

Analysis, Design and Control of Solar Photo-Voltaic Energy Integration for a Smart Grid Distribution System

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CERTIFICATE

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ABSTRACT

To overcome energy crisis and global warming, the SPV (Solar Photovoltaic) systems have attracted significant attention in recent years. Besides being emission-free, the energy coming from the SPV energy is available in abundance in the nature. In addition, it offers a solution for power supply in remote areas which are not accessible by the utility grid, and in the countries that lack in fossil-based resources.

In addition, the solar PV energy is not available almost two third period of the day in a typical SPV generating system and its power converter is not utilized when there is no solar PV energy and normally it is switched off in order to reduce its losses. This leads to poor utilization of the power converters involved in the grid interfaced SPV system.

Therefore, in order to utilize the power converters for whole day, these power converters may be used as active shunt compensators at PCC (Point of Common Coupling) in the distribution system. Moreover, many single-phase distributed nonlinear loads and other modern electrical products in three-phase three-wire and three-phase four-wire distribution systems are widely used in residential and office buildings at PCC. These nonlinear loads result in poor PQ (Power Quality) in terms of poor power factor, load unbalancing, harmonics and excessive neutral current at AC mains. In view of these PQ issues of connected nonlinear loads at PCC, these power converters of SPV generating systems are used for additional functions of reactive power compensation, load balancing, harmonics elimination and neutral current mitigation for power factor correction at AC mains resulting in reduction in losses and improved utilization of distribution systems. In addition, it may offset part of the cost of SPV generating systems.

The proposed grid interfaced SPV generating system consists of SPV array with DC-DC boost converter to track MPP (Maximum Power Point) and a three-leg or four-leg VSC (Voltage

Source Converter) to feed DC power to AC grid. The output power of PV array with MPPT is fed to the DC-DC boost converter in order to boost the output voltage of the PV array and to feed the active power to DC link of VSC. The VSC is used for DC-AC conversion and it also provides the functions of an active shunt compensator at PCC in the distribution system.

When the solar intensity is reduced to zero, the VSC (Voltage Source Converter) can still be utilized for power quality improvement. At full sun, the grid interfaced SPV system under consideration can supply the load and simultaneously solves the problems of harmonics, unbalanced loads and reactive power in a 3-phase, 3-wire and neutral current in 4-wire distribution systems. Moreover, the load leveling may be achieved as per the requirement of the peak load period and lean load period, with the battery energy storage through charging and discharging of the electric vehicle (EV) and plug-in hybrid electric vehicle (PHEV) which have a new feature in smart grid distribution system along with grid interfaced solar PV array. With the energy transfer from the grid to electric vehicle and electric vehicle to grid, the concept of smart grid may be visualized. One can transfer energy from PHEV to the grid when it is parked in peak hours and can take energy back from the grid in lean hours.

Existing SPV power generating systems are suffering with key technical challenges which effect quality of power. These are voltage fluctuations, harmonics, reactive power, electromagnetic interference, switching, synchronization, low power factor, storage system and load management. Along with these problems, the optimum use of the SPV power generating system may be achieved for load leveling, and to improve the performance of the grid in terms of efficiency, active power control, tracking of variable renewable energy sources, load balancing and current harmonics filtering. These are the key challenges to act upon in order to optimal use of grid interfaced solar PV array system.

In this thesis, the analysis, design, control and implementation of various three phase configurations of the SPV power generating system are carried out for power quality improvement in three-phase three-wire and three-phase four-wire distribution systems with load compensation and without load compensation. The other major emphasis of the investigation has been on novel control algorithms and an efficient operation. Based on these considerations, a wide range of control algorithms with electric vehicle integration to the grid for SPV power generating systems are analyzed, designed, modelled and their performance is evaluated in detail. The V2G technology may offer improve the performance of the traditional electricity grid in areas such as efficiency, stability, and reliability. A V2G-capable Electric vehicle/plug-in hybrid electric (PHEV) offers reactive power compensation, active power regulation, tracking of variable renewable energy sources, load balancing, and current harmonic filtering. Various control algorithms and configurations have been developed for validation of the simulated performance of SPV power generating system.

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LIST OF SYMBOLS

V_{dc}	DC link voltage of the VSC
m	Modulation Index
v_{LL}	Line to Line Grid voltage
L_b	Boost Inductor
D	Duty cycle of DC-DC boost Converter
Δi_1	Boost converter input current ripple
f_{sw}	Switching frequency of DC-DC Boost converter
f_s	Switching frequency of Voltage source converter
h	Over loading factor
C_{dc}	DC link capacitor of VSC
L_f	Interfacing Inductor
I_d	DC link current of VSC
ω	Angular frequency
v_{drip}	% ripple voltage of V_{dc}
R_f	Ripple filter resistance
C_f	Ripple filter capacitance
i_{sg}	Grid current with Electrical Vehicle

C_{dg}	single phase VSC DC link used for vehicle
L_o	bi-directional DC-DC converter inductor
V_b	Battery voltage
I_b	Battery Current
C_{bb}	Battery Capacitance
R_b	battery shunt resistance
V_{oc}	Open circuit voltage
R_s	Battery Series Resistance
L_{sg}	Source inductance of EV assembly