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Direct Predictive Power Control of Grid Tied Distributed Generator Systems

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Abstract: ***This paper explains the direct power predictive control of three phase VSI interfaced DG. The controller aims are three-fold: a) Maintain the nominal voltage and frequency, b) Supply the required load power, c) Match the reference setpoint for power. The traditional direct power control utilizes complex optimal sequence calculations for the implementation and in this paper a methodology aimed at incorporating the discrete switching nature of power electronic switches. The switch can be either ON or OFF at a given instance and for any converter, the number of possible switching vectors is limited. By limiting the search space for the solution of switching vectors the optimization problem is reduced to an evaluation problem and by utilizing the direct power control, it is possible to quickly control the converter and support the active and the reactive power demands. The proposed control is simulated in MATLAB-Simulink and is compared against traditional control for performance of tracking.***

Keywords: Distributed generation, Power Control, Current Control, Predictive control

1. Introduction

Solar photovoltaic power generation is climbing in popularity and implementation across the globe due to its flexibility of operation in AC and DC microgrid with ratings ranging from few Watts to millions of Watts. Power electronic converters are essential for interfacing of solar and other renewable sources like wind [1]. The control of power electronic converters play a major role in system operation due to the fast functioning and for this proper modeling of the voltage source converters is needed for an AC microgrid [2]. With many countries actively increasing the installed capacity of solar photovoltaic panels, the control of the same is vital as it may introduce issues during the interface stage [3].

The inverter control has been under research for many decades, looking for improvements in the current control and PWM techniques [4-6] used as they form the core and a small change can modify system dynamic performance. Among the various current controllers, predictive control has always been a good candidate for systems requiring high dynamic response and for power electronic converters control, model predictive control has been used extensively due to the ease of including the discrete nature of the converter switches [6-10]. Adding the advantage of introducing the constraints of our control to the objective function, model predictive control has given us the flexibility of control variables [11].

Functioning of power electronic switches is discrete-being either ON or OFF and this helps us in limiting the search space for the required switching position for a given reference value and comparing with linear current controllers, including this aspect has improved system accuracy and performance [12]. With modern smart grid systems, the control of converters need to be optimal so that the maximum power point of the solar (or renewable source) is extracted properly. Traditionally, when the power reference point is given to the inverter control it is converted to reference current and is tracked; but few control strategies based on Direct Torque Control in drives [13] can control the power directly.

These control strategies are termed as Direct Power Control (DPC) and for grid connected renewable sources, is more suitable as solar photovoltaics or wind energy conversion systems often come with maximum power point tracking in their control. For optimal control of the power, the switching sequence of the converter can be controlled [14] or the virtual flux estimation can be done [15], but the calculations are intense. In order to reduce some cost component, usually the sensors-voltage or current sensor, can be avoided and with the benefit of predictive control-with estimations in control calculations the power can be controlled directly [16 and 17].

Direct power control's complexity can be reduced by going for addition of Deadbeat control principle [18] or deriving the controller in a reduced order fashion [19] which helps us in reducing the intense calculations needed. This paper explores one such less complex Direct power control using the Model Predictive Control, which utilizes the discrete nature of power switches to convert the optimization problem into an evaluation problem while calculating the power at each sampling instance.

This paper is organized as follows: Section 2. describes the system components and requirements for direct power control, Section 3. provides the control principle and functioning of Direct predictive power control, Section 4. gives the results and discussion for few of the operating scenarios and Section 5. shows the advantage of going for direct power predictive control over traditional multi loop control for grid tied distributed generators. The system is simulated in MATLAB-Simulink.

2. Grid tied Distributed generators

Distributed generators are increasingly introduced in the modern power systems due to their flexible control and introduction of renewable energy sources based distributed generators calls for inclusion of power electronic converters.

Fig.1 depicts a sample grid tied solar photovoltaic generator interfaced with an AC grid and the proposed direct predictive power control is implemented for the inverter stage. Traditional control of such system involves three loops-outer power loop, middle voltage loop and inner current loop while the proposed direct predictive power control can work with power loop.

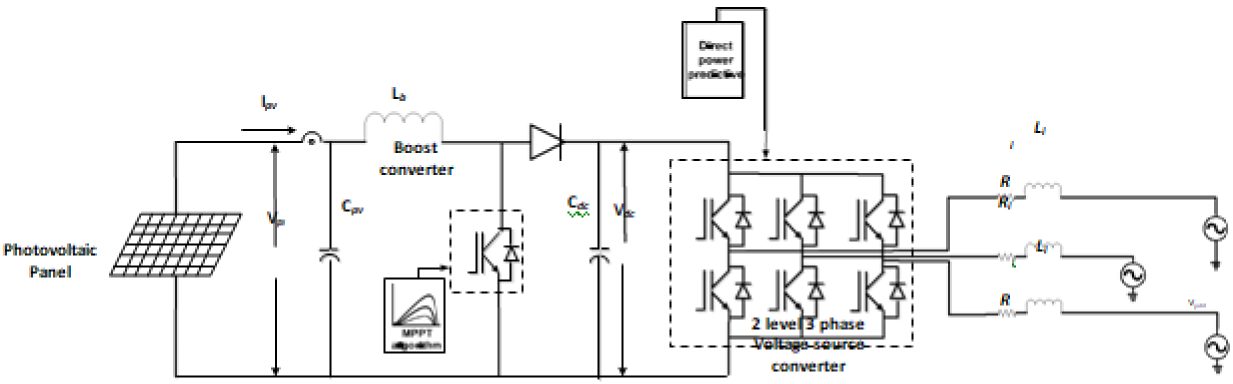

Figure 1: Grid tied Solar Photovoltaic generator with MPPT

With the implementation of model predictive control it is easy to incorporate multiple cascaded loops in the traditional control into power control loop itself and this process works similar to the direct torque control for power converter fed drives. The two level three phase inverter is suited and works satisfactorily for most of the applications of renewable source integration; because of the discrete nature of the switches, for a three phase two level inverter, the number of possible switching states is 23=8.

For the study of the performance of the direct power control, the dynamics of DC side of the inverter is neglected and is assumed to be working similar to a fixed/stiff DC source and the two stage conversion of the photovoltaic generator is changed to single stage conversion so as to give the MPPT command directly to the inverter control, thereby getting the reference point for Power for the voltage source conversion. Fig.2 depicts the test system and given that most of the DC-DC converters are operating at high switching frequency- this is a reasonable assumption.

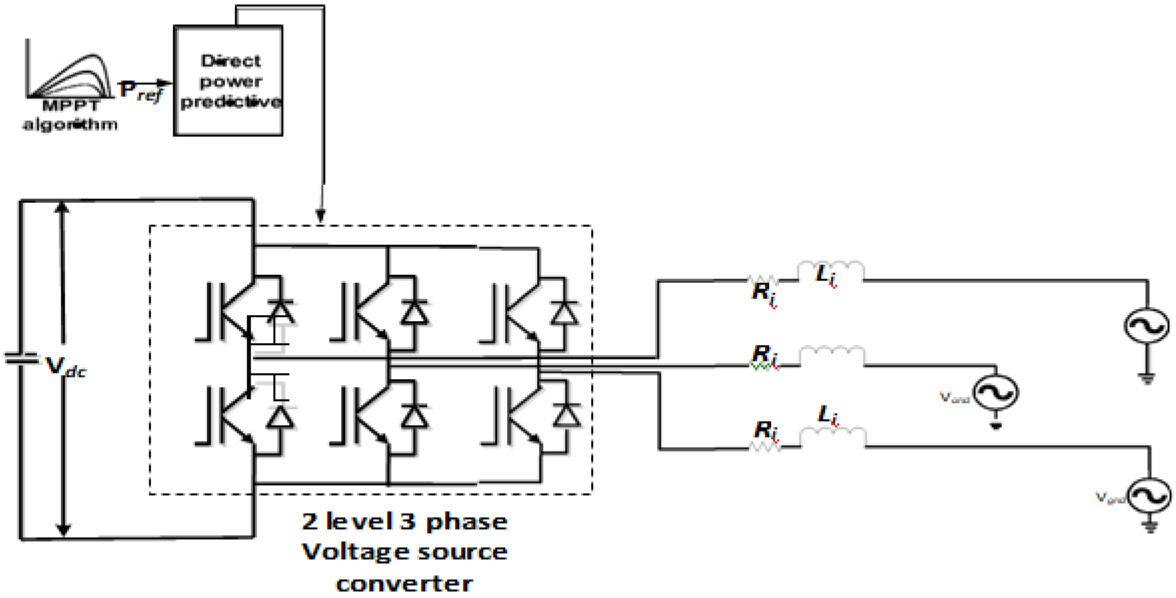

Figure 2: Grid tied DC source fed VSC

3. Direct predictive power control

Conventional control of voltage source converters aims at controlling the current faster, then the voltage and then the power which is based on the conventional power system where only the loads are varying quickly. In modern power systems where the renewable energy sources are being included in large numbers, the previous case sometimes produces adverse effects as the source side can also vary quickly and a power imbalance can endanger the system stability. Given that the power converter based systems are static and don't have inertial response, it is better to directly control the power instead of indirectly controlling it to have safer operation of the system.

Also, as seen from the literature [16-17], sensorless control of converters is possible while going for direct power control. Fig.3 shows the traditional control structure where Pset, Qset is our outer power loop, reference current generation functions as middle voltage loop and inner current control is responsible for the dynamic performance of the system.

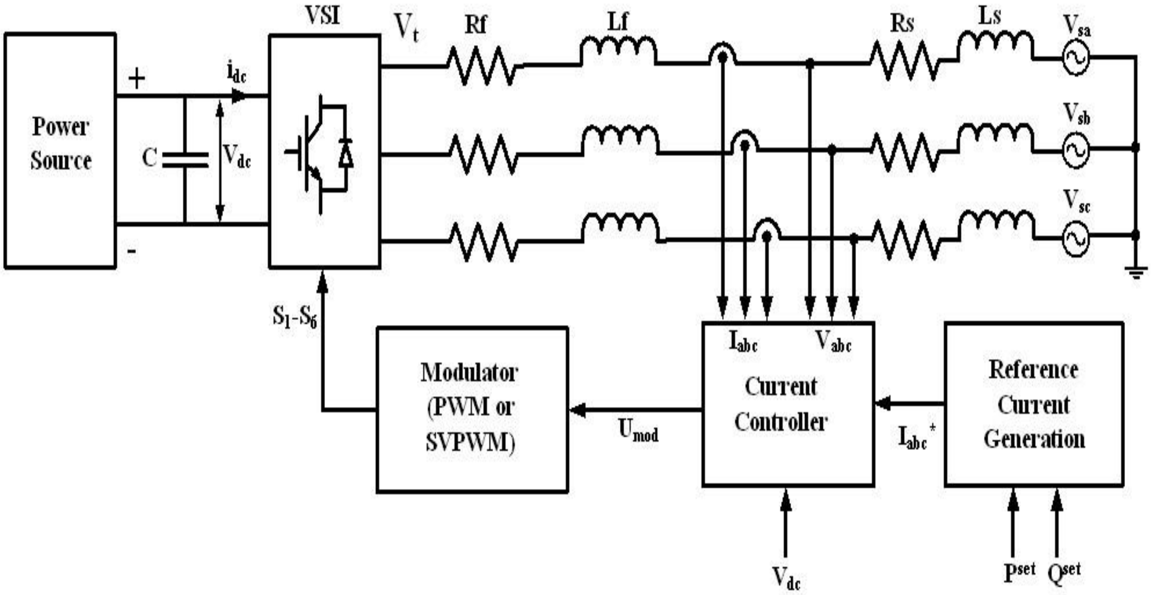

Figure 3: Current controlled Voltage source inverter

The modern power system is dynamic with constantly varying sources and loads, which leads to variation of voltages. This indirectly affects the performance of current control based voltage source converters and it can add up to the stability issues. Fig.4 depicts the power control based VSI operation.

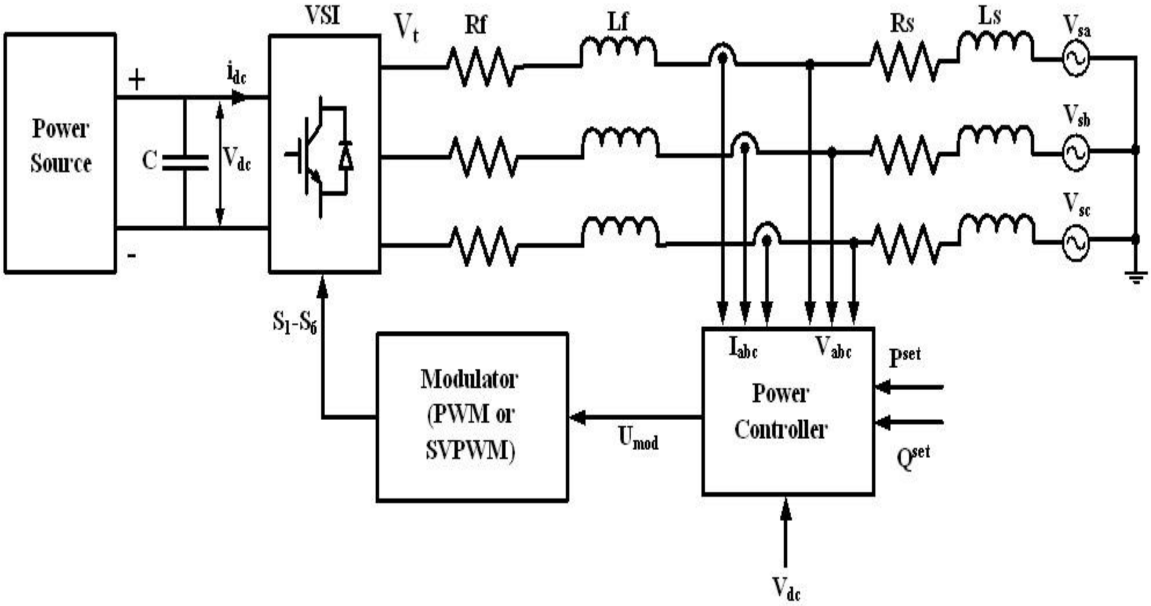

Figure 4: Power controlled Voltage source inverter

For every voltage source converters, there are limited numbers of switching states and for a two level three phase inverter, eight states are possible. Fig.5 illustrates the switching vectors from which the final solution of our control problem has to be chosen.

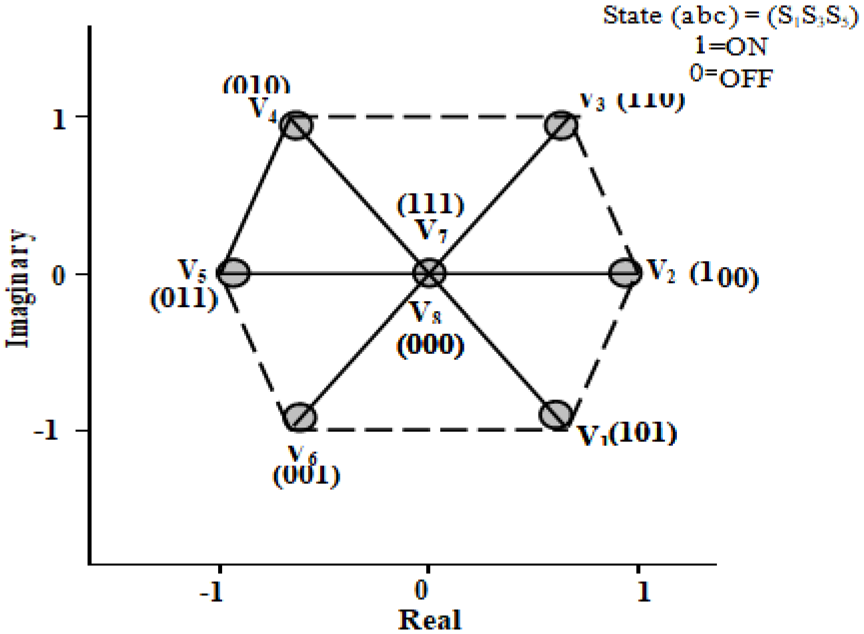

Figure 5: Power controlled Voltage source inverter

The following equations give the calculation of one step ahead prediction of power with the help of voltage vectors and based on the available sensor inputs it can be calculated. For the setpoint power command, even when the sensor input is malfunctioning or data is suddenly lost due to some issue, the current or the voltage can be calculated internally. This compensates for the variations in voltage and thus the control works well for distorted voltages too as the calculations are made based on ideal switching vectors.

$$P_{k+1} = P_k + T_s * \{[v_\alpha * (\frac{(V_{\alpha k} - v_\alpha)}{L} + \omega i_\beta)] + [v_\beta * (\frac{(V_{\beta k} - v_\beta)}{L} - \omega i_\alpha)]\}$$

$$Q_{k+1} = Q_k + T_s * \{[v_\alpha * (\frac{-(V_{\beta k} - v_\beta)}{L} + \omega i_\alpha)] + [v_\beta * (\frac{(V_{\alpha k} - v_\alpha)}{L} + \omega i_\beta)]\}$$

4. Results and Discussion

For the test system, the performance is tested by varying real power setpoint command. Because renewable energy source power generation is dependent on the physical and atmospheric parameters, the reference power command to the inverter control will be changing abruptly sometimes and this needs to be tracked quickly by the inverter. For the comparison of performance of the proposed Direct power predictive control, Deadbeat control and current control based Finite Control Set-Model Predictive Control (FCS-MPC) is also implemented.

The test scenario is created with consideration of various operating conditions like sudden reduction in active power command, ramp up and ramp down of active power command which are common occurrences in practical operating conditions. Fig.6 depicts the active power command and the controller tracking of the command.

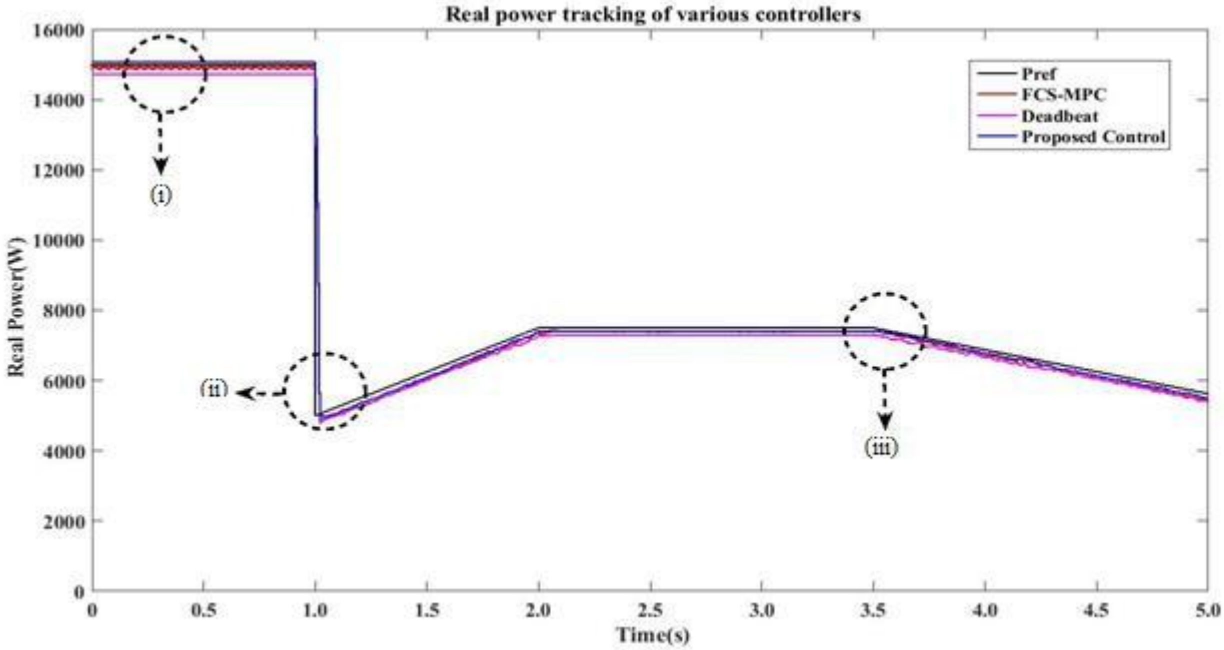

Figure 6: Active power tracking performance of proposed Direct power control

Fig.7 shows the dynamic performance of the proposed controller for step change and ramp down of the command change.

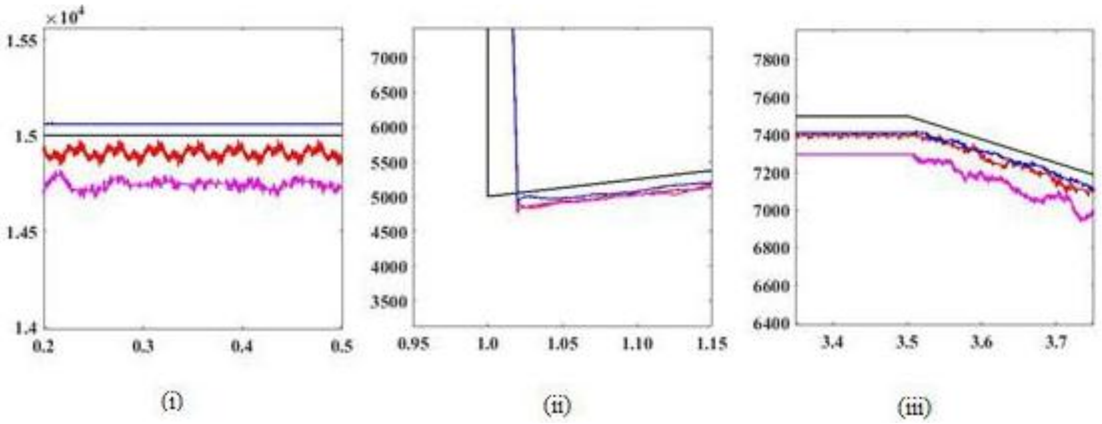

Figure 7: Dynamic performance of Direct power control

5. Conclusion

This paper proposes a direct predictive power control of grid tied distributed generators and explores the possibilities of implementing the state of the art predictive control nuances for improving the dynamic performance of the distributed generator. This control is prioritizing power balance and by incorporating the limits of current and voltage in power calculations is working robustly for bigger changes in operating conditions. One step ahead prediction is satisfactory for two level three phase voltage source inverter and the performance of the direct predictive power control is tested against state of the art predictive current controllers. The future scope of this work lies in implementing the proposed control for higher level converters.

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