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Power Quality Inverter on Photovoltaic SEPIC Converter

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ABSTRACT

The photovoltaic (PV) generation is increasingly popular nowadays, while typical loads require more high-power quality. Basically, one PV generator supplying to nonlinear loads is desired to be integrated with a function as an active power later (APF). In this paper, a three-phase three-wire system, including a detailed PV generator, dc/dc boost converter to extract maximum radiation power using maximum power point tracking, and dc/ac voltage source converter to act as an APF, is presented. The instantaneous power theory is applied to design the PV-APF controller, which shows reliable performances. The MATLAB/Simpower Systems tool has proved that the combined system can simultaneously inject maximum power from a PV unit and compensate the harmonic current drawn by nonlinear loads.

KEYWORDS: *Photovoltaic, Sepic converter, power quality, Inverter.*

I. INTRODUCTION

Power supply and power quality have been critical issues in power system recently. The grid-connected photovoltaic (PV) generator has nowadays become more popular because of its reliable performance and its ability to generate power from clean energy resources [1]_[3]. The dc output voltage of PV arrays is connected to a dc/dc boost converter using a maximum power point tracking (MPPT) controller to maximize their produced energy [5]. Then, that converter is linked to a dc/ac voltage source converter (VSC) to let the PV system push electric power to the ac utility.
The local load of the PV system can especially be a nonlinear load, such as computers, compact fluorescent lamps, and many other home appliances, that requires distorted currents [4]. Development of a means to compensate the distribution system harmonics is equally urgent. In this case, PV generators should provide the utility with distorted compensation capability, which makes currents injected/absorbed by the utility to be sinusoidal [7]. Therefore, the harmonic compensation function can be realized through flexible control of dc/ac VSC.

Instantaneous power theory has successfully completed active power filter (APF) designing with good performance [8]. However, the PV-APF combination has just been gradually developed for several years [9]. This combination is capable of simultaneously compensating power factor, current imbalance, and current harmonics, and also of injecting the energy generated by PV with low total harmonic distortion (THD). Even when there is no energy available from PV, the combination can still operate to enhance the power quality of the utility. To the best of our knowledge, this idea was initiated in 1996 by Kim *et al.* [10]. In this study, the PV system needs energy storage elements, which negatively increase the entire cost. Besides, the mathematical demonstration was not sufficiently provided. After that, the control techniques have been improved in some later efforts to develop PV inverters with real power injection and APF features [11]_[16]. However, their research did not show consistent results obtained by their proposed theories, and they are applicable for a single-phase PV only. The most recent completely released paper in 2013 [17] uses current references as the main functions of the dc/ac controller, which coincides with the basic ideas of this paper. By another manner in this paper, the proposed PV-APF controller utilizing power references shows some significant improvements in theory and a simple control topology. The PV-APF system helps the utility supply a unity power factor and pure sinusoidal currents to the local nonlinear loads by generating the oscillating and imaginary components. When there is an excess power, that PV unit will only inject average power to the utility. As a result, this system can be considered as a distributed APF, which is a better solution than adopting passive filters or centralized APFs [18]. The main contributions of this paper are threefold.

1) For the first time, a fully complete PV-APF combination system is presented.

2) The controller based on instantaneous power theory and instantaneous power balance is proposed to replace the conventional *dq*-current controller for a PV unit.

3) Flexible operation modes of the PV-APF combination system are possible in the proposed model.

II. Related Work

2.1 PV-APF Combination System

The detailed PV-APF configuration is shown in Fig. 1, which consists of the following.

1) The PV 5series-66parallel array, which is SunPowerSPR-305-type, delivers a maximum of 100-[kW]power at 1000-W/m2 solar irradiance, assuming that there is no battery storage system connected to the dc bus.

2) A 5-kHz boost dc/dc converter implements MPPT by an incremental conductance integral regulator technique, which automatically varies the duty cycle in order to generate the required voltage to extract maximum power.

3) The dc bus is connected to a two-level three-phase dc/ac VSC with a CVSC capacitor. The dc/ac VSC converts the 500 [V] dc to 260 [V]/60 [Hz] ac supplying to local nonlinear loads and connects to a stiff utility. The *dq*-current and PV-APF and APF controllers are applied for this dc/ac VSC subsequently.

4) A 10-kVAr capacitor bank filters out switching harmonics produced by the dc/ac VSC.

5) The loads include a three-phase diode rectifier supplying a current of 450 or 50 [A] at dc side and one phase diode rectifier with 50-[A] dc current connecting

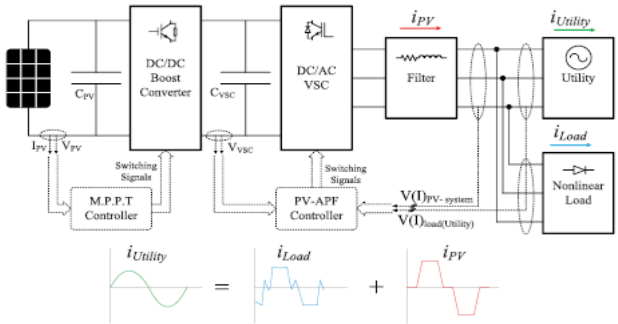

Figure 1. Proposed design of PV-APF combination.

between phase A and phase B to make an overall unbalanced load.

6) This PV-APF combination system is connected directly to the utility for shunt active later implementation

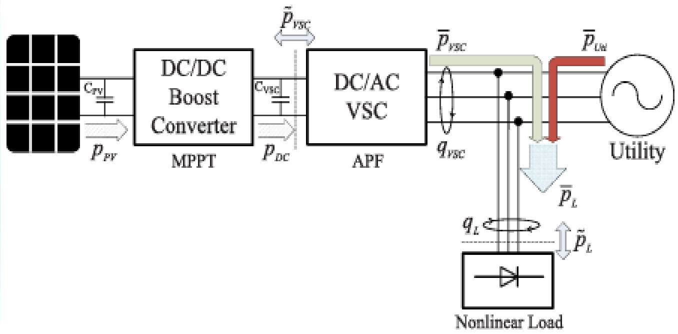

Figure 2. Instantaneous power flows among the PV-APF

III. Implementation

3.1 Controllers for DC/AC Converter

In this section, the controllers for dc/ac VSC based 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 used to compensate 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.

A. PV-APF Controller

The dc/ac VSC integrated by an APF function should provide the harmonic elimination 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. Furthermore, the dc-link voltage regulation passes through a PI-controller via the LPF, which filters out the switching harmonics existing in the dc capacitor voltage. Eventually, reference powers are passed to a current references calculation block. These ideas make the following equations. The complete algorithm of a controller for three-phase three-wire dc/ac VSC that compensates oscillating real power and oscillating imaginary power, and supplies real power of load. The hysteresis control technique is used to switch insulated-gate bipolar transistor gates.

B. APF Controller

This section reminds the topology of well-known APF controllers based on instantaneous power theory. The utility currents are not measured by this controller. Only the load currents and the output currents of the APF are measured. The greatest difference of this controller compared with the PV-APF controller is the calculated reference values generated from C VSC, which are oscillating powers. In this case, the utility must supply the constant dc-link voltage regulation.

IV. EXPERIMENTAL WORK

The system is simulated in MATLAB/Sim power Systems to test the PV-APF unit, which connects directly to the ac-utility, and to validate its ability to Filter out the harmonic of nonlinear loads.

A. Simulation Circuit

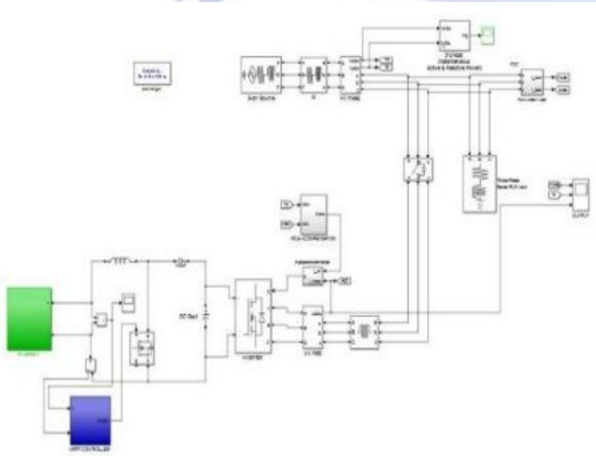

Fig 5 Simulation Circuit

The APF controller mode requires only CVSC for the APF purpose when the PV unit generates zero power. In short, there are four modes of running simulation, as clarified.

B. Simulation Output

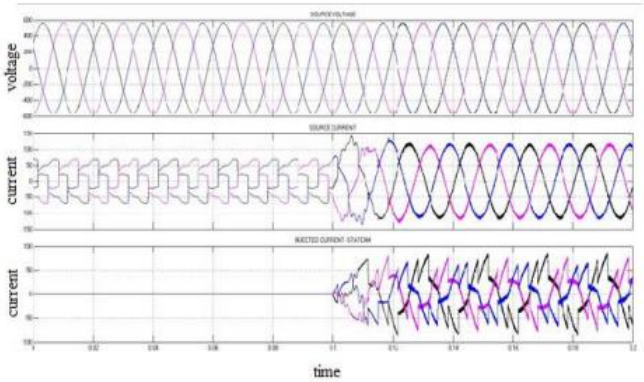

Fig 6. Simulation Output

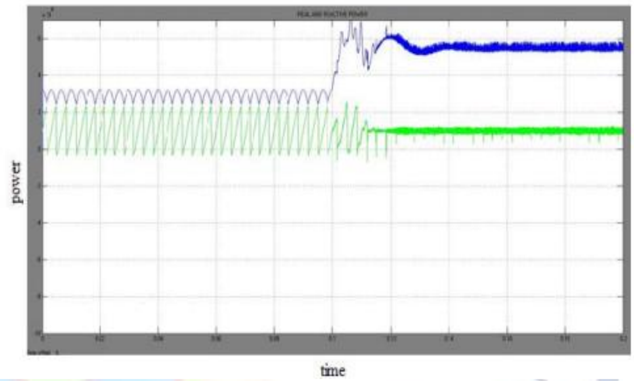

Fig 7. Real power and reactive power.

Fig 8. Hardware module

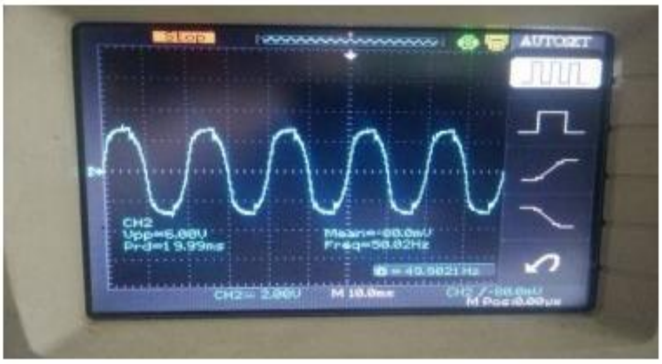

Fig9. CRO output

V. Conclusion

Regarding the multifunctional DG concept, in this paper, a dynamic grid-connected PV unit is built and the PV-APF combination system with a local controller is proposed. The controller implements two purposes, which are supplying power from the PV unit and filtering the harmonics of the local nonlinear load. The new controller based on instantaneous power balance has been explained accordingly. The MATLAB/Simpower 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 view point. Preferably, the PV-APF controller compensates the utility currents successfully. While a PV unit is deactivated, the APF function can still operate. It is, therefore, technically feasible for these power electronics-interfaced DG units to actively regulate the power quality of the distribution system as an ancillary service, which will certainly make those DG units more competitive.

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