Predictive control of Grid tied Solar Photovoltaic Inverter based on Instantaneous symmetrical component theory

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***Abstract*— This paper explains the implementation of non-linear Model Predictive Control (MPC), which incorporates the finite switching nature of the inverter-called Finite Control Set MPC (FCS-MPC) for three phase grid tied photovoltaic systems. The controller aims are twofold: a)Inject the set point real and reactive power, b)unity power factor operation. FCS-MPC is used for current control whose reference currents are generated by Instantaneous Symmetrical Component theory. The power electronic converters are made up of switches, which are discrete in nature-i.e., either ON or OFF. Conventional MPC is simplified by taking advantage of this nature and converts the actual optimisation problem into evaluate and choose the best solution type problem. Because of the limited number of switching states, the evaluation is quick and can be considered to an online optimal control. The effectiveness of the FCS-MPC is validated against the Hysteresis current control and Deadbeat current control.**

Keywords— **FCS-MPC, Instantaneous Symmetrical Component Theory, Renewable energy, Microgrids.**

I. Introduction

Distribution networks are becoming active, with inclusion of Distribution Generation. Because of active participation of the consumer side, power flows both, from and to the consumer. Around the globe, Solar power generation is being encouraged more along with wind power generation.

Various inverter topologies for solar and wind based renewable systems and various grid regulations for solar photovoltaic systems are explained in [1]. Control involves reference current generation and a current controller. Overview of some current control techniques is given in brief.

[2] gives brief idea of the control of Voltage Sources Converters in Synchronous Reference Frame Theory (SRFT) (*d-q)* and Instantaneous Reactive Power Theory (IRPT) $(\alpha - \beta)$ frames. [3] and [16] explains in detail about the IRPT based control. [4] explains about Active Power Balance Theory (APBT) control and [5] explains about Instantaneous Symmetrical Component Theory(ISCT) based control.

[6] explains in detail about the *d-q* frame control of solar photovoltaic inverter system and [7] gives some of applications of SRFT based control of solar PV systems. There are variants of the ISCT based control, like one explained in [8] and ISCT is suited for reference current generation, as it takes the present values of measurements for computation and the power factor control is quite easy.

Once reference currents are generated, they have to be tracked properly; there are many controllers used for this purpose like PI control, Hysteresis control, Sliding Mode Control, State Feedback Control, Deadbeat Control, Fuzzy Logic Control, Neural Network Control, Model Predictive Control and their variants.

Various linear and non-linear control techniques are compared in [9], [10] and [11]. There are large number of applications with PI controller and its variants, but at the same time-active research is being carried out for advanced controllers also. Sliding Mode Control [12] and Deadbeat Control [13] are being applied for various applications.

A new set of control called predictive control is growing in popularity and various predictive controls are explained in[14]. It is also to be noted that MPC is the only advanced control, to be applied widespread in industrial applications[14]-process industries.

Discrete time MPC and Matlab implementation of the same are explained in [15] and [17]. Applying the discrete nature of the switches in the power electronic converters, the MPC optimisation problem is modified into an evaluate and choose problem.

PI controller tuning is done through hit & trial or Ziegler Nichols method or through an optimisation technique, which may not give optimal gains and for various operating conditions, it becomes even more tedious. Hysteresis control is simple, but its varying switching frequency and band is a problem for converter applications.

Auto-tuning or re-tuning PI and adaptive band hysteresis control are existing in literature, but the optimality of it is not guaranteed. MPC, is based on the system model and so for varying system operating conditions, it gives optimal control and with FCS-MPC it is online optimal control.

In this paper, ISCT based FCS-MPC is used for Solar Photovoltaic Control and the performance of the control is compared with Hysteresis current control and Deadbeat current control.

II. ISCT BASED FCS MPC CONTROL

The ISCT based control doesn't require a PLL and Park's transformation, which is used for popular *d-q* based control. So, the delay associated with PLL is not present.

The reference currents are generated as

$$i_{inv,a}^{ref} = i_{load,a} - \frac{\left(v_{grid,a}+\beta(v_{grid,b}-v_{grid,c})\right)*(P_{load})}{v_{grid,a}^2+v_{grid,b}^2+v_{grid,c}^2} \quad \text{-----(1)}$$

$$i_{inv,b}^{ref} = i_{load,b} - \frac{\left(v_{grid,b}+\beta(v_{grid,c}-v_{grid,a})\right)*(P_{load})}{v_{grid,a}^2+v_{grid,b}^2+v_{grid,c}^2} \quad \text{-----(2)}$$

$$i_{inv,c}^{ref} = i_{load,c} - \frac{\left(v_{grid,c}+\beta(v_{grid,a}-v_{grid,b})\right)*(P_{load})}{v_{grid,a}^2+v_{grid,b}^2+v_{grid,c}^2} \quad \text{-----(3)}$$

where. $\beta = tan\phi/\sqrt{3}$ and ϕ is the power factor angle.

For a two stage grid connected PV, as shown in Fig.1,MPPT control is taken care by the DC-DC boost converter and the PQ injection control is taken care by the inverter control. The PV panel considered here has MPP =15.2 kW with Ns=650 and Np=4. Boost converter takes care of MPP control(with derating) and inverter control is the ISCT based MPC control. Grid is three phase 415 V.

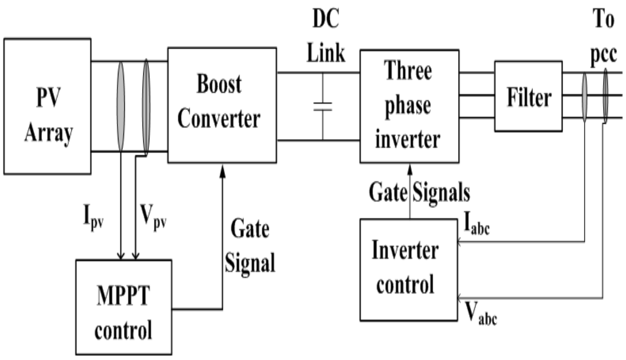

Fig. 1: Two stage Grid connected PV system

Model Predictive Control (MPC) is called as receding horizon control and is a non-linear control. It aims at optimising a cost function and does so by predicting the trajectory of the future input and manipulates the same. Because of including the discrete nature of the switches, for a three phase two level inverter, the number of possible switching states is 2^3=8.

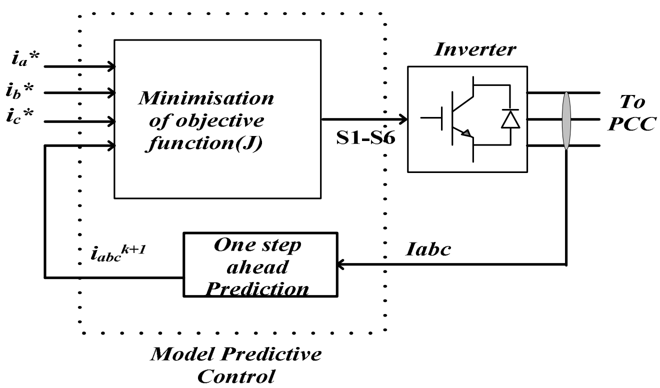

Fig. 2: Model Predictive Control based Current Control of Three phase inverter

Objective function used for selection of the switching pulses is:

$$J = (i_a^* - i_a^{k+1})^2 + (i_b^* - i_b^{k+1})^2 + (i_c^* - i_c^{k+1})^2$$

The eight voltage vectors of the two level three phase inverter is given by

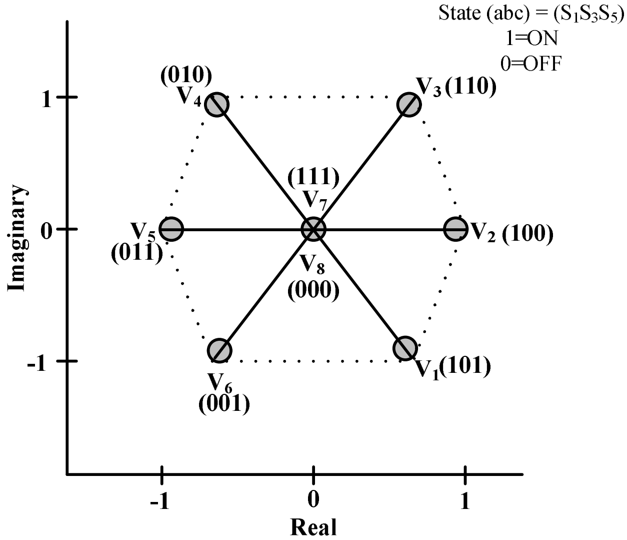

Fig. 3: Voltage vectors of a 2level 3ph inverter

Brief algorithm for the FCS-MPC based current control is given as:

Step-1:Acquire the reference and actual currents . Acquire the DC voltage input.

Step-2:For all possible switching states, from the DC voltage find out the inverter output and using it, find out the inverter output voltage for each switching state.

Step-3: From the inverter output voltage, predict the next time step currents. Evaluate the objective function for each of these states.

Step-4:Whichever states has the least J, choose it and give it as the switching pulses for the converter.

Step-5:Repeat the above steps for each time increment Δt.

The current control is implemented with hysteresis and deadbeat control(another type of predictive control) and the comparative real power tracking is to be given in the final manuscript. The real power tracking of FCS-MPC based control is given in the following figure. The Ramp-up and the ramp-down set-point commands are evaluated and the controller is tracking them well.

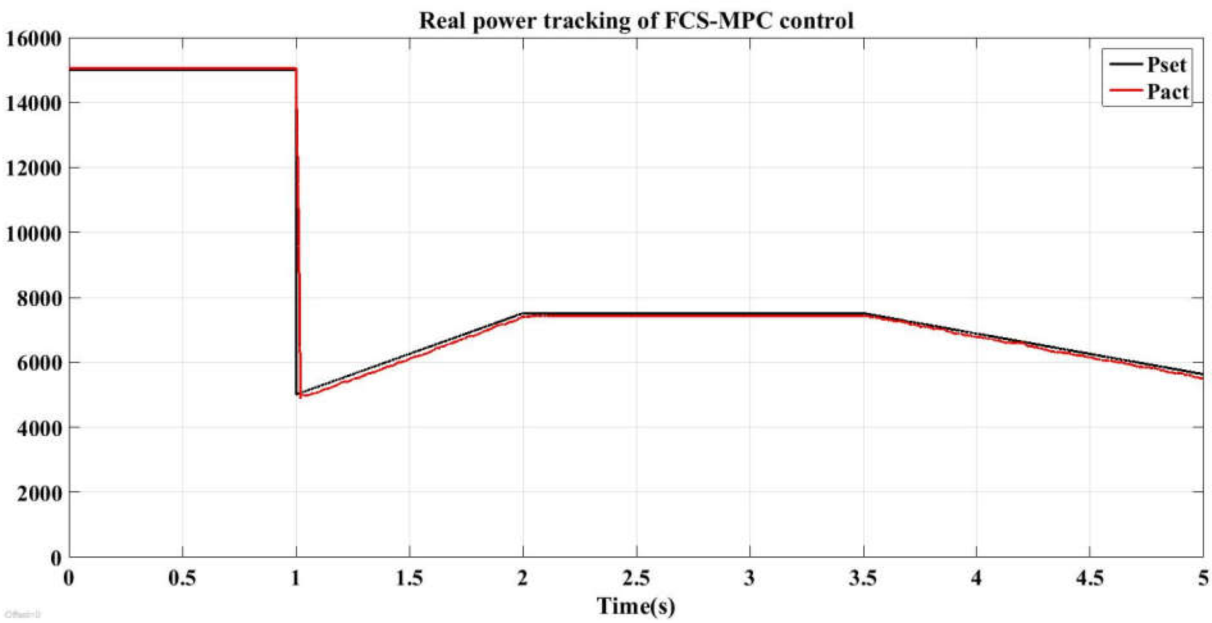

Fig. 4: Real power set point tracking performance of FCS-MPC control based on ISCT

III. Conclusion

Finite Control Set Model Predictive Control (FCS-MPC) is implemented for inverter control of solar photovoltaic system and the control tracks the required set point for active power at the set power factor. The proposed control is compared against the performance of Hysteresis control and deadbeat control. Switching pulses are directly generated by the proposed control. Observing the tracking performance, the proposed control is faster than the Hysteresis controller. Non-linearities can be directly included and it makes the control more accurate. Also, with varying system operating conditions, the FCS-MPC works satisfactorily as it is a predictive control. One step ahead prediction is used in this paper and it works satisfactorily.

Very fast tracking of the proposed FCS-MPC is useful for improving the transient response and high accuracy for varying system operating conditions is achievable. ISCT algorithm for reference current generation produces reference currents as three phase signals and no PLL is needed, as compared with the Synchronous Reference Frame Theory based reference current generation.
The future scope of this work lies in testing the performance of the proposed control for frequency and voltage regulation-which is simple modifications in the outer loop of the control and if required, multi-step ahead prediction needs to be used for accurate tracking without compromising the transient performance.

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