Power Quality Compensation of Grid Integrated to Non-Linear Loads Using PV Based Active Power Filters

D. GOWTHAMI1, G. ARUN SEKHAR2
1PG Scholar, Dept of EEE, CREC, Tirupati, AP, India.
2Assistant Professor, Dept of EEE, CREC, Tirupati, AP, India.

Abstract: In this paper, a 3-phase 3-wire system, with a detailed PV system, dc/dc step-up converter to generate maximum power using maximum power point tracking technology, and dc/ac voltage source converter to works as an APF, is implemented. To show desirable characteristics, instantaneous power theory is used to propose the PV-APF topology. The photovoltaic (PV) generation has wide range applications as a distribution power generation systems and power controllable devices in power systems, while typical loads need good-power quality. Basically, one PV system providing power to nonlinear loads is required to be interlinked to operate as an active power filter (APF). The MATLAB/Simpower Systems tool has used to study performance characteristics that the system can parallel provides maximum power from a PV generator and regulates the harmonic current generated by nonlinear loads.

Keywords: 3-Phase, 3-Wire System, PV-APF, Simpower.

I. INTRODUCTION

Power supply has been critical issue in power system recently. The dc output voltage of PV arrays is interconnected to boost converter using a MPPT controller to maximize their produced energy. Then, converter is connected to a dc/ac VSC to let the PV system increase power to the ac system. The load of the PV cell can specially be a nonlinear load, such as PC’s, lamps, and many other home devices. In this case, PV systems must supply the utility with compensation ability. Therefore, the harmonic elimination can be realized by control of VSC. However, the PV-APF combination is getting implemented for several years. This combination is having ability of mitigating power factor, unbalanced currents, and harmonics, and also injection of the energy produced by PV with less total harmonic distortion (THD).

A. Objective

In this paper, a 3-phase 3-wire system, including a PV system, dc/dc boost converter to get maximum power using maximum power point tracking technique, and dc/ac voltage source converter (VSC) to act as an APF, is presented. The instantaneous power study is applied to model the PV-APF controller. The grid-integrated photovoltaic (PV) system has nowadays become more familiar because of its reliable operation and its capability to generate power from renewable energy resources. The output dc voltage of PV cells is connected to a dc/dc boost chopper using a maximum power point tracking (MPPT) controller to increase their generated power. Then, that converter is interlinked to a dc/ac voltage source converter (VSC) to let the PV device increase energy supply to the ac utility.

B. Photovoltaic (PV) and Power Quality

The inverter is the main part of the PV system and is the aim of all utility-integration codes and benchmarks. A Solar inverter or PV inverter is a type of electrical inverter that is made to change the direct current (DC) electricity from a photovoltaic array into alternating current (AC) for use with home appliances and possibly a utility grid. Since the PV system is a dc energy source, an inverter is must require to convert the dc energy to ac supply that is used very frequently in domestic applications. To conserve power while they run only when the daylight conditions and should be located in cool locations away from direct sunlight. Of particular concern to utility engineers is how much current a generator can deliver during a fault on their system.

II. ACTIVE POWER FILTER (APF)

A. Voltage Source Active Power Filter

Generally, the voltage-source is considered over the current-source to develop the shunt active power filter because it has some advantages.
The filter supplies currents in the PCC in order to: 1- remove/mitigate the harmonic component in the AC system, 2- Correction of the power factor at fundamental frequency, 3- To control voltage magnitude, and 4- balance loads.

Fig.2. Voltage Control of the Active Power Filter

Fig.3. Current Control of the Active Power Filter

III. CONTROLLERS

A. P-I Controller

P-I controller is especially used to remove the steady state error ensuing from P controller. However, in terms of the speed of the response and overall stability of the system, it's a negative impact. This controller is usually utilized in conditions where speed of the system isn’t a problem.

Fig.4. P-I Controller

Since P-I controller has no ability to predict the long run errors of the system it cannot decrease the increase time and eliminate the oscillations. If applied, any quantity of I gives set point overshoot value.

\[ u(t) = MV(t) = k_p e(t) + k_i \int_0^t e(\tau) d\tau + k_d \frac{de(t)}{dt} \]  \hspace{1cm} (1)

Fig.5. Plot of PV vs Time, for 3 Values of \( K_p \) (\( K_i \) and \( K_d \) as Constant)

B. Fuzzy Logic Controller

In FLC, basic control performance is decided by a set of linguistic rules. These rules are obtained by the system. Since the mathematical terms are converted into linguistic variables, dynamic modeling of the system doesn’t needed in FC. The FLC contains of 3 parts: fuzzification, interference engine and defuzzification. The FC is classified as

Fig.6. Fuzzy Logic Controller

Fig.7. Membership Functions
C. The Membership Function Editor

The Membership function Editor gives some options to the FIS Editor. In fact, all of the 5 basic GUI tools have same menu choices, status lines, and facilitate and close buttons. The Membership function Editor is the window that subjects you to display and edit the membership functions similar to all of the input and output variables for the whole fuzzy inference system. Fig 7 shows the Membership function Editor. You’ll first use the cursor to pick out a specific membership function related to a particular variable quality, and then collect the membership function. This will have an effect on the mathematical description of the standard related to that membership function for a required variable.

Fig.8. The Updated Membership Function Editor

Now that the variables are named, and therefore the membership functions have acceptable shapes and names, you are able to write down the principles. To call up the Rule Editor, move to the view menu and select Edit.

IV. MODELING PV-APF

A. Introduction

The elaborated PV-APF configuration is shown in Fig 8. The description of the proposed system will be explained in the following section.

Fig.9. Proposed PV-APF Combination System

B. Dynamic Modeling of PV Array

The PV array designed with N strings of modules connected in parallel and every string has M number of modules connected in series to obtain a suitable power rating. The equivalent circuit of PV cell is described.

Fig.10. Equivalent Electrical Circuit of the PV Cell

Fig.11. Controller Mechanism of the Boost Converter

Fig.12. Instantaneous Power Flows among the PV-APF System

The dc/dc step-up converter regulates its semiconductor switches to get the maximum power delivered by PV array (P_{PV}). The MPPT strategies could be selected nearly in any specific circumstance. Beyond that converter with the power output p DC, the dc/ac VSC keeps a significant role in implementing a given control duty. At the dc side, the power concept is consistent. However, at the ac side, the instantaneous power includes both the active part (p VSC) and the imaginary part (q VSC) [8]. The losses at the dc/dc boost converter and the dc/ac VSC are ignored.
D. Controllers for Dc/Ac Converter

In this section, the controllers for dc/ac VSC depends on instantaneous power theory and instantaneous power balance are presented. In a conventional way, the dq-current controller is used to inject maximum real power from PV and zero reactive power to keep unity power factor of the utility. While a nonlinear load is connected close to PV position, the proposed unique PV-APF controller should be utilized to mitigate the harmonics and help transfer the PV power. At night (no irradiance and no battery) or when there is no PV array, the APF controller is switched into the system in order to operate the CVSC capacitor just for an APF purpose.

1. PV-APF Controller

The dc/ac VSC interconnected by an APF operation must supply the harmonic mitigate and reactive power compensation and simultaneously inject the maximum power generated by PV units. The controller is established based on the instantaneous power theory, where all the parameters are processed instantaneously. The input signals of that controller include utility voltages (v abc), nonlinear load currents (i abcL), output currents of dc/ac VSC (iabc VSC), utility injected currents (iabcUti), and dc-link voltage VVSC (to prevent overcharge dc-link capacitor). Instantaneous power balance at the dc/ac VSC-utility-load connection point makes (regardless of utility flow direction).

![Fig.13. Controller Topology of dc/ac VSC in the PV-APF Combination](image)

V. SIMULATION RESULTS

A. MATLAB Model with PI Controller

![Fig.14. MATLAB Model of Proposed System](image)

![Fig.15. MATLAB Model for Control Diagram](image)

![Fig.16. Output Power of PV During Running Time with PI Controller](image)

![Fig.17. V_pv and Duty Cycle Changed by MPPT](image)
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Fig. 18. Utility Supplied Current Waveform with PI Controller

Fig. 19. Supplied Current of Utility and PCC Voltage Under PI Controller

Fig. 20. Supplied Current of PV with PI Controller

Fig. 21. Real Power from the (a) Grid, (b) PV Cell, and (c) Load, While the Grid Provides Power under PI Controller

Fig. 22. Current Subjected to Grid with PI Controller

Fig. 23. Real Power by the Grid, PV Cell, and Load, When the Grid Receives Power under PI Controller

Fig. 24. Output Power of PV During Running Time with FLC

Fig. 25. Current by Grid Utility with FLC
VI. CONCLUSION

Regarding the multi-operational DG topology, in this project, grid-connected PV system is designed and the PV-APF network with a linear strategy is proposed. The controller provides two requirements, which are supplying power from the PV system and reducing the harmonics of the local nonlinear load. The MATLAB/ Sim power Systems simulation shows good performances of this controller. The positive influence of MPPT on maximizing PV power output is also validated. The switching among three controllers to dc/ac VSC brings different current waveforms. As a result, the conventional dq-current controller should not be applied when PV is connected to a local nonlinear load regarding power-quality viewpoint.

VII. REFERENCES


Author’s Profile

D. Gowthami Received B.Tech Degree In Electrical & Electronics Engineering from Vaishnavi Institute of Technology for Women. Currently pursuing M. Tech (Power Electronics)from Chadalawada Ramanamma Engineering College, Tirupati, A.P, INDIA.

G. Arun Sekhar Received B.Tech Degree In Electrical & Electronics Engineering from Chadalawada Ramanamma Engineering College, Tirupati. M. Tech degree from Sri Venkatesa Perumal College of Engineering & Technology, Puttur. Working as Assistant Professor in the Department of Electrical & Electronics Engineering, Chadalawada Ramanamma Engineering College, Tirupati, A.P, INDIA.