Central Power Research Institute

Vol. 14(1)/79-84, June 2018
ISSN (Print) : 0973-0338
DOI : 10.33686/pwj.v14i1.142188

Power Research

Novel Model Predictive Current Controller for Grid Connected Inverters in a Smart-Grid Environment

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Abstract

This paper proposes a novel current controller for grid connected inverter. It is a new variant of non-linear Model Predictive Controller (MPC) which is modified from the available MPCs widely applied in chemical process systems. This proposed MPC is developed such that to adapt for fast response systems such as micro-grid and smart-grid systems. Using Matlab/ Simulink a micro-grid system model with one inverter and local loads connected to grid is developed to study the new MPC along with already available Proportional Integral controller and hysteresis controller

Keywords: Model Predictive Control, Smart Grid, Voltage Source Inverter

1. Introduction

Sustainable energy sources are renewable energy sources (RES) as these energies are generated from inexhaustible sources such as solar, wind, water and others. These sustainable energy sources spreads across the consumer locality and the generators generating power from them are rightly known as Distributed Generation (DG) systems. Here in DGs power flows bidirectional i.e., even consumers can export power to the grid. This minimizes transmission power loss and also power produced is clean and environment friendly.

Inverters play a major role in facilitating these DGs power to the end-users in terms of safety and quality. As power flows in either direction safety is a main concern and in a micro-grid environment there will be multiple power sources injecting power to the grid through inverters affects the quality of the grid power[1,2].

These Multiple inverter systems connected to a common AC grid, essentially operate in parallel and they have to be controlled for stable system operation and to prevent overloading of individual inverter[4]. Inverters are operated in parallel because of the diversity in generation systems and its geographical spread of the sites of operation.

There are a variety of control strategies available, such as a Droop control method, H-infinity control, Model Predictive Control (MPC), PI control, hysteresis control, Sliding Mode Control, resonant control and many so[3, 8, 9, 11]. In this work behavior of PI control, hysteresis control and MPC[13] are designed and applied for single inverter connected to grid their behavior is studied to prove their efficiency.

2. System Structure and Model of a Grid Connected Inverter

Figure 1 shows a basic model of an inverter feeding an utility network. The utility grid and local load connected to the source are considered. The main aim is to reduce THD of u_o as small as possible and this can be done by keeping microgrid voltage u_o as close as possible to the sinusoidal reference voltage u_{ref}. Two circuit breakers S_c and S_g are assumed to be closed for controller design.

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Inductor currents such as i_1, i_2, i_3 and capacitor voltage v_0 are the state variables. I_d, u_{ref}, and u_g are the external input variables, disturbances, references and grid voltage respectively.

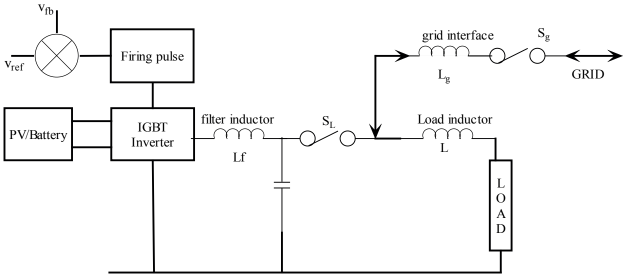


Figure 1. Inverter connected to load and grid.

State equation is written as

$$x = \begin{bmatrix} i_1 \\ i_2 \\ i_3 \\ u_0 \end{bmatrix}; \quad \begin{bmatrix} w \\ u \end{bmatrix} = \begin{bmatrix} i_d \\ u_g \\ u_{ref} \\ u \end{bmatrix}$$

$$\dot{x} = Ax + \begin{bmatrix} B_1 & B_2 \end{bmatrix} \begin{bmatrix} w \\ u \end{bmatrix}$$

$$A = \begin{bmatrix} \frac{-R_f r_f}{(R_f + r_f) L_f} & 0 & 0 & \frac{-r_f}{(R_f + r_f) L_f} \\ 0 & \frac{-R_g r_g}{(R_g + r_g) L_g} & 0 & \frac{-r_g}{(R_g + r_g) L_g} \\ 0 & 0 & \frac{-Rr}{(R+r)L} & \frac{r}{(R+r)L} \\ \frac{r_f}{(R_f + r_f)c} & \frac{r_g}{(R_g + r_g)c} & \frac{-r}{(R+r)c} & -\left(\frac{1}{(R+r)L} + \frac{1}{(R_f + r_f)} + \frac{1}{(R_g + r_g)} \right) \frac{1}{c} \end{bmatrix}$$

$$B = \begin{bmatrix} B_1 & B_2 \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 & \frac{r_f}{(R_f + r_f) L_f} \\ 0 & \frac{r_g}{(R_g + r_g) L_g} & 0 & 0 \\ 0 & 0 & 0 & 0 \\ \frac{-1}{c} & \frac{1}{(R_g + r_g)c} & 0 & \frac{1}{(R_f + r_f)c} \end{bmatrix}$$

Output equation

$$y = \begin{bmatrix} c_1 \\ c_2 \end{bmatrix} x + \begin{bmatrix} D_{11} & D_{12} \\ D_{21} & D_{22} \end{bmatrix} \begin{bmatrix} w \\ u \end{bmatrix}$$

$$c = \begin{bmatrix} c_1 \\ c_2 \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 & -1 \\ 0 & \frac{-r_g}{R_g + r_g} & \frac{r}{R+r} & \frac{-r_g}{R_g + r_g} + \frac{r}{R+r} \end{bmatrix}$$

$$D = \begin{bmatrix} D_{11} & D_{12} \\ D_{21} & D_{22} \end{bmatrix} = \begin{bmatrix} 0 & 0 & 1 & 0 \\ 0 & \frac{-1}{R_g + r_g} & 0 & 0 \end{bmatrix}$$

The distributed inverters are highly reliable because of their redundancy. N number of inverter units supplies the load and remaining one or more inverters will be in the reserve [2]. This makes the system flexible, an additional inverter units could be added when system needs more power.

3. Proportional Integral Controller (PI)

The PI controller is used for current error compensation i.e., the inverter output current and grid injected current are compared and the resulting error is compensated or reduced with a PI control algorithm. As the name implies Proportional Integral controller it has two constants namely Kp and Ki known as proportional gain constant and Integral gain constant respectively.

The proportional term obtained by multiplying kp gain and error will reduce the overall error of the system with respect to time. But proportional term cannot bring down the error to zero. The ki constant is multiplied with the integrated error and this integral term reduces the steady state error considerably and improves the system.

The PI control algorithm unlike advanced controllers doesn't require system model to be designed and thus they does not bother system parameters. These simple controllers can be implemented either in stationary frame (αβ-frame) or synchronous frame (dq-frame). Among these two synchronous reference frame PI controller is preferred as they make the control variable DC and are capable of reducing the error to zero[5, 7]. Even though the synchronous reference frame scheme is complex with need of two coordinate transformation and phase information of the grid voltage they are preferred against αβ-frame scheme as they impose tracking error of phase and amplitude.

dq-frame scheme can set the real and reactive power sent to the grid directly. It can work well with balanced linear loads. It is poor in dealing with harmonics as they can't handle nonlinear loads. In case of an unbalanced system the negative and positive sequence components should be considered separately.

4. Hysteresis Controller

A simple Hysteresis current controller is easy to implement for inverter control. This controller immediately senses the error signal and gives control signal to the inverter directly. In this scheme the current is controlled within a narrow band, which has an upper and lower band limit. The output ramps up and down inside this hysteresis band width. The required signal is maintained to stay within the limits by turning OFF the top switch and turning ON the bottom switch of a leg corresponding to a phase of the inverter when the output current touches or crosses the upper limit[10]. Else if the output current touches or crosses the lower limit, bottom switch is turned OFF and top switch is turned ON

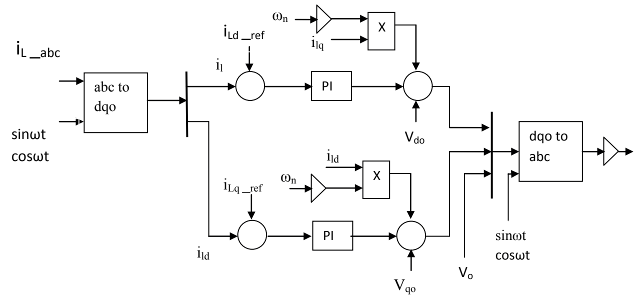


Figure 2. PI controller block representation as in Matlab simulation.

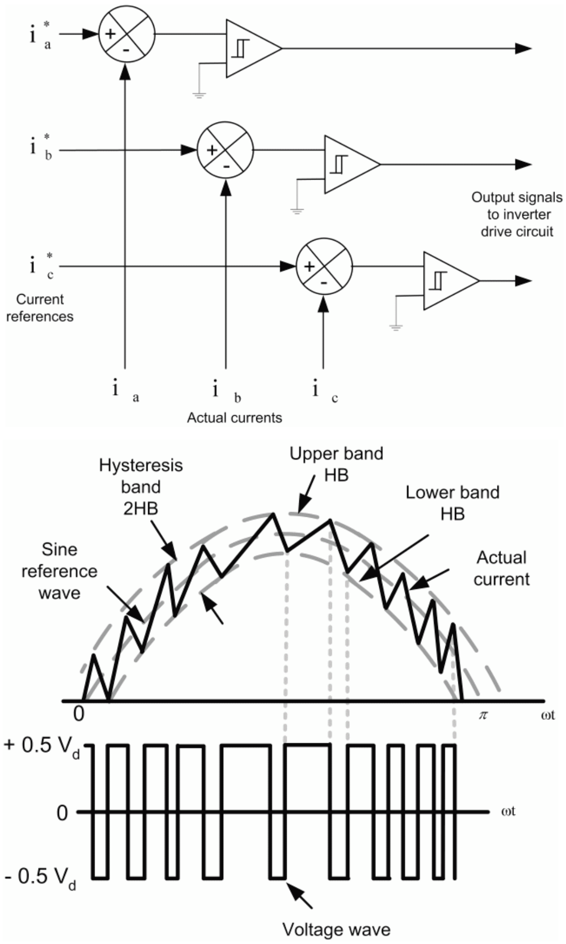


Figure 3. Hysteresis operation controller.

The harmonic performance is not good; however it can be improved by varying the width of the hysteresis band. When width of the hysteresis band is reduced the switching frequency will increase but harmonic performance could be improved[16]. The inductor and the DC voltage applied to the inductor by the inverter also influence the switching frequency.

5. Model Predictive Controller

MPC is a controller used extremely in process industries. Receding-horizon principle is the basis for model predictive controller. MPC acts as a single controller which selects the possible state that minimizes the cost function of the system model[12]. These calculations are made in the discrete environment.

Control horizon is maintained same for all the inverters, thereby giving equal weightage for each and every inverter module connected[13]. Now one can write a cost function easily for two or more such inverters connected parallel to the grid.

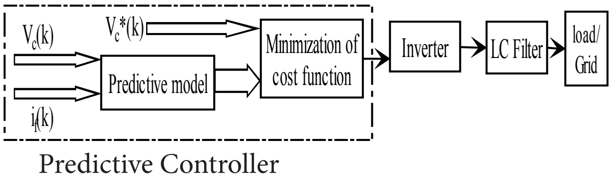


Figure 4. Block diagram of model predictive controller.

Algorithm for proposed MPC:

Step 1: Reference current value (dq-domain) is acquired first, and load current is measured.

Step 2: inverter output is calculated by following equations (dq-domain)
vtq(j)=2*((vpcck1(1)*cos(wcon))+(vpcck1(2)*cos(wcon-(2*pi/3)))+ (vpcck1(3)*cos(wcon+(2*pi/3))))/3;
vtd(j)=2*((vpcck1(1)*sin(wcon))+(vpcck1(2)*sin(wcon-(2*pi/3)))+ (vpcck1(3)*sin(wcon+(2*pi/3))))/3;

Step 3: Evaluate the cost function, J=((idref-idk1)*(idref-idk1))+((iqref-iqk1)*(iqref-iqk1)); for all possible switching states,

Step 4: The reduced cost function which has minimum value and its corresponding switching state signals (firing pulses) are sent to switches.

Step 5: Repeat the procedure each time

Major advantage of MPC over other controllers is an optimization function is enough for finding the optimal control action and controller is easy to understand. Among the advanced controllers MPC is very suitable for industrial applications. In MPC the control set is discrete in nature and one does not need any modulator or any supporting circuits.

6. Results and Simulation

The Figure 5 shows Simulink model of a single voltage source inverter connected to the grid of 415 volt and local load in the micro-grid. Control mpc block produces the switching pulses (S1a, S2a, S1b, S2b, S3a, S3b) directly without need of any modulators.

Signal builder gives the Pset and Qset value the Pset i.e., Real power set-point value is varied and the system behavior is studied to evaluate the proposed MPC controller[6]. Qset value i.e., Reactive power set-point value is maintained zero so as to maintain the power factor as one.

One can observe that set-point (Pset) following capability of the proposed MPC from the Figure 5 MPC follows and settles quickly without much oscillation. PI controller has oscillations and settles but takes more time compared to other current controllers. However hysteresis controller tracks the set point quickly but has meager oscillations during the complete course. From the Figure 5 MPC control wave which is in red color settles quickly and tries following Pset wave accurately.

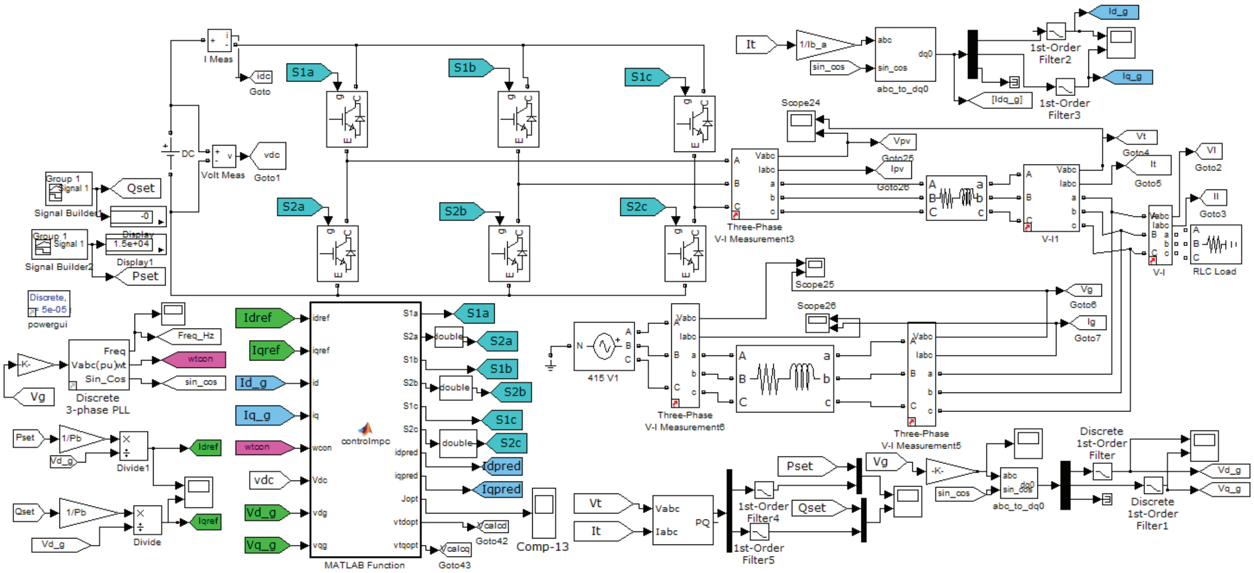


Figure 5. Simulink model of the proposed model predictive controller for a grid connected micro-grid system.

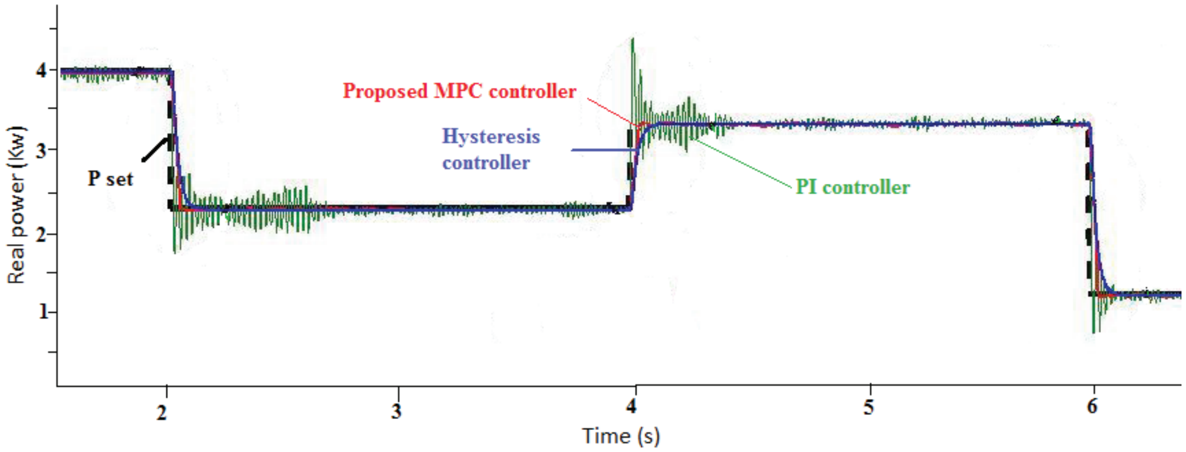
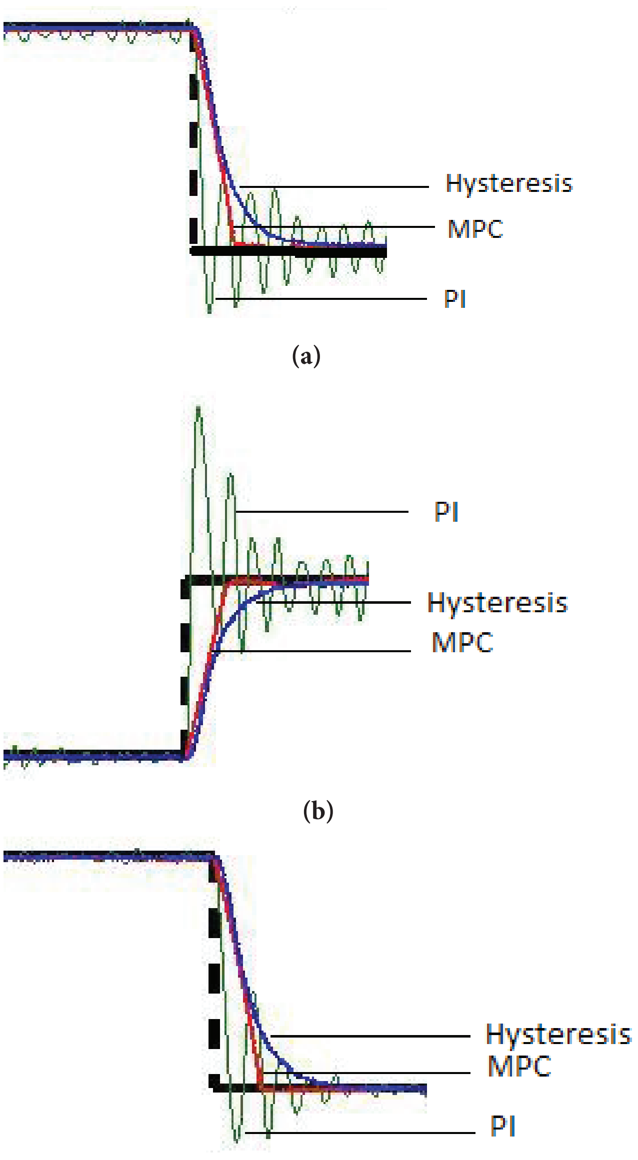


Figure 6. Wave form of the proposed MPC control and other controllers together.



(a)

(b)

(c)

Figure7. Enlarged view of the controller behavior at different times periods are shown separately. (a) Waveform at 2 sec; (b) Waveform at 4th sec; (c) Waveform at 6th sec.

As the real power set value increased from 2.4 kw to 3.5 kw at time 4 sec the PI controller wave in green color makes a high peak overshoot and settles at about 4.35 sec. when the real power set value is decreased to 1 kw at 6 sec the oscillations and settling time gets reduced considerably. However during initial stages i.e., at 2 sec even though the Pset value is 2.4 kw PI controller shows a prolonged oscillation and settles at 2.7 sec. but there is no high peak overshoot at 2 sec like 4th sec.

This behavior is noted only in PI controllers, the other hysteresis and MPC controller behaves well in these aspects. It is obvious from the waveform that MPC controller follows the Pset finely outperforming other two controllers. Effectiveness of a controller is judged by the accurate following of set-point (Pset) value.

7. Conclusion

A voltage source inverter in micro-grid fed by a renewable DC source is connected to the gird and other local load is considered for evaluating the performance of the proposed MPC controller. Two other controllers such as PI and hysteresis controllers are tried and their behavior is studied. These two methods need a modulator like PWM for generating pulses or a comparator for detecting the band limits were as proposed MPC is an online controller as they don't need any other support like modulator or comparator mere optimal reduction of cost function gives switching pulses to the inverters. It is obvious from the waveforms generated by the Matlab/Simulink models the proposed MPC is very quick and nearly accurate in following the set point values. This controller will be an effective option for the smart-grid environment in future.

8. References

1. Li YW and Kao C. An accurate power control strategy for power electronics interfaced distributed generation units operating in a low voltage multibus microgrid, IEEE Trans. Power Electron. 2009; 24(9):2977–88.
2. Zhong QC and Hornik T. Control of power inverters in renewable energy and smart grid integration, A John Wiley & Sons, Ltd., Publication; 2013.
3. Kazmierkowski M and Malesani L. Current control techniques for three-phase voltage-source PWM converters: A survey, IEEE Transaction on Industrial Electronics, 1998; 45(5).
4. Tuladhar A, Jin H and Mauch K. Control of parallel inverters in distributed AC Power systems with consideration of line impedance effect, IEEE Transaction on Industrial Applications, 2000; 36(1).
5. Hamzeh M, Karimi H and Mokhtari H. A new control strategy for a multi- bus MV microgrid under unbalanced conditions, IEEE Transactions on Power Systems, 2012; 27(4).
6. Abdalrahman A, Zekry A and Alshalzly A, Simulation and implementation of grid connected inverters, International Journal of Computer Applications, 2012; 60(4).

7. Mao H, Yang X, Chen Z and Wang Z. A hysteresis current controller for single phase three level voltage inverters, IEEE Transaction on Power Electronics, 2012; 27(7).
8. Castilla M, Garcia De vicuna L, Guerrero JM, Matas J and Miret J, Design of voltage mode hysteretic controllers for synchronous buck converters supplying microprocessor loads, IEEE Proceedings Electric Power Applications, 2005; 152(5).
9. Castilla M, De vicuna LG, Guerrero JM, Matas J and Miret J, Designing VRM hysteretic controller for optimal transient response, IEEE Transaction on Industrial Electronics, 2007; 54(3).
10. Castilla M, De vicuna LG, Guerrero JM, Miret J and Berbel N. Simple low cost hysteretic controller for single phase synchronous buck converters, IEEE Transaction on Power Electronics, 2007; 22(4).
11. Hooshmand A, Malki HA, Mohammadpour J. Power flow management of microgrid networks using model predictive control, Elsevier Computer and Mathematics with Applications. 2012; 64(5):869-76.
12. Low KS and Cao R. Model predictive control of parallel connected inverters for uninterruptible power supplies, IEEE Transaction on Industrial Electronics, 2008; 55(8).