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Improved Performance of Photovoltaic Inverters Utilizing in VAR Mode

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ABSTRACT

Although the number of PV installations is rapidly growing, the effective utilization of PV inverters remains low. On average, most of today's grid-tie PV inverters operate an average of 6-8 hours per day. In order to increase the utilization of grid-tie PV inverters, they can be operated in reactive power compensation mode when PV power is unavailable. While injecting reactive power into the grid can be easily realized by applying the appropriate phase shift between current reference and grid voltage, the task gets more complex when PV power is not available since the inverter needs to draw power from the grid, regulate the DC bus, and inject the desired level of reactive power. This paper will provide a detailed analysis of PV inverters' operation in VAR compensation mode when active power is not available. A new control scheme is proposed that enables inverter to absorb little active power from grid, regulate its DC bus voltage within limits, and inject the desired level of reactive power. Simulation and experimental results are provided to validate the analysis.

Keywords: *PV Inverters, VAR Mode, Compensators, Solar sources.*

I. INTRODUCTION

Grid-tie inverters are at the heart of today's renewable energy conversion systems. These inverters convert the energy harnessed from the various renewable energy sources, such as wind, sun, into a grid quality AC power that can be fed into the utility grid. These inverters inject power into the grid as long as the renewable sources are active (i.e. if sun is out and wind is blowing). However, if the renewable sources are not available, such as during night hours in the case of PV systems, inverters will remain idle. This reduces the effective utilization of these inverters. One way to increase the effective utilization of these inverters is to operate them as VAR compensators to generate reactive power whenever the renewable sources are not available. As the number of grid-tied inverters increases, their usage as VAR compensators will help in grid voltage regulation and reduce the need of expensive capacity banks. Employing inverters to operate as active filters and compensate for reactive power is not a new concept [1],[2],[3].

However, these special designed active filter inverters are not suitable for grid-tie applications. It will be interesting to enable existing grid-tied inverters to operate in reactive power generation mode in the absence of active input power, which usually powers the control circuitry, compensates for the inverter losses, and maintains a regulated DC bus voltage. In general, reactive power compensation can be accomplished by applying appropriate phase shift between the reference current and grid voltage [4]. When active power is not available, the challenge is how to pre-charge the DC bus and keep it regulated within limits while injecting the desired level of reactive power into the grid. If the inverter is to merely operate in reactive power mode, it needs to compensate for its internal losses and keep its DC bus voltage within an acceptable range. Although a number of papers discuss the design of PV inverters and reference operation in VAR mode during night hours [5, 6, 7, 8], none of the aforementioned issues have been addressed or discussed.

This paper will provide a novel control strategy that enables PV inverters to absorb little active power from the grid when the renewable source (e.g. sun) is not available to compensate for the inverters" internal losses, regulate the DC bus voltage to keep it within limits, and operate the inverters in VAR mode. This eventually extends the

utilization of PV inverters beyond active power generation and helps improving grid stability and voltage regulation. Detailed design procedure is provided and will be validated by simulation and experimental results.

II. ANALYSIS

Typically, grid-tie inverters are preceded with a DC/DC stage that regulates the DC bus voltage of the inverter; however when active power is not available, the DC/DC stage becomes idle, (Fig. 1). However an appropriate control scheme can help the inverter operate in reactive power compensation mode even with the absence of active input power. Operating the inverter in VAR mode involves two steps: 1. Pre charging the DC bus capacitance 2. Regulating the DC bus voltage within limits while regulating the injected reactive power In order to overcome the inverter losses while supplying the required house-keeping power, the inverter needs to draw some active power from the grid. In the following sections, these steps will be discussed in greater detail.

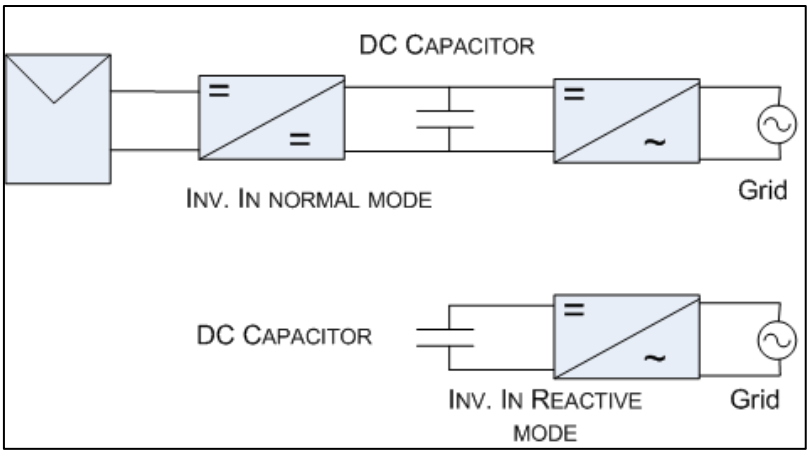

Fig.1. Inverter switching to reactive mode

A. Pre Charging the DC Bus Capacitor

In order to operate the inverter in VAR mode, the DC bus capacitor must be pre charged first. To do so, the inverter can be operated as a line rectifier by utilizing the inverter switches‟ antiparallel diodes as shown in Fig. 2. Since most PV inverters incorporate AC relays to connect / disconnect from the AC grid, the same relays can be employed to precharge the DC bus.

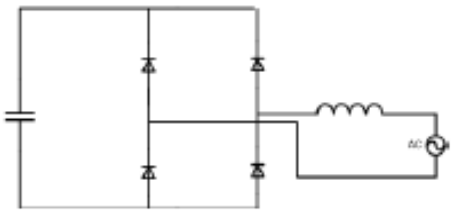

Fig. 2. Inverter bridge used as a charger

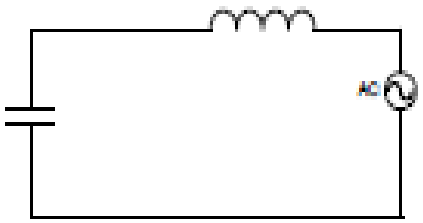

Fig.3. Inverter bridge in rectifier/pre-charge mode

It is critical to have the peak voltage and current of this circuit below the inverter components‟ ratings. As such, and in order to limit the current inrush and minimize the potential for a voltage overshoot across the DC bus, an inrush

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limiting circuit needs to be incorporated. The maximum voltage and current stress happen within the first half cycle when the capacitor voltage starts rising from zero. During this interval the circuit of Fig. 2 can be reduced to an LC circuit as shown in Fig. 3.

B. Regulating the DC Bus Capacitor Voltage and Injecting Reactive Power

Typically, the inverter efficiency is quite high, above 95%. As such, the inverter losses are relatively small. For example for the case of a 200VA inverter, losses are less than 10W. These losses are typically supplied by the active power available from the renewable resources (e.g. sun, wind). However when the active power is not available, and in order to operate the inverter in VAR mode, the inverter needs to draw some active power from grid to compensate for these losses and power its internal control circuitry.

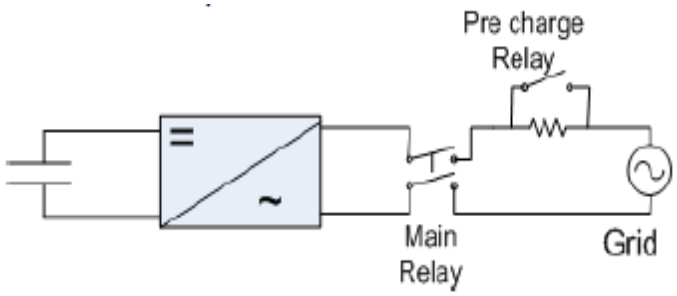

Fig.4. Limiting the inrush current

To alleviate the problem of DC bus regulation, a hysteresis band controller for determining „P" is proposed. Figure 5 shows the proposed hysteresis control scheme. The current loop controller may be any of the conventional current loop controllers such as PI, PI with feed forward [9], [10], [11], as well as P+R [4].

Assuming that the desired DC bus voltage needs to be maintained between 225 and 250, if DC bus voltage drops below 225, active power needs to be drawn from the grid to charge the DC bus capacitor. The active power drawn should be in excess of the estimated inverter losses to ensure that the capacitor bus will charge properly. The active power command reference is set as a ratio of the inverter losses, namely -K*Losses, where K > 1.0. Typically, it is recommended that the K value be higher than 2.0 to ensure proper and rapid charging of the DC bus. Once the DC bus voltage reached the upper limit (250V), the active power reference in (6) and (7) is set to zero. As a result, and due to the inverter internal losses, the DC bus voltage will start decreasing gradually. Once it hits the lower limit, the charging process repeats as explained above. The proposed DC bus voltage hysteresis controller is shown in Fig. 6.

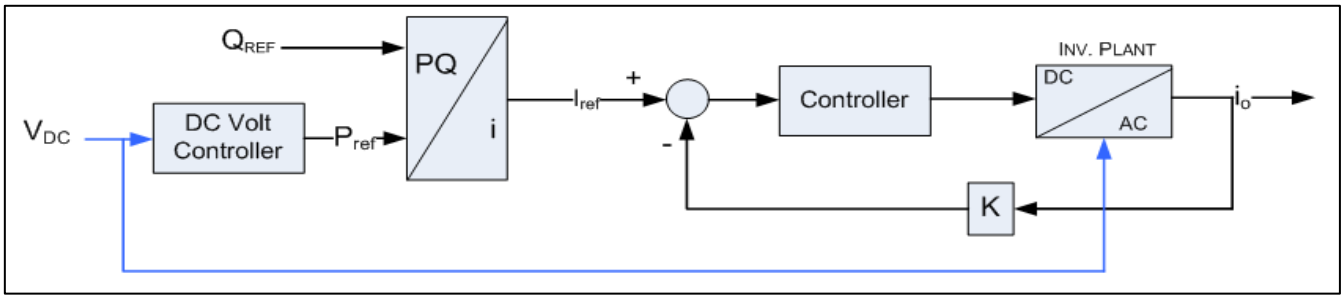

Fig.5. A hysteresis VAR mode controller block diagram

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While the above DC bus voltage regulation control loop is active, the desired reactive power injection level can be realized. By choosing the desired Q reference in [13].[14],[15],[16],[17] the output current magnitude and phase will be adjusted to inject the desired Q. As such, an efficient and easy to implement VAR control algorithm is devised, which helps the inverter inject the commanded reactive power and regulate its DC bus voltage at the same time.

III. SIMULATION AND EXPERIMENTAL RESULTS

Simulation and experimental results for a 200VA PV inverter with L = 4mH and C = 400μf are provided. Assuming a grid voltage of V = 120V @ 60Hz, according to (3)-(6) the maximum voltage and current will be 290V and 36A respectively. Clearly this current exceeds the ratings of the inverter. To limit the peak current below 3A, an inrush limiting resistor of $120\sqrt{2}/3 \approx 56\Omega$ needs to be used. The inverter losses have been assumed to be approximately 8W (96% efficiency). A 7KΩ resistor was added in parallel with the DC capacitor to simulate the overall inverter losses. Charging power (-K*Losses) command, shown in Fig. 6, was chosen to be -30W. Lower values could also be used, but the - 30W allows for faster re-charge and response times and makes it possible to see the DC bus voltage fluctuations more clearly in the simulations. Fig. 7 shows the DC voltage and inverter current and voltage. Pre-charge continued until about .25s, after which the DC voltage regulation based on hysteresis control is activated. Fig. 8 shows inverter typical active and reactive power injection of the proposed scheme. It can be seen that after the first few cycles after which the DC bus capacitor is pre charged, the inverter starts injecting the desired reactive power, in this case 200VAR, while at the same time drawing some active power to regulate its DC bus.

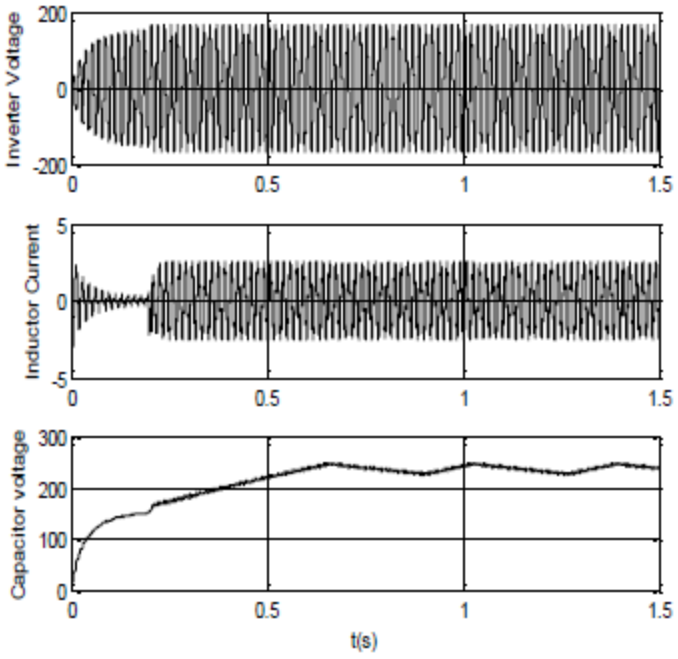

Fig.6. Current and voltage of inverter in VAR mode

This corresponds to the negative value of active power whenever the DC bus voltage needs to be charged. Figure 6 shows the experimental result for the pre charge of the DC bus capacitor .This matches the simulation result of Fig. 7 and shows that the DC bus capacitor can be charged without any overshoot. Figure 10 shows the DC bus voltage

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(top waveform) and the output current of the inverter operating in VAR mode while absorbing little active power from grid to regulate the DC bus voltage. In this figure a step VAR command change from %25 to %75 of the nominal power has been applied to show how the DC bus charge and discharge times will vary with the change of the VAR command and hence loss changes. This also shows the effectiveness of the controller for different VAR commands.

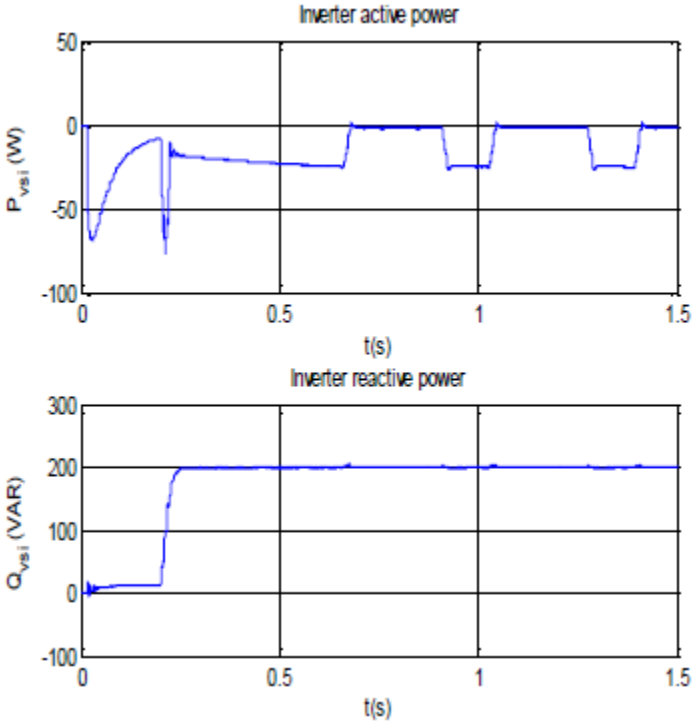

Fig.7. Active and reactive power flow in VAR mode

IV. CONCLUSIONS

In this paper, a novel controller was proposed which enables grid-tie inverters to operate in VAR mode when active power is not available. It was shown that the same inverter bridge can be used to draw some active power from grid, regulate the DC bus voltage within limits, and inject the desired level of reactive power into the grid. Detailed analysis showed that some precautions need to be considered so as to limit the maximum current and voltage during pre-charge to be within the inverter elements‟ ratings. A hysteresis band controller was proposed to set the level of active power drawn and regulate DC bus voltage and keep it within limits.

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