ANALYSIS OF SINGLE-PHASE INVERTERS WITH DIFFERENT POWER QUALITY CONTROL STRATEGIES FOR DISTRIBUTION POWER GENERATION SYSTEMS

Original Research Article

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ABSTRACT

This paper deals with the analysis of single-phase inverter for DG systems requiring for power quality features, such as harmonic and reactive power compensation for grid-connected operation. Power electronic converters are commonly used for interfacing distributed generation (DG) systems to the electrical power network. The idea is to integrate the different DG unit functions with shunt active power filter capabilities. With this approach, the inverter controls the active power flow from the renewable energy source to the grid and also performs the nonlinear load current harmonic compensation by keeping the grid current almost sinusoidal. The control scheme employs a current reference generator based on sinusoidal signal integrator and instantaneous reactive power (IRP) theory together with a dedicated repetitive current controller.

Keywords :

Power quality,
Active power,
Reactive power,
Distribution generation,
Power electronic converters.

I. INTRODUCTION

Due to the high price of oil and the concern for the environment, renewable energy is in the limelight. This scenario has stimulated the development of alternative power sources such as photovoltaic panels, wind turbines and fuel cells [1,2]. The distributed generation (DG) concept emerged as a way to integrate different power plants, increasing the DG owner's reliability, reducing emissions, and providing additional power quality benefits [3,4]. The cost of the distribution power generation system using the renewable energies is on a falling trend and is expected to fall further as demand and production increase [5].

The energy sources used in DG systems usually have different output characteristics, and for this reason, power electronic converters are employed to connect these energy sources to the grid, as shown in Fig. 1. The power electronic front-end converter is an inverter whose dc link is fed by an AC/dc converter or by a dc/dc converter, according to with the DG source type [6]. The commercial front-end inverters are designed to operate either as grid-connected or in island mode. In grid-connected mode, the voltage at the point of common coupling (PCC) is imposed by the grid; thus, the inverter must be current-controlled [7].

When operated in island mode, the inverters are voltage-controlled, generating the output voltage at a specified amplitude and frequency.

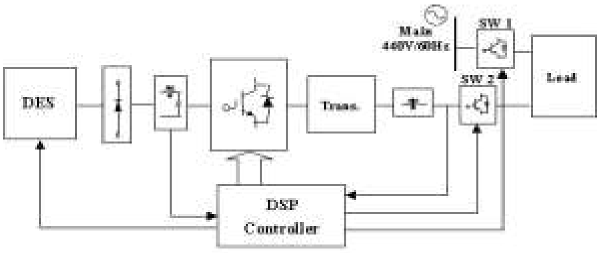

Fig.1. General Scheme of a DG unit connected to the grid.

Coming to the grid-connected mode, almost all the commercial single-phase inverters for DG systems inject only active power to the grid, i.e., the reference current is computed from the reference active power p^*that must be generated [1,8]. It is possible and can be convenient to integrate power quality functions by compensating the reactive power and the current harmonics drawn by specific local nonlinear loads [9]. The single-phase inverter can acquire active filtering features just adding to its control software some dedicated blocks that are specific to shunt active power filter (APF).

This paper proposes and validates an enhanced power quality control strategy for single-phase inverters used in DG systems. The idea is to integrate the DG unit functions with shunt APF capabilities. With the proposed approach, the inverter controls the active power flow from the energy source to the grid and also performs the compensation of reactive power and the nonlinear load current harmonics, keeping the grid current almost sinusoidal.

II. MODELING AND CONTROL OF INVERTER INTERFACED DG UNITS

Basically, each DG unit may have DC type or rectified generation unit (Fuel cell, solar cell, wind turbine, microturbine…), storage devices, DC-DC converter, DC-AC inverter, filter, and transformer for connecting to loads or utility in order to exchange power. Model and dynamic of each of this part may have influence in system operation. But here for simplification, it is considered that DC side of the units has sufficient storage and considered as a constant DC source. Hence only DC-AC inverter modeling and control investigated in this paper.

A circuit model of a three-phase DC to AC inverter with LC output filter is further described in Fig. 2, the system consists of a DC voltage source (V_{dc}), a three- phase PWM inverter, an output filter (L_f and C with considering the parasitic resistance of filter- R_f). Sometimes a transformer may be used for stepping up the output voltage and hence L_f can be transformer inductance.

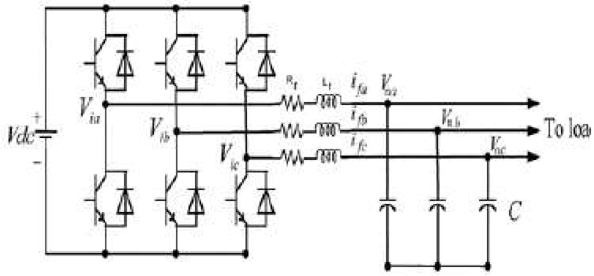

Fig. 2 PWM inverter diagram

There are two ways for controlling an inverter in a distributed generation system.

A. PQ Inverter Control

This type of control is adopted when the DG unit system is connected to an external grid or to an island of loads and more generators. In this situation, the variables controlled by the inverter are the active and reactive power injected into the grid, which has to follow the set points P_{ref} and Q_{ref}, respectively. These set points can be chosen by the customer or by a central controller. The PQ control of an inverter can be performed using a current control technique in qd reference frame which the inverter current is controlled in amplitude and phase to meet the desired set-points of active and reactive power [10].

With the aim of Park transform and equations between inverter input and output, the inverter controller block diagram for supplying reference value of P_{ref} and Q_{ref} is as Fig. 3 For the current controller, two Proportional-Integral (PI) regulators have been chosen in order to meet the requirements of stability of the system and to make the steady state error be zero. With this control scheme, it is possible to control the inverter in such way that injects reference value of P_{ref}, Q_{ref} into another part of the stand-alone network. When the output voltage is needed to be regulated, the PV control scheme that is similar to PQ mode with feedback of voltage used to adjust Q_{ref}.

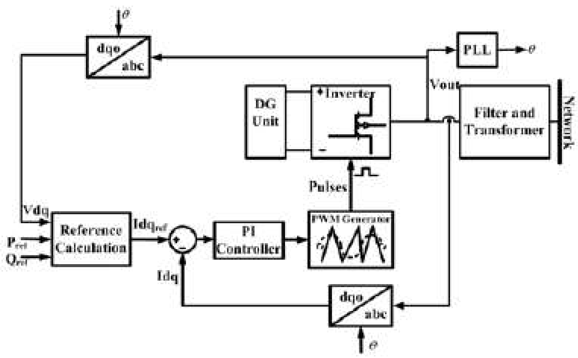

Fig. 3 PQ control scheme of inverter

B. V/f Inverter Control

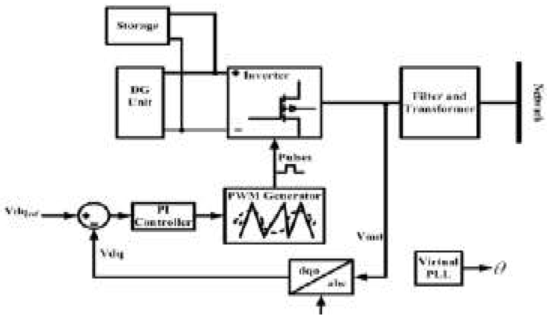

Fig. 4 V/f control scheme of inverter

This controller has to act on the inverter whenever the system is in the stand-alone mode of operation. In fact, in this case, it must regulate the voltage value at a reference bus bar and the frequency of the whole grid. Regulators work in order to keep the measured voltages upon the set points. Moreover, the frequency is imposed through the modulating signals of the inverter PWM control by mean of an oscillator [11,12]. A simple PI controller can regulate bus voltage in reference value with getting feedback of real bus voltage. Fig. 4 outlines this control strategy. In this case, it is obvious that the DG unit should have a storage device in order to regulate the power and voltage.

III. INVERTER CONTROL SCHEME

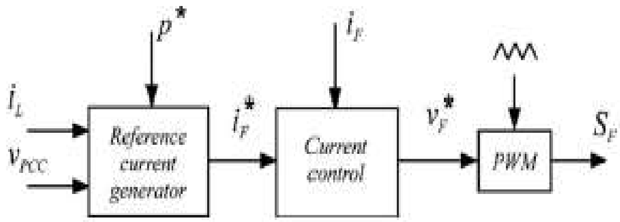

Fig. 5 Inverter control scheme

The block diagram of the single-phase inverter control scheme with enhanced power quality features is shown in Fig. 5. The inverter reference current i_F^* is generated by the reference current generator block and the current control is based on a repetitive controller.

A. Reference Current Generator:

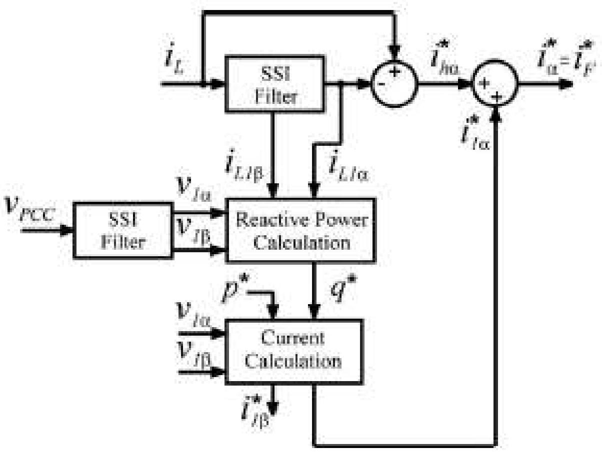

Fig. 6 Reference current generation scheme.

The reference current generation scheme is shown in Fig. 6 and can be divided into two parts: the computation of the harmonic current reference $i_{h\alpha}^*$ and the generation of the fundamental reference current $i_{1\alpha}^*$ corresponding to the active and the reactive power to be generated.

B. Current Control:

For inverters that generate active power and also compensate the reactive power, the reference current is sinusoidal at the fundamental frequency, so the use of conventional PI controllers would probably suffice if their bandwidth is high enough. If the inverter must also compensate the current harmonics, the reference current will become non-sinusoidal.

In this case, achieving zero –steady-state error is not possible with PI controllers unless particular control schemes are employed.

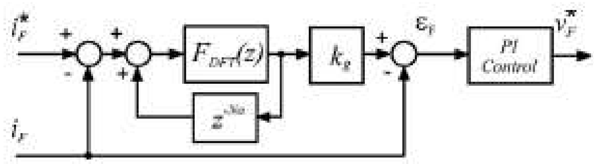

Fig.7. Current control scheme.

The adopted current control scheme is shown in Fig. 7 and is based on a repetitive controller along with a conventional PI regulator in order to achieve zero steady-state error when the reference current has a high harmonic content. This scheme has been originally proposed for shunt APFs, and for this reason, it is also suitable for inverters used for active power generation and having power quality features.

IV. SIMULATION RESULTS AND DISCUSSION

In order to understand the performance of the Single Phase Inverters along with Power Quality Control Strategies, a simple distribution network as shown in Fig.8 is implemented. There are different analyses conditions like normal operation, injection of the load for measuring the active and reactive power are considered and designed using MATLAB/SIMULINK software for validation of the proposed control strategies as shown in the output voltage waveforms are shown in Fig. 9 to Fig. 19 with different load conditions.

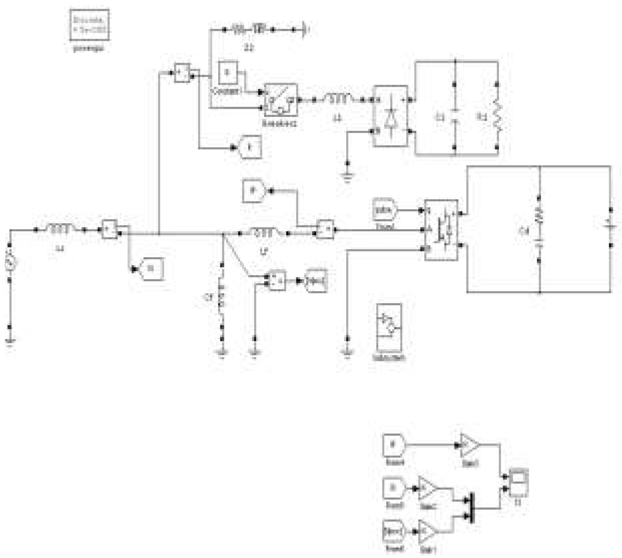

Fig. 8 MATLAB/Simulink Model

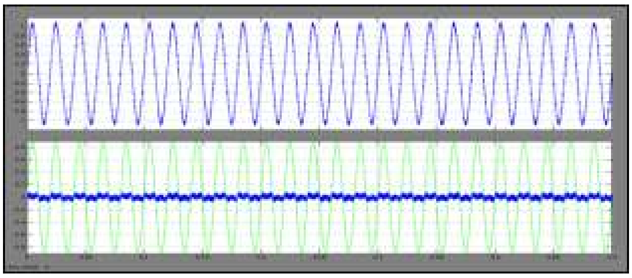

Fig.9 Steady-state operation of the inverter injecting the active power requested by the resistive load (2 kW).

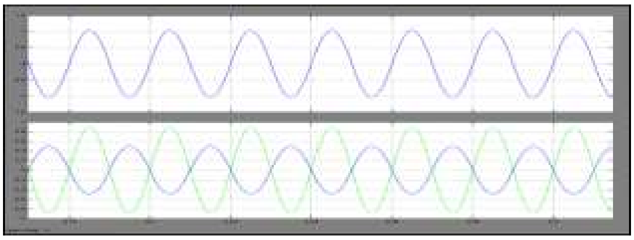

Fig. 10 Steady-state operation for 3 kW active power generation. Only the 2 kW linear load is connected in this case.

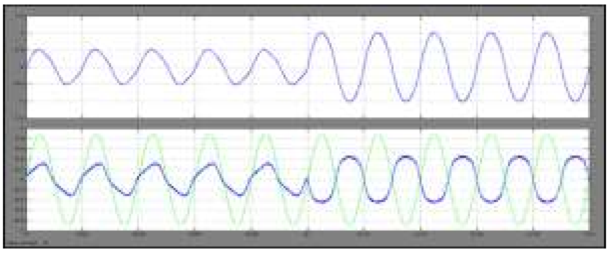

Fig. 11 Inverter transient response during a step-up of the injected active power (1–3 kW). Only the 2 kW linear load is connected.

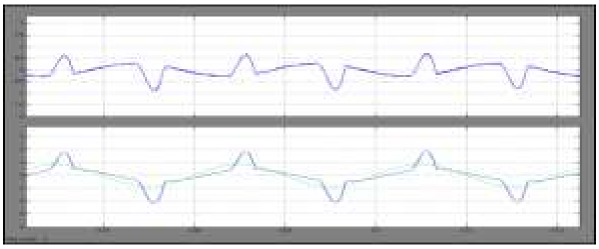

Fig. 12 Steady-state operation of the inverter injecting 1 kW active power and compensating the current harmonics of the local load.

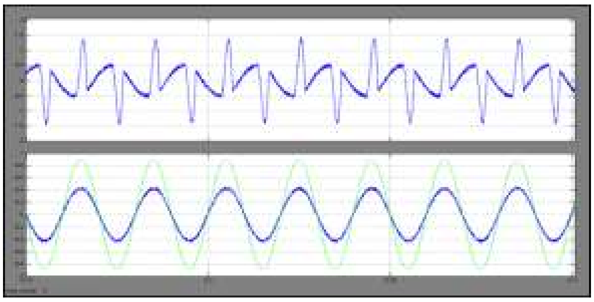

Fig. 13 Steady-state operation of the inverter injecting 1 kW active power and compensating the current harmonics of the local load.

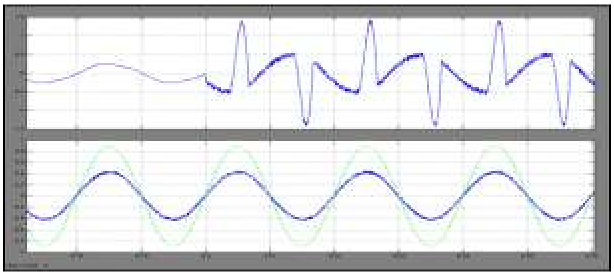

Fig. 14 Inverter transient response during nonlinear load turn-on

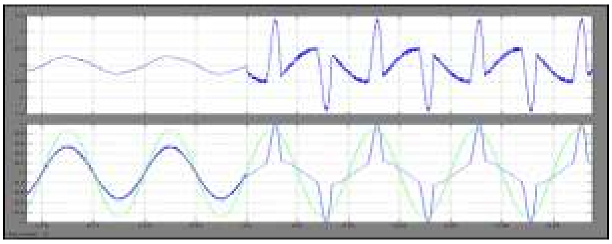

Fig. 15 Inverter transient response for nonlinear load turn-on.

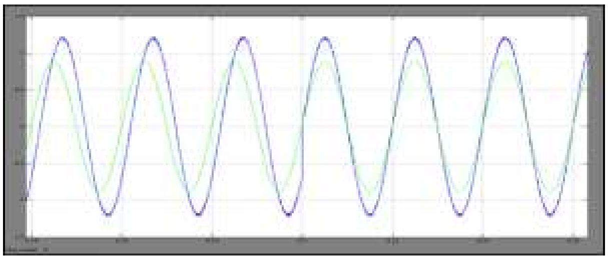

Fig. 16 Steady-state linear resistive–inductive load operation

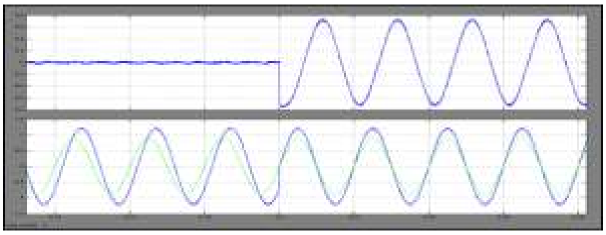

Fig.17 Inverter transient response when only the reactive power compensation is enabled and the load is resistive–inductive

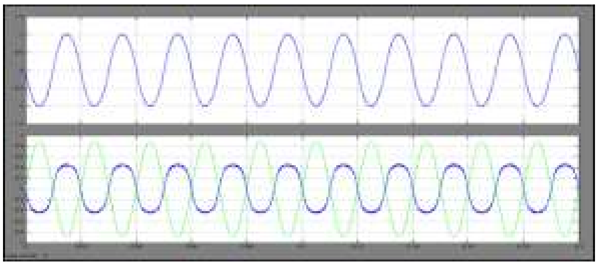

Fig.18 Steady-state operation for 3 kW active power generation with reactive power compensation

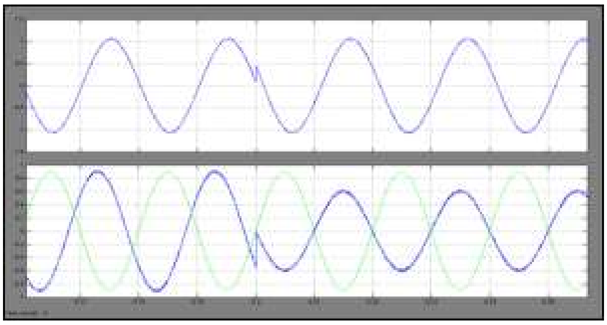

Fig.19 Inverter transient response for step reactive power compensation when the injected active power is 3 kW.

V. CONCLUSION

This paper deals with a single-phase H-bridge inverter for DG systems, requiring power quality features as harmonic and reactive power compensation for grid-connected operation. The proposed control scheme employs a current reference generator based on SSI and IRP theory, together with a dedicated repetitive current controller. The grid-connected single-phase H-bridge inverter injects active power into the grid and is able to compensate the local load reactive power and also the local load current harmonics. The integration of power quality features has the drawback that the inverter will also deliver the harmonic compensation current with the direct consequence of increase the inverter overall current and cost. A current limitation strategy should be implemented and if the inverter output current exceeds the switch rating, then the supplied harmonic current must be reduced. In this way, the inverter available current is mainly used for active power injection and if there is some current margin, this can be used for the compensation of reactive power and nonlinear load current harmonics.

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