to stabilize the impedance between source and ground, split noise emitted from the device under test passing to analyzer, and attenuate noise coming from the main power supply passing through the focused system in order to measure or determine the noises and also reach the safety condition.



Fig. 2. Boost converter with line impedance stabilization network

3.2. Simulation result

The conducted EMI simulation has been divided into two modes; 1) differential mode (DM) emission: the emission caused by current flowing in line and ground that can be calculated the differential mode voltage by measuring neutral to ground voltage subtracted by line to ground voltage, and the obtained term is divided by 2, and 2) common mode (CM) emission: the emission caused by the current flowing in line through ground bypassing with parasitic conductor generated by ground to circuit, represented by adding line to ground voltage with neutral to ground voltage, and then divided by 2. This calculation is done by mathematical equation written in MATLAB. The EMI is next plotted in frequency domain using Fast Fourier Transform (FFT) and compared with the EN55022 standard. The DM and CM simulation results are depicted, respectively, in Fig. 3.



Fig. 3. Spectrum of simulated DM emission

The simulation results in DM and CM noises showed the exceeded amount of EMI emissions compared with the international EMC standard. EMI filter, which is one reduction technique, is taken into account to eliminate excessive unwanted noise out of the system. The function of EMI filter is similar to a low-pass filter. However, it works in high frequency region, containing of appropriated inductor and capacitor. After adding the designed EMI filter, the simulated results are illustrated in Fig. 4, respectively.



Fig. 4. Spectrum of simulated CM emission

4. Experiment

4.1. EMI examination

The experiment of a proposed boost converter with voltage control connected to PV panel works properly and confirms the simulation results. The electromagnetic interference test results are based on the assumptions and simulation results described above, and the actual values of the tests are divided into two parts, which are noises conducted in line and neutral cable, the test conditions are 220 Volt 50 Hz within room temperature (25 Celsius) and 60% humidity with EN55022 Class B standard are shown in Fig. 5 and Fig. 6.



Fig. 5. Noise distribution in line cable



Fig. 6. Noise distribution in neutral cable

The tests result in form of a graph show data about electromagnetic interference level at various frequencies in the conducted noise emission range with laboratory level tools. It is obvious that magnitude of conducted EMI is exceeded the standard. These points cause electrical power losses in the circuit and may cause the system not to function properly. The results of the points which are exceeded the EN55022 Class B standard and high peak that should be lowered points are shown in the Table 1 and Table 2. The high peak point affects the durability of the sensitive electronics devices.

| No. | Frequency MHz | Reading QP dB(uV) | Reading CAV dB(uV) | c.f dB | Result QP dB(uV) | Result CAV dB(uV) | Limit QP dB(uV) | Limit AV dB(uV) | Margin QP dB | Margin CAV dB |
|-----|------------------|-------------------------|--------------------------|-----------|------------------------|-------------------------|-----------------------|-----------------------|--------------------|---------------------|
| 1 | 0.02713 | 51.8 | | 10.3 | 62.1 | | 110.0 | 0.0 | 47.9 | |
| 2 | 0.05419 | 64.7 | | 10.2 | 74.9 | | 89.3 | 0.0 | 14.4 | |
| 3 | 0.08004 | 45.7 | | 10.2 | 55.9 | | 85.7 | 0.0 | 29.8 | |
| 4 | 0.09999 | 47.0 | | 10.1 | 57.1 | | 83.7 | 0.0 | 26.6 | |
| 5 | 0.10853 | 38.7 | | 10.1 | 48.8 | | 82.9 | 0.0 | 34.1 | |
| 6 | 0.12003 | 46.4 | | 10.2 | 56.6 | | 82.0 | 0.0 | 25.4 | |
| 7 | 0.13998 | 47.6 | | 10.2 | 57.8 | | 80.6 | 0.0 | 22.8 | |
| 8 | 0.23987 | 52.9 | 49.9 | 10.2 | 63.1 | 60.1 | 62.1 | 52.1 | -1.0 | -8.0 |
| 9 | 0.25961 | 53.0 | 50.0 | 10.2 | 63.2 | 60.2 | 61.4 | 51.4 | -1.8 | -8.8 |
| 10 | 0.27939 | 52.8 | 49.9 | 10.2 | 63.0 | 60.1 | 60.8 | 50.8 | -2.2 | -9.3 |
| 11 | 15.001 | 38.2 | 36.9 | 10.8 | 49.0 | 47.7 | 60.0 | 50.0 | 11.0 | 2.3 |
| 12 | 26.6196 | 40.1 | 38.0 | 11.1 | 51.2 | 49.1 | 60.0 | 50.0 | 8.8 | 0.9 |

Table 1. Information on the measurement of noise distribution in line cable

| No. | Frequency MHz | Reading QP dB(uV) | Reading CAV dB(uV) | c.f dB | Result QP dB(uV) | Result CAV dB(uV) | Limit QP dB(uV) | Limit AV dB(uV) | Margin QP dB | Margin CAV dB |
|-----|------------------|-------------------------|--------------------------|-----------|------------------------|-------------------------|-----------------------|-----------------------|--------------------|---------------------|
| 1 | 0.02713 | 51.9 | | 10.3 | 62.2 | | 110.0 | 0.0 | 47.8 | |
| 2 | 0.05449 | 61.4 | | 10.2 | 71.6 | | 89.3 | 0.0 | 17.6 | |
| 3 | 0.07998 | 46.4 | | 10.2 | 56.6 | | 85.7 | 0.0 | 29.1 | |
| 4 | 0.100 | 46.3 | | 10.1 | 56.4 | | 83.7 | 0.0 | 27.3 | |
| 5 | 0.1085 | 36.1 | | 10.1 | 49.2 | | 82.9 | 0.0 | 33.7 | |
| 6 | 0.12002 | 46.7 | | 10.2 | 56.9 | | 82.0 | 0.0 | 25.1 | |
| 7 | 0.140 | 47.6 | | 10.2 | 57.8 | | 80.6 | 0.0 | 22.8 | |
| 8 | 0.23931 | 52.9 | 49.8 | 10.2 | 63.1 | 60.0 | 62.1 | 52.1 | -1.0 | -7.9 |
| 9 | 0.26005 | 53.2 | 50.2 | 10.2 | 63.4 | 60.1 | 61.4 | 51.4 | -2.0 | -9.0 |
| 10 | 0.2803 | 52.7 | 49.7 | 10.2 | 62.9 | 59.9 | 60.8 | 50.8 | -2.1 | -9.1 |
| 11 | 14.9596 | 38.1 | 36.7 | 10.7 | 48.8 | 47.4 | 60.0 | 50.0 | 11.2 | 2.6 |
| 12 | 26.9408 | 39.2 | 37.2 | 10.6 | 49.8 | 47.8 | 60.0 | 50.0 | 10.2 | 2.2 |

Table 2. Information on the measurement of noise distribution in neutral cable

4.2. EMI filter

According to the EMI examination results the EMI filter has been taken into order to mitigate the conducted emission in the points which the EMI values exceeded the standard. When the low pass EMI filter connected to the system, the EMI effect is significantly reduced. As shown in Fig.7, most of the high peak value are satisfactory diminished.



Fig. 7. Noise distribution in line and neutral cable of improved circuit with EMI filter

5. Conclusion

This paper proposed the design of DC-DC boost converter in photovoltaic system and EMI mitigation using passive low-pass EMI filter. The result has revealed that conventional boost converter generated EMI which is needed to be reduced. After inserting the proposed low-pass EMI filter, the conducted EMI in both line and neutral has been reduced significantly. By comparing with EN55022 Class B standard, it has shown that low-pass EMI filter mitigates EMI within standard value. Thus, it showed the effectiveness of the EMI mitigation method in such a system. This can also be extended to be used for various electrical/electronic devices/equipment that contain electronic components with high EMI generation.

Although the EMI mitigation improved the performance and reliability of the system, lower overall efficiency must be compromised. The balancing of efficiency and EMI is a necessary key, the highest system efficiency within excepted EMI level is the desire of every circuit creator.

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