Stability Analysis of Grid Integration of Photovoltaic Systems Using Partial Power Converters

N. Saravanakumar, A. Amudha, G. Emayavaramban, M. Siva Ramkumar, S. Divyapriya

Abstract--- An advanced power control strategy by limiting the maximum feed-in power of PV systems has been proposed, which can ensure a fast and smooth transition between maximum power point tracking with Partial Power Converter (PPC)[6] and Synchronous Reference Frame (SRF) method. Regardless of the solar irradiance levels, high-performance and stable operation are always achieved by the proposed control strategy. It can regulate the PV output power according to any set-point and force the PV systems to operate at the left side of the maximum power point without stability problems. The effectiveness of the proposed PPC control[3] in terms of high accuracy, fast dynamics, and stable transitions improvement. Overall power management unit is controlled by the converter & control loop. Performance analysis (power & stability) [10] of the overall system is carried out using MATLAB/SIMULINK model.

Keywords--- PV, SRF, PPC, Matlab/Simulink.

I. INTRODUCTION

The performance of a solar photovoltaic array PV is dependent upon the temperature and irradiance level and it is necessary to study the characteristics of photovoltaic (PV) array. Currently, Maximum Power Point Tracking (MPPT) [5] operation is mandatory for [8]-connected PV systems in order to maximize the energy yield. Catering for more PV installations requires advancing the power control schemes as well as the regulations in order to avoid adverse impacts. Perturb & Observe MPPT algorithm is utilized through dc-dc boost converter to track MPP and boost the dc voltage for required application.

One of the most efficient and adequate application and utilization of power generated through PV is operation in grid connected mode. The grid integration of PV system requires a power electronics interface capable of conversion from dc-ac. Voltage source inverter (VSI) used as a power electronics interface and dc voltage as an input to converter have to be regulated to the required level for the power flow from converter side to load/grid side. In order to increase the conversion efficiency in photovoltaic (PV) systems [4], different configurations and topologies were developed. Depending on the application, the converters used for grid connection are built using one or two conversion stages. The advantages of the converters with a DC-stage are mainly the distributed maximum power point tracking algorithm per PV string or PV module and, when required for grid connection, the possibility of voltage elevation. However, the conversion efficiency is lower than configurations with a single-stage as the central inverter [7].

Therefore, the proposed work presents a Partial Power DC-DC converter (PPC) which process part of the entire system power and the remaining power is directly supplied to the output side. The PLL is used for the grid frequency synchronization and SRF is used for stability improvement. VSI interfaced grid connected PV system implemented based upon the outer voltage control loop responsible for the dc voltage regulation and inner current control fed with generated reference current.

There are various control algorithms for generation of reference quantity implemented for grid interfaced PV system [1-2]. The current control based scheme is implemented more dominantly in comparison to voltage control based scheme because of high power factor obtaining capability with better transient current suppression under disturbance. Synchronization [9] and power control strategy is required for the operation of PV system integration to grid. The various control strategy is mentioned in the literature and researches based on the power control algorithms and synchronization. The synchronous reference frame (SRF) theory implemented for control.

The SRF based control is implementing using phased locked loop (PLL) for frequency synchronization. In general, inner current loop implemented using proportional-integral (PI) control and generates the ac voltage reference for the inverter. The PI controller implemented for dq reference quantity obtained using synchronously rotating frame (SRF) because of incapable to track the reference signal accurately under stationary frame. abc-dq transformation converts the ac signal into dc quantity by changing from stationary frame to rotating frame. PI controller employed on constant signal in the dq reference frame can ensure to track the reference adequately with easy design and implementation.

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The VSI consists of six switching devices to generate the three-phase ac voltage output and couple to the grid by proper generation of gate signals. The generated voltage reference/current error used to generate the gating signals fed to the switching device.

Some of the common method to generate the switching signal is sinusoidal pulse width modulation (SPWM).

II. LITERATURE SURVEY

Jaime W. Zapata et al., —In order to increase the conversion efficiency in photovoltaic (PV) systems, different configurations and topologies were developed. Depending on the application, the converters used for grid connection are built using one or two conversion stages. The advantages of the converters with a DC-stage are mainly the distributed maximum power point tracking algorithm per PV string or PV module and, when required for grid connection, the possibility of voltage elevation. However, the conversion efficiency is lower than configurations with a single stage as the central inverter. Therefore, the proposed work presents a Partial Power DC-DC converter (PPC) which process part of the entire system power and the remaining power is directly supplied to the output side. A topology is proposed and the details of its operation are explained based on the operating principle. Simulations are performed in order to evaluate the converter performance.

Sumitha T L et al., DC/DC converters which form interface between photovoltaic panels and the batteries/inverters is an integral part of any photovoltaic power plant. These converters regulate the charge provided by PV panels to the batteries/inverters. Therefore in this work, for PV architectures, DC/DC converter with partial power processing technique is proposed. This proposed topology is said to have the advantage of simplicity, high efficiency, low cost and high reliability. The high efficiency of the converter output will be achieved by having the input PV power fed forward to the output without being processed and only a portion of the PV power is processed by the converter depending on the voltage regulation requirement. Here Peturb and Observe MPPT controller algorithm will be used for locating maximum power points, at any sunlight conditions for extracting the maximum power from the PV module and transferring that power to the load. The performance of the proposed topology is analyzed with the help of MATLAB/Simulink model.

Aratrika Ghosh et al., With the increased penetration of renewable-based distributed generation, such as the wind and solar-photovoltaic (solar-PV) power generation, the power grid is going through a rapid structural change inflicting stability issues in the power network. In particular, with the increased solar-PV penetration level, it is imperative to analyze the impact of distributed solar-PV power generation on power system stability.

Typically, stability issues are studied and analyzed by developing an aggregated model of the solar-PV system, since the aggregated model is an time efficient method to examine the system stability. At the beginning of this research, a dynamic simulation model of a single-phase solar-PV system was designed by employing a solar-PV array model, maximum power point tracking (MPPT) system, inverter model, power and current controllers. This model was tested with perturb & observe (P&O) MPPT algorithm and different current control schemes to characterize its dynamic behavior. ®Then, an aggregated solar-PV dynamic simulation model was developed in Dig SILENT Power Factory with same architecture to represent the aggregated response of large-scale solar-PV power generation.

This large-scale solar-PV model was developed with necessary Power Factory. This modification to the existing solar-PV model in the Dig SILENT aggregated model was then used for transient stability analysis. Results of the transient stability analysis have enabled to identify the limitations of the aggregated model. The solar-PV power generation is spread across a large geographic area, hence an aggregated solar-PV model is not a realistic representation of the solar-PV power generation. Therefore, a detailed distribution network model is developed with solar-PV power generation in the next stage of this research. This detailed distribution network model is then used to compare the dynamic response of the aggregated solar-PV model under various scenarios, and finally, necessary improvements are identified to enhance the aggregated model.

Samir Kouro et al, This work presents a partial power converter allowing us to obtain, with a single DC-DC converter, the same feature as the classical interleaved operation of two converters. More precisely, the proposed topology performs similarly as the input-parallel output-series (IPOS) configuration reducing the current ripple at the input of the system and dividing the individual converters power rating, compared to a single converter.

The proposed topology consists of a partial DC-DC converter processing only a fraction of the total power, thus allowing high efficiency. Experimental results are provided to validate the proposed converter topology with a Flyback-based 100 W test bench with a transformer turns ratio n1 = n2. Experimental results show high performances reducing the input current ripple around 30%, further increasing the conversion efficiency.

Yongheng Yang et al, This letter proposes a hybrid power control concept for grid-connected Photovoltaic (PV) inverters. The control strategy is based on either a Maximum Power Point Tracking (MPPT) control or a Constant Power Generation (CPG) control depending on the instantaneous available power from the PV panels. The essence of the proposed concept lies in the selection of an appropriate power limit for the CPG control to achieve an improved thermal performance and an increased utilization factor of PV inverters, and thus to cater for a higher penetration level of PV systems with intermittent nature. A case study on a single-phase PV inverter under yearly operation is presented with analyses of the thermal loading, lifetime, and annual energy yield. It has revealed the trade-off factors to select the power limit and also verified the feasibility and the effectiveness of the proposed control concept.

III. PROPOSED MODULE

3.1 Proposed Topology & Its Principle

- In existing system NRF control loop is used.
- So overall switching losses reduced in this system,
- We needed only two switches for overall operation but power management control is not focused.
- In this scheme, two or more PV units are combined together for improving power-supply reliability.
- A novel control scheme based on the FPC converter is used to improve the smoothing performance of a grid-connected system.

3.1.1. Existing System Drawbacks

Existing system has disadvantages of

- Stability problem.
- In partial shading condition existing converter not able to track the global peak.
- Power management problem raised.
- System Performance Reduced.
- Less Efficiency.

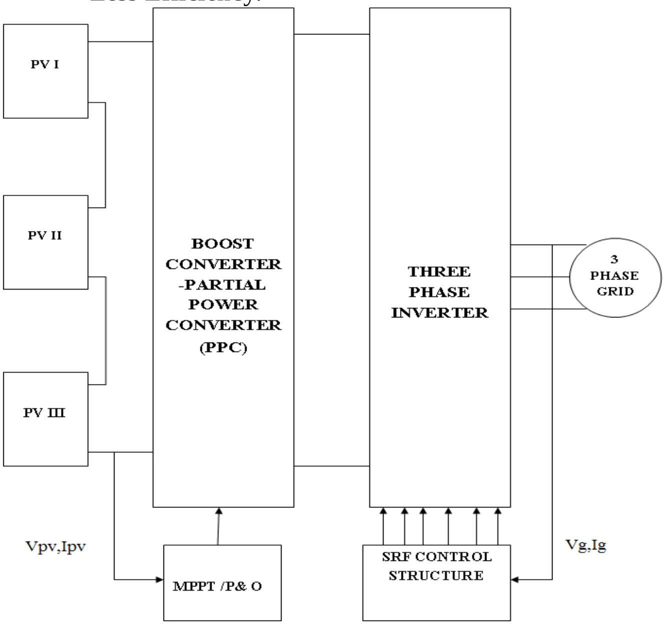

Figure 3.1: Block diagram of Proposed System

3.2 Proposed System Block Diagram Description

- A high-performance active power control scheme by limiting the maximum feed-in power of PV systems has been proposed in this method. The proposed solution can ensure a stable constant power generation operation.
- Compared to the traditional methods, the proposed control strategy forces the PV systems to operate at the left side of the maximum power point, and thus it can achieve a stable operation as well as smooth transitions.
- Simulation results have verified the effectiveness of the proposed control scheme in terms of reduced overshoots, minimized power losses, and fast dynamics. Notably, for single-stage PV systems, the same CPG concept is also applicable. However, in that case, the PV voltage operating range is limited and minor changes in the algorithms are necessary to ensure a stable operation.

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3.2.1 Proposed System Advantages

- In partial shading condition proposed converter able to track the global peak.
- Power flow management is controlled.
- Cost of design is low.
- System Performance improved.
- Overall Stability improved
- Overall Efficiency of the system improved.

IV. SIMULATION RESULTS

4.1 About MATLAB

This project is simulated in MATLAB R2011a tool which is user friendly software. MATLAB is a high-level language and interactive environment for numerical computation, visualization, and programming. Using MATLAB, you can analyze data, develop algorithms, and create models and applications. The language, tools, and built-in math functions enable you to explore multiple approaches and reach a solution faster than with spreadsheets or traditional programming languages, such as C/C++ or Java™. We can use MATLAB for a range of applications, including signal processing and communications, image and video processing, control systems, test and measurement, computational finance, and computational biology. More than a million engineers and scientists in industry and academia use MATLAB, the language of technical computing, Simulink is a data flow graphical programming language tool for modeling, simulating and analyzing multi domain dynamic systems.

Its primary interface is a graphical block diagramming tool and a customizable set of block libraries.

It offers tight integration with the rest of the MATLAB environment and can either drive MATLAB or be scripted from it. Simulink is widely used in control theory and digital signal processing for multi domain simulation and Model-Based Design.

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4.1.1 SIMULINK

Simulink, developed by Math Works, is a data flow graphical programming language tool for modeling, simulating and analyzing multi domain dynamic systems. Its primary interface is a graphical block diagramming tool and a customizable set of block libraries.

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Simulink provides a graphical editor, customizable block libraries, and solvers for modeling and simulating dynamic systems. It is integrated with MATLAB®, enabling you to incorporate MATLAB algorithms into models and export simulation results to MATLAB for further analysis. Figure 4.1 Simulation Diagram of PMSG based Current Control Structure with MATRIX Converter & SVPWM.

4.2. Simulation Diagram of Proposed Method

Figure 4.1 shows the PV- PPC-simulated model of a converter with SRF and current control loop for a grid connected system.

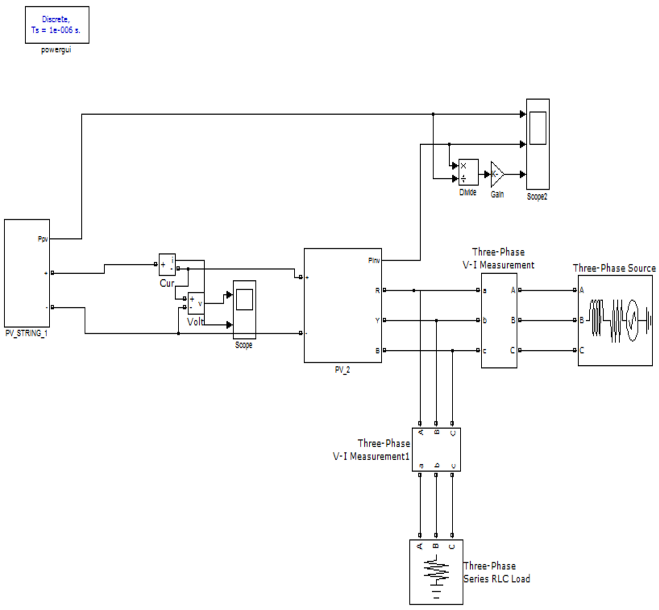

Figure 4.1: Simulation Diagram of PV based Partial power converter with SRF Control Structure for grid connected system

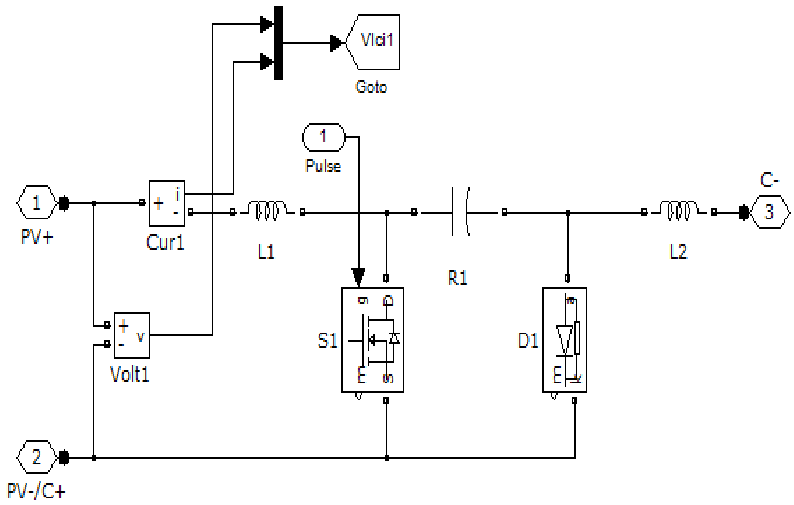

Figure 4.2: Simulation Diagram of Partial Power Converter

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Due to the additional stage, the global conduction, switching and magnetic losses increase. Therefore, the efficiency [6] presented in two-stage configurations are lower compared with single-stage configurations. Moreover, the whole power generated by the system is handled by the converter which also reduces the conversion efficiency. In order to overcome the low efficiency, some authors have proposed different solutions based on interleaved connections. Moreover, the concept of partial power converter, as shown in Fig. 4.2 has been introduced in which uses the isolated converters in order to make the connection and avoid a short circuit. The technique of partial power processing, where only a portion of the total power is required to elevate the input voltage, can significantly reduce the converter size and power loss .

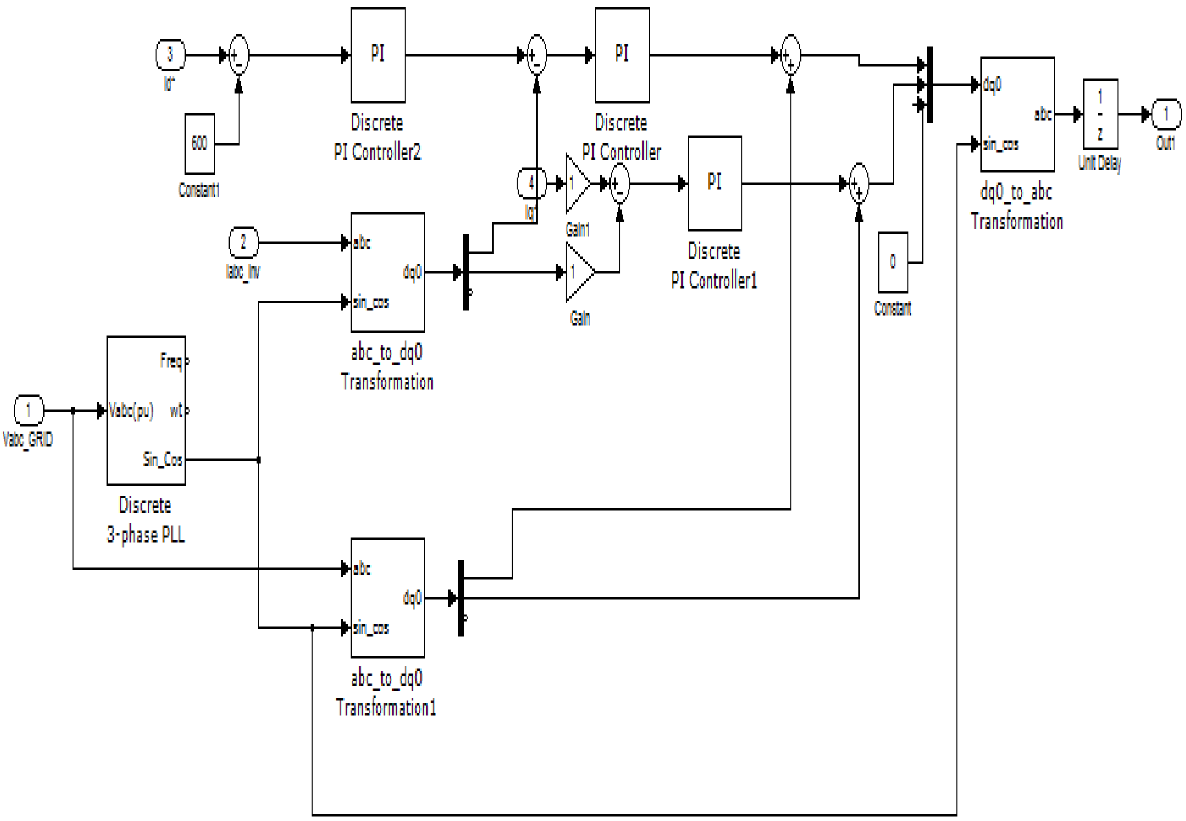

Figure 4.3: Simulation Diagram of Control Loop Structure

In order to compare the performance of the proposed configuration, a simulation of a full power converter is made for the same operating point. Both converters work at the same parameters, with the exception of the voltage and current sizing for the semiconductors and the power ratings, so that they are optimized in order to reach their maximum efficiencies.

It is noted that the partial power converter not only has a better efficiency, but the requirements for the semiconductors are lower as well. This aspect may lead to an improved reliability of the grid system with good THD.

Several aspects of the design and operation are improved in comparison to a full power converter, such as a higher efficiency of the DC-DC conversion and a small power rating for the converter is achieved. Despite of the variations in solar irradiation, the power handled by a partial power converter remains lower compared with a full power converter, it leads to smaller conversion losses and a greater efficiency and achieves better THD than the existing.

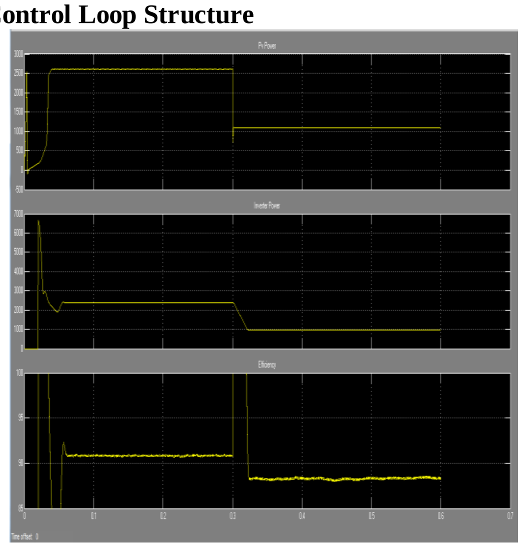

Figure 4.4: Output Waveform of Existing FPC PV Power /Inverter Power /Efficiency

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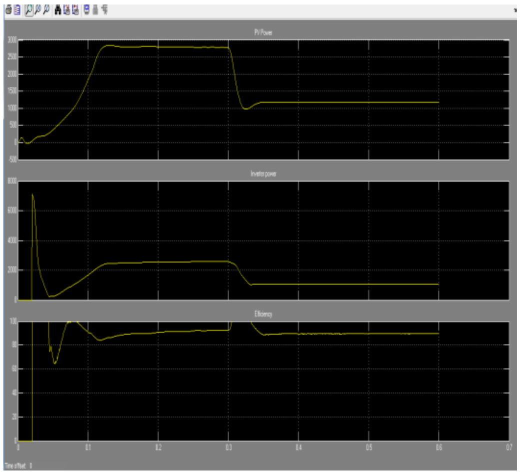


Figure 4.5: Output Waveform of Proposed PPC PV Power /Inverter Power /Efficiency

Table 4.1 Efficiency Comparison for FPC & PPC

IRRIDANCE	Efficiency of FPC (%)	Efficiency of PPC (%)
1000 W/m2	90.85	92.6
500 w/m2	88.25	89.5

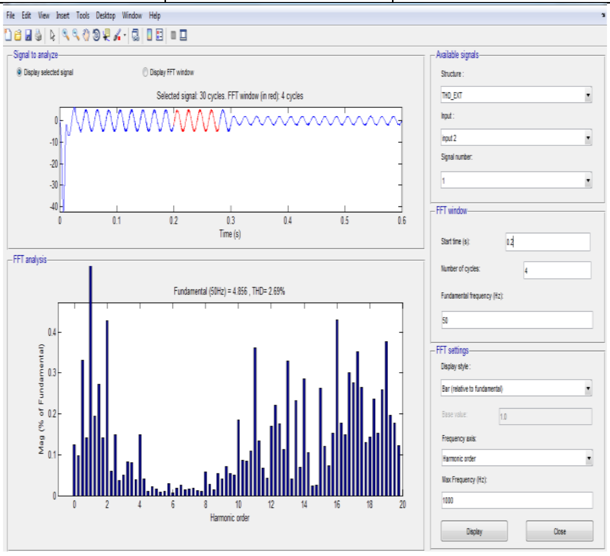
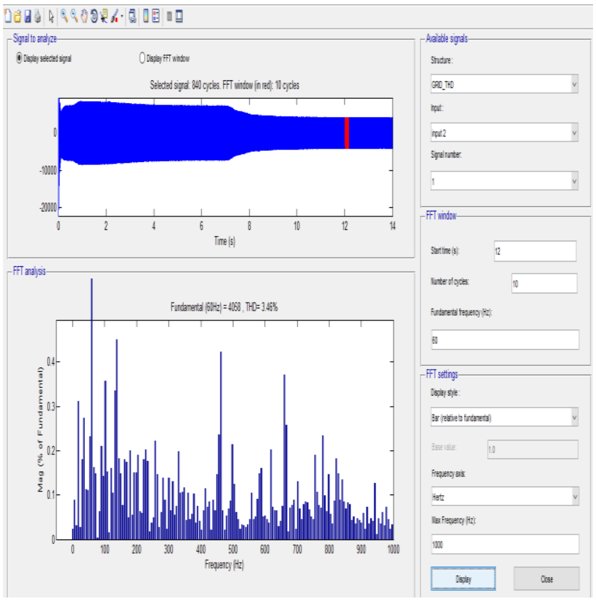


Figure 4.6: Output FFT analysis for FPC THD =2.69%



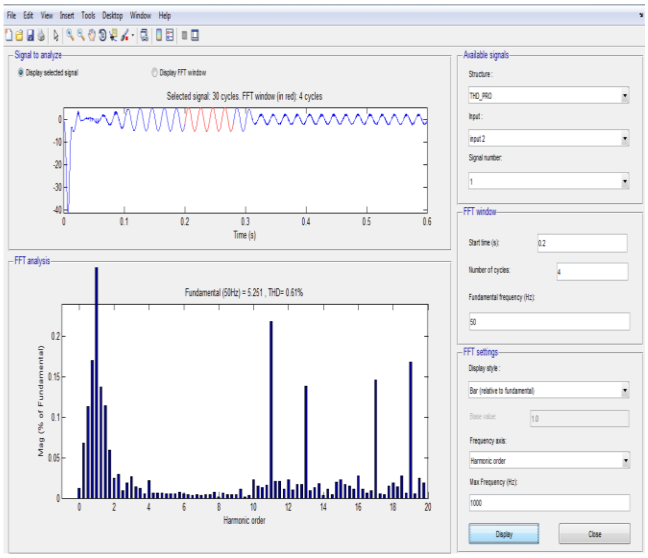


Figure 4.7: Output FFT analysis for PPC THD =0.61%

Fig.4.6 & 4.7 is the fast Fourier transform (FFT) analyzes to the current flowing in the gird for full power converter and partial power converter, in that Figure THD is 2.68% for FPC & 0.61% for PPC. The proposed method results efficiency & THD is greater than the existing method discussed in this paper.

V. CONCLUSION

A simple, high efficient dc/dc boost converter with MPPT control employing Peturb and Observe algorithm suitable for medium to large scale PV systems is proposed. High efficiency of the converter is achieved by means of partial power processing also by the coordinated operation of the converter with SRF structure control loop. Also overall efficiency of the plant was seen improved through the use of MPPT.

The reliability was seen improved through the design of the proposed converter. The proposed converter was simulated for testing of performance parameters including the efficiency, reliability, switching operation, MPPT performance and parallel operation. Simulation results show excellent performance and fulfillment of the work objectives. Finally, the THD of the overall system improves when compared to the existing full power converter (FPC) and also proposed system reaches higher conversion efficiencies compared with the FPC configuration.

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