Journal of Harbin Engineering University
ISSN: 1006-7043

Vol 46 No. 11
November 2025

Mitigation of Harmonics in MPPT based PV Plant using Power Quality Compensators

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Abstract

Green energy is most important contributor of national grid system, one among them is the solar power and Photovoltaic solar power plant is designed and developed for feeding the remote loads. The PV solar plant is designed with incremental conductance based Maximum Power Point Tracking (MPPT) algorithm to extract the optimal power from the PV panels. The PV Solar plant is integrated with the power grid for extracting power from PV system. The PV plant is equipped with the STATCOM for mitigating voltage harmonics from the solar plat output. The power quality of the system has been analysed using Fast Fourier Transform (FFT) and computed the Total Harmonic Distortion (THD) for the output voltage in different load scenarios. The case one illustrates the THD analysis of the system without compensators and it is recording a very high value which is highly undesirable according to IEEE standards. In second case the voltage harmonics have been analysed and recorded a very lowest value which is highly accepted according to IEEE standards.

Keywords: PV Plant, Power Quality, THD minimisation, MPPT, Sustainable Energy.

1. Introduction

Green energy playing a vital role in the contribution of renewable energy of the grid for reducing atmospheric pollution and temperature rise especially during summer seasons.

Author's previous contributions: One is Hill climbing algorithm-based PV system has developed to extract optimal power from the plant and is simulated and tested with compensation active filters for minimizing the voltage harmonics and achieved the required result [15]. Second is the development of Perturb and Observe based solar plant and design and implementations of power quality improvement equipment at each stage of the conversion and has achieved the mitigation of voltage and current harmonics at all stages of conversion [14]. The third is the integration of solar plat to grid and implementation of the active filters and minimization of harmonics have been achieved [16]. The Photovoltaic solar plant is equipped with dc-dc converter with MPPT algorithm using incremental conductance method [1] to [6]. The duty ratio of the dc-dc converter is controlled in closed loop using incremental conductance algorithm [7] to [10]. This article focussed on the development of the incremental conductance based photovoltaic plant with the dc-dc converter fed inverter and integrated to the ac grid through step up transformer. The complete system Simulink diagram is developed and carried out the simulations for various scenarios of the loads. The harmonic spectrum is analysed with computation of the total harmonic distortion without and with harmonic filters [9] to [16]. The THD content is enormously reduced with the application of harmonic filters.

2. System Description: Solar Power Plant Integrated to the Grid

The photovoltaic solar power plant is designed and developed with PV solar panels fed to buck-boost converter equipped with Maximum Power Point Tracking (MPPT) with incremental conductance method. The MATLAB programme is built with the Simulink model for executing MPPT from the solar panels, then it is connected to the STATCOM along with PWM signals and harmonic filters. This system is then connected to the coupling transformer

And this whole system is integrated to the power grid as illustrated as in the Fig.1, which shows the Single line diagram of Grid tied solar power plant with dc-dc converter fed inverter along with harmonic filters.

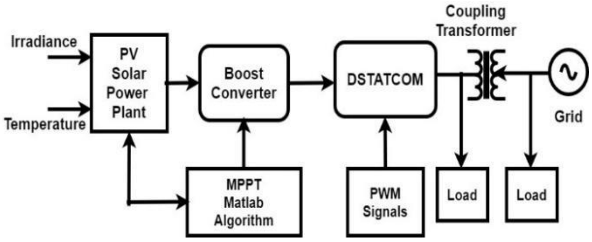

Fig. 1. Single line diagram of Grid tied solar power plant with dc-dc converter fed inverter

Solar Photovoltaic (PV) Cell

The photovoltaic solar power plant is developed with the help of the series and parallel combinations of solar cells to attain the required voltage, current and power ratings. The solar cell equivalent circuit is shown in Fig. 2. The equations from (1) to (3) describes the pv panel model and Fig. 3 illustrating the PV panel characteristics.

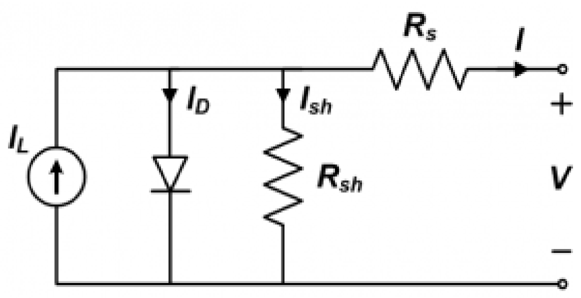

Fig. 2. Eequivalent circuit of Solar cell

$I = I_L - I_0[e^A - 1] - B$

(1)

$A = \frac{V+IR_S}{nV_t}$

(2)

$B = \frac{V+IR_S}{R_{sh}}$

(3)

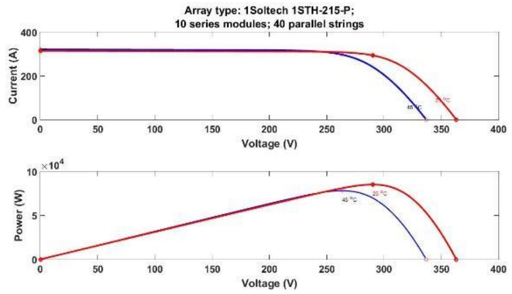

Fig. 3. VI and Power Characteristics of Solar power plant

MPPT Algorithm

The incremental conductance method is applied to extract the maximum power from the solar panel as illustrated in Fig.4, which shows the Maximum Power point characteristics and Fig.5 illustrating the Incremental Conductance based MPPT Algorithm of Solar power plant.

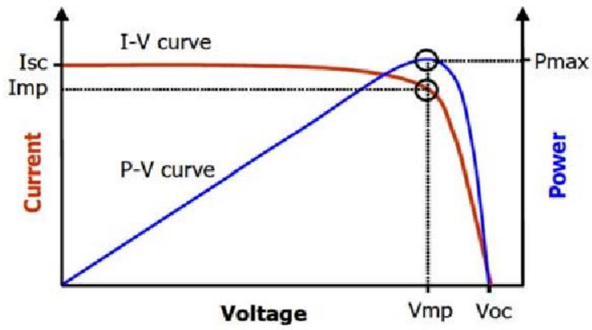

Fig. 4. Maximum Power point characteristics

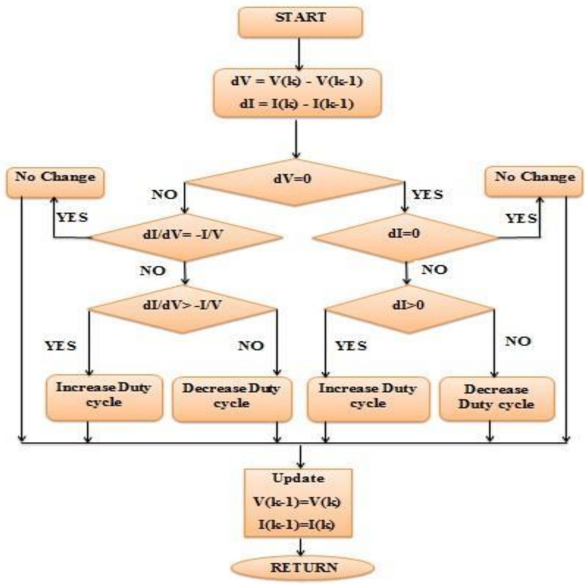

Fig. 5. Incremental Conductance based MPPT Algorithm of Solar power plant

3Boost Converter

Journal of Harbin Engineering University
ISSN: 1006-7043

Vol 46 No. 11
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The dc-dc converter is utilized to regulate the dc output voltage of the solar power plant to intact with the system requirements. The schematic diagram of the boost converter has clearly illustrated in the Fig. 4 shown below and equation (4) shows the relation between output dc voltage and input dc voltage.

$$Vo = Vi/(1-D)$$

(4)

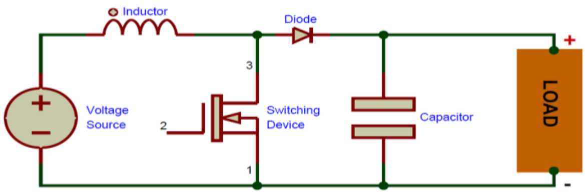

Fig. 6. dc-dc converter schematic circuit

3. Mathematical Modelling of Inverter

The modelling equations of the inverter have been developed and described in the following equations from (5) to (9), which is suitable for integrating the PV plant with the existing ac grid and fig.7 shows the inverter schematic circuit.

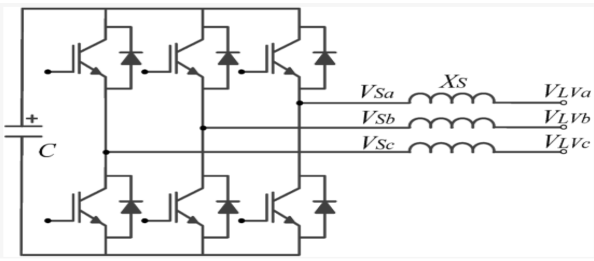

Fig. 7. Inverter schematic circuit

V_C= DC capacitor input voltage

$$P = \frac{V_t V_C}{X_L} \sin \sin \alpha$$

(5)

$$Q = \frac{V_t V_t}{X_L} - \frac{V_t V_C}{X_L} \cos \cos \alpha$$

(6)

The mathematical equations of inverter can be expressed as;

$$L\frac{di_{ac}}{dt} = R + V_{ac} - V_{at}$$

(7)

$$L\frac{di_{bc}}{dt} = R + V_{bc} - V_{bt}$$

(8)

$$L\frac{di_{cc}}{dt} = R + V_{cc} - V_{ct}$$

(9)

4. Case Study and Results

The photovoltaic solar power plant equipped with the DC-DC Converter used for the maximum power point tracking using incremental conductance method and STATCOM with filters has described in Fig.8, which extrapolates the Grid Connected Solar System with MPPT based Boost Converter and STATCOM complete system Simulink Model. The power quality of the system has been analysed using Fast Fourier Transform (FFT) and computed the Total Harmonic Distortion (THD) for the output voltage in different load scenarios. All these results have been described in the subsequent sections of this chapter. Fig.9 illustrates FFT of output voltage without Filters for R load and the THD is found from the FFT window as 59.62%, which is highly undesirable. The output voltage THD is only 0.1% with STATCOM and filters as depicted in Fig.10, which shows the FFT of R phase output voltage for R load. Similarly in Y phase voltage the THD has been decreased to a very low value of 0.12% only as desired by the IEEE Standards. Subsequently Fig.11 illustrates the FFT of Y phase output voltage with Filters for R load which is about 0.14% only, as described by the Fig.12, which shows the FFT of B phase output voltage with Filters for R load. similarly Fig.13 illustrates the FFT of output voltage without Filters for RL load as equal to 59.73% of THD which is highly undesirable according to IEEE standards. Subsequent figures encapsulates the FFT windows of solar system for RL type loads with STATCOM and filters leading to reduced values of THD which are highly accepted according to IEEE standards as depicted by Fig.14, as the FFT of R phase output voltage without Filters for RL load of THD equal to 0.33%, 0.31% and 0.28% in Y phase and B phase respectively which described as in Fig.15, as an FFT window of Y phase output voltage without Filters for RL load, in Fig.16, as an FFT window of B phase output voltage without Filters for RL load.

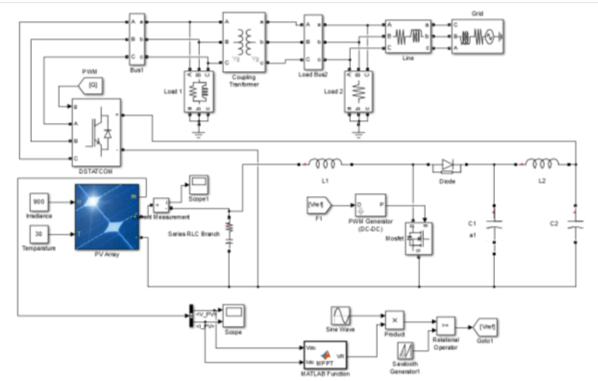

Fig. 8. Grid Connected Solar System with MPPT based Boost Converter and STATCOM complete system Simulink Model.

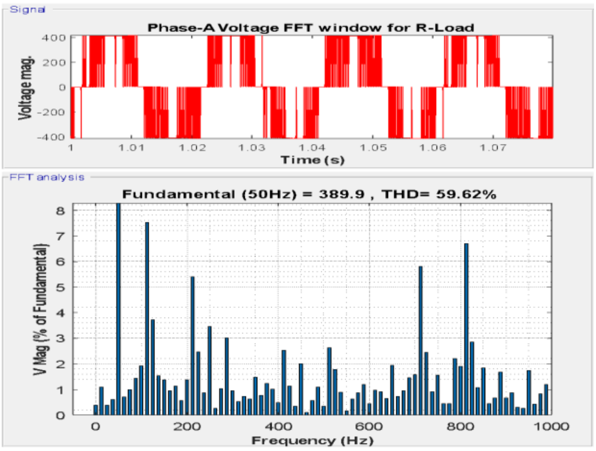

Fig. 9. FFT of output voltage without Filters for R load

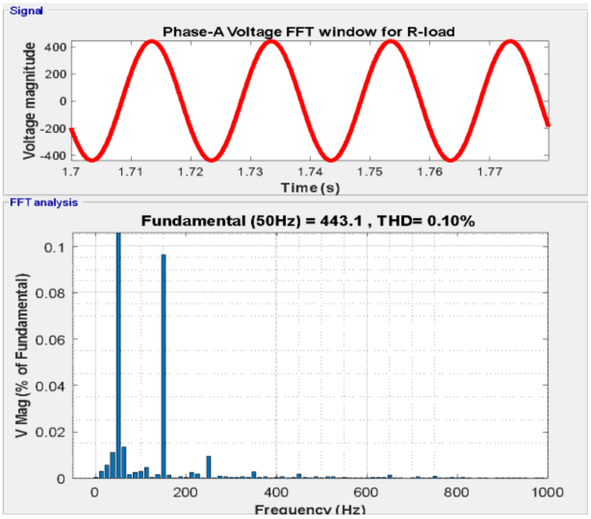

Fig. 10. FFT of R phase output voltage with Filters for R load

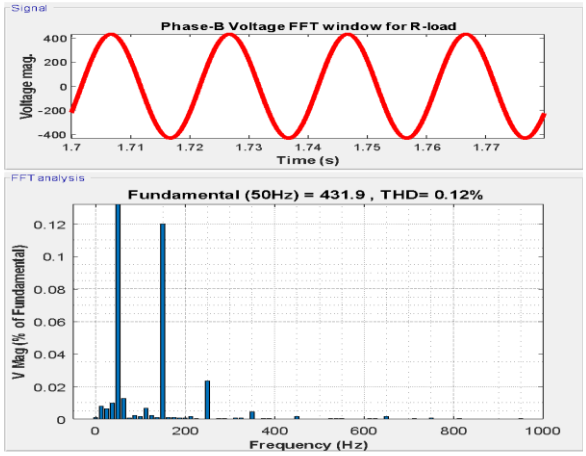

Fig. 11. FFT of Y phase output voltage with Filters for R load

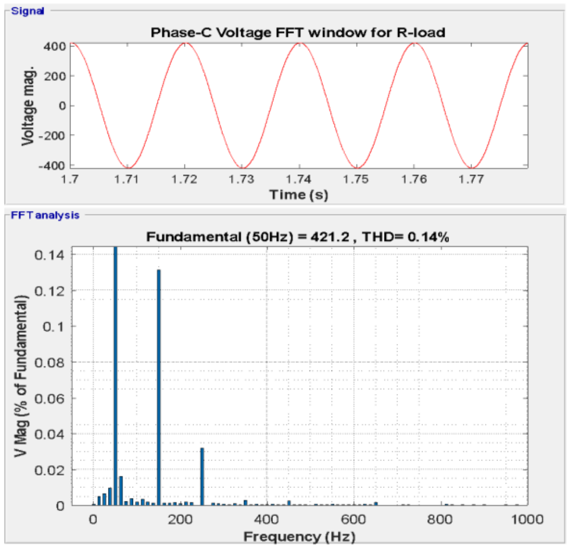

Fig. 12. FFT of B phase output voltage with Filters for R load

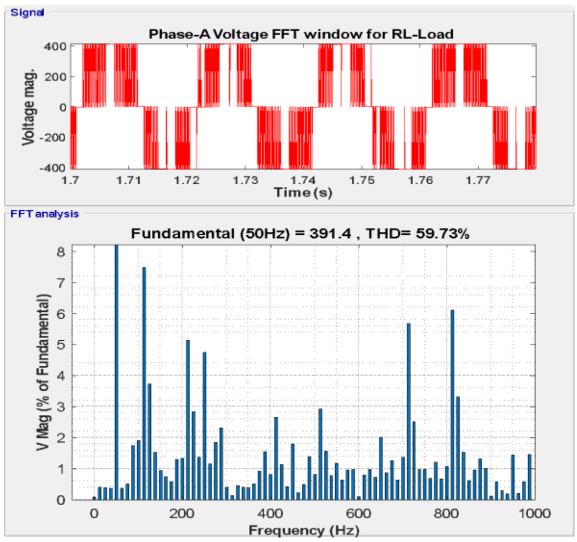

Fig. 13. FFT of output voltage without Filters for RL load

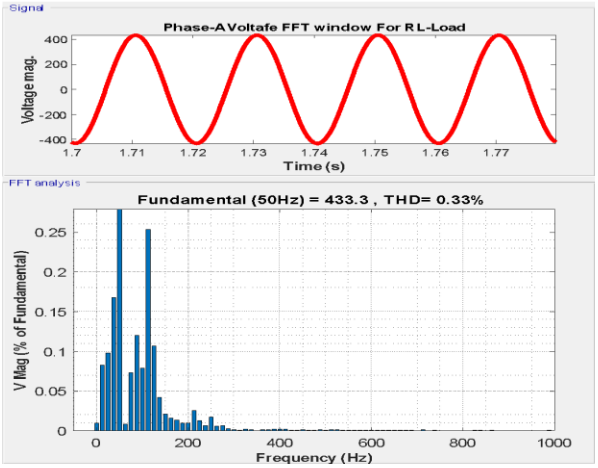

Fig. 14. FFT of R phase output voltage without Filters for RL load

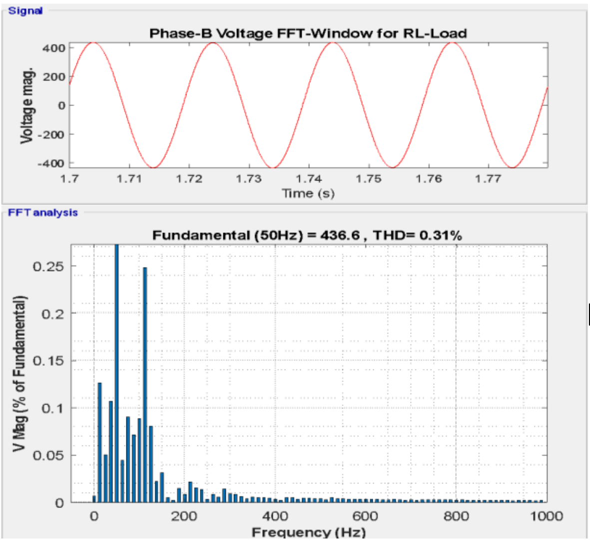

Fig. 15. FFT of Y phase output voltage without Filters for RL load

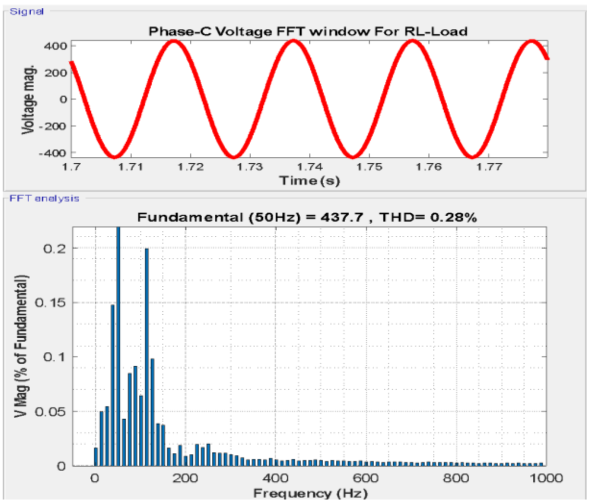

Fig. 16. FFT of B phase output voltage without Filters for RL load

5. Conclusions

The incremental conductance based maximum power point tracking algorithm is used for obtaining optimal power from the solar plants and this model is equipped with the STATCOM including harmonic filters. The integration of solar plant is done with the help of the coupling transformer and switches. The output voltage harmonics of the system have been analysed with the help of the FFT window and it is recorded as very high value of about 59%, which is highly undesirable according to IEEE standards. The STATCOM along with the Harmonic filters have been used to mitigate these harmonics. The effect of the power quality compensators on the mitigation of output voltage harmonics have been analysed with the FFT window and is recorded as very low value of the order less than 2% which is highly accepted according to IEEE standards and it proves the effectiveness of STATCOM along with harmonic filters on mitigation of harmonics in power system.

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