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Design and Comparison of PID and Proportional Resonant Controllers for Matrix Converter

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Abstract

In this paper we represent a comparison between PID and Proportional resonant controllers for matrix converter used for unbalance load application. The simulation has been done in Matlab Simulink. A linear model transfer function of matrix converter has been taken to be control by Proportional Resonant controller and PID controllers. Various parameters are taken to find out the close loop system stability. First PID controller and then Proportional resonant controller checked for close loop system's responses. Optimal controller has been suggested on the basis of best performance for reference sinusoidal tracking.

Keywords: Matrix Converter, PID Controller, Proportional Resonant Controller (PR)

1. Introduction

Matrix converter is AC-AC converters. They have advantage over classical voltage source converters due to the presence of less number of energy storage components which cause losses as well as ageing of the converters[1]. But we cannot say matrix converter is pure static solution for AC-AC conversion[2]. In the direct matrix converter the main energy components are its output and input filters. For each phase of input, it is connected via 3 switches per phase to connect with subsequent 3 output phases as shown.

Input filter is applied mainly to stop switching noise to enter into the supply system and also to reduce the angle between V and I[3]. On the other side the output filter is completely a very important phenomenon for our system. It is basically low pass LC filter. Its main purpose is to get rid of the ripples present in the output waveform.

For linear system we consider our system transfer function as transfer function of output filter and load as represent the matrix converter by unity gain and one sample delay unite. For a system having unbalance, balance or no load conditions, the worst scenario is that of no load. First we check our system's response as open loop system. It shows that our system is unstable. After that various controllers were applied and the system is consider as close loop. The system input Voltage is 415 with 50 hertz and output is 100 Volts with 400 hertz and our rating is 7.5 Kilo-voltampare. In this paper a single voltage control loop is used. As the internal

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current loop is very fast as compared to the outer voltage loop so it is recommended to not use the internal current loop[4].

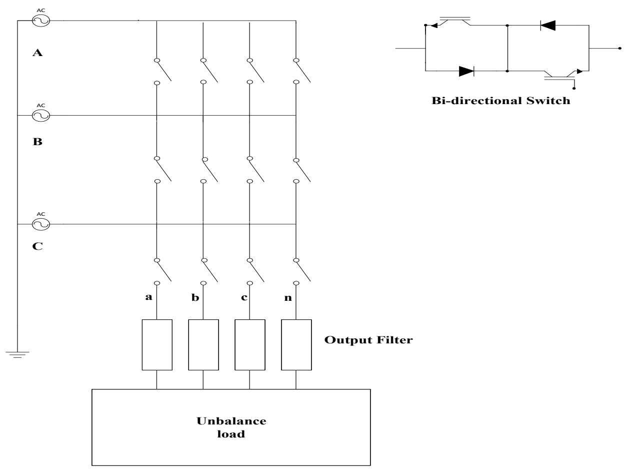

Figure 1. Three Phase Matrix Converter diagram.

2. System Parameters and Output Filter

As at output matrix converter gives our desired frequency sinusoidal waveform. As in direct matrix converter the output waveform is purely derived by consequent sampling of input waveform through switching. There are two types of harmonics exist in our system, the low frequency harmonics and high frequency harmonics. Due to fast switching the high frequency harmonic are more visible in input current waveform for which input filter is use as alternative path. Low frequency harmonics are caused due to switching ripples in the incoming voltage and current waveform, non-linearity included in converter. These all leads to low frequency harmonics in the waveforms of perspective input current and output voltage. Thus the output waveform is not that smooth having harmonics which lowers the power quality. To purify the output waveform and to extract sinusoidal waveform at output a low pass LC filter is use which actually distorts the harmonics from the waveform. To design a control system and to analyze it, the system compensators and filters are select as low pass so the higher frequency regarding knowledge is not accountable here.

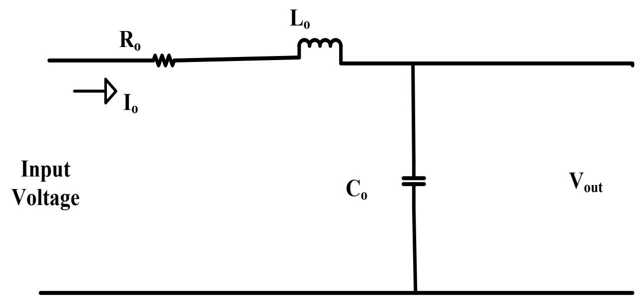

Figure 2. Output filter diagram.

The cutoff frequency is dependent on controller bandwidth and is approximately taken as 1/10th of the switching frequency[5]. The values of inductor and capacitor depend upon the cutoff frequency of filter as,

$$f_{resonant} = \frac{1}{2\pi\sqrt{L*C}} \tag{1}$$

To use this converter as a voltage source converter as inductive load is connected at the other side in normal case. For this purpose inductor value is taken very small and high value of capacitor to keep cut off frequency but very exceeding value of capacitor may lead to inrush current flow into the system. So we have to be in balance between these two extreme conditions[6]. The value of inductor is taking as 0.58 mH with an internal resistance of 0.8 Ohms. From the equation by putting the values in equation as,

$$C = \frac{1}{\omega^2 * L} \tag{2}$$

While ω=2*π*f and L=0.58 mh. The value of f is taken as 1.1 KHz.

$$C = \frac{1}{(2*\pi*1100)^2*(0.00058)} \tag{3}$$

For approximation the capacitor value is selected as 35*10-6 Farads. Now the transfer function of the filter circuit in frequency domain is as,

$$Tf = \frac{1/L_oC_0}{S^2 + {r_0}/{L}\,S + 1/L_0C_0} \tag{4}$$

By putting the values of ro, Co and Lo in the above transfer function and by converting that transfer function into discrete form taking 12800 Hz sampling frequency. The discrete transfer function is presented as,

$$G(z) = \frac{0.145Z + 0.144}{Z^2 - 1.6932Z + 0.981}$$

(5) Here I applied a PID controller for the above system's stability and checked the system response through various parameters shown.

3. PID Controller

As we know PID is basically combination of 3 types of controllers Kp (proportional), Ki (Integral controller) and Kd (derivative controller). The values of the above three controllers are arranged so that over all controller stabilize our system. Kp controllers have the flaw to cannot eliminate steady state error but it actually decreases the Tr (rise time). Similarly Ki controller decreases steady state error but increase settling time. Similarly Kd decrease both overshoot and settling time.

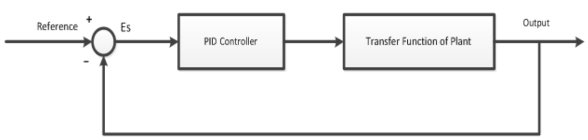

Figure 3. PID Controller with plan.

Table 1. Effect of P, I and D values in PID

Controller name	Tr(Rise time)	Overshoot	Ts (settling time)	Steady state error
Proportional	Diminish	Enhance	Little effect	Diminish
Integral	Diminish	Increase	Increase	Eliminate
Derivative	Little change	Diminish	Diminish	No change

Here P, PI and then PID are applied directly in series with the plant transfer function. The final system a PID is selected in frequency domain. The values for the perspective P, I and D are hunted through controller design in Simulink Matlab, which gives us the optimized values.

By applying the above conditions although the close loop transfer function is stable for continues time system but it has very minute gain enough to track sinusoidal signal[7]. By applying PID the system shows no results even more due to derivative action of PID, which make the system the numerator of the system zero at certain unknown value which make our system unable to run at that point.

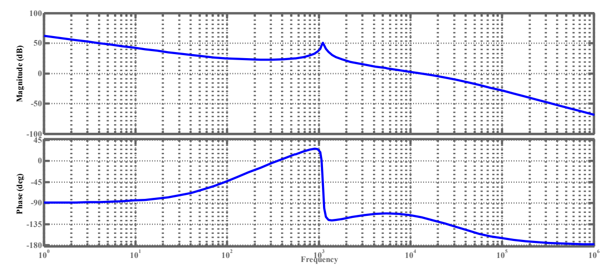

Figure 4. Bode of continuous of the system with PID controller.

In discrete model it shown very poor model response and the controller was almost unable to track the reference sinusoidal signal.

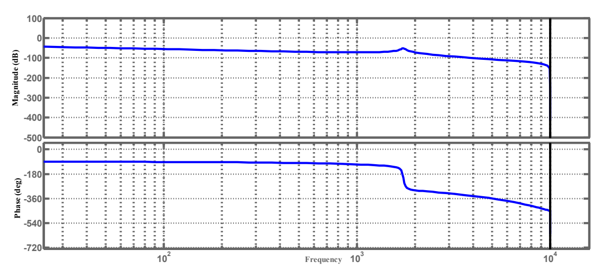

Figure 5. Bode of the discrete system PI controller.

4. Proportional Resonant Controller

I used a parallel proportional resonant controller with a proportional gain of 3. Basically an ideal Proportional resonant controller gain value is infinity ideally but practically we put some real values for our system. Normally we use PR control to reduce steady state error up to zero. Therefore it is an efficient controller to use in the systems involving sinusoidal signals. Here in our system as we use a system involved sinusoidal signals or AC power so the PR controller work very efficiently in such systems to track the desired input reference signal. Due to very high gain value at fundamental frequency it provides us better disturbance rejection and also can handle individual harmonic. We can say that PR controller is actually an AC integrator having similarity with an integrator which introduces infinite DC gain. As the controller provides infinite gain ideally for AC frequency systems but it provides neither gain nor phase shift at other frequencies[8]. In PR controller we deal individually with each harmonic, but going for higher order harmonics may complicate our system. This in return will also complicate our system hardware. The digital hardware will be more difficult to implement as a result. The transfer function of ideal PR controller is given as below.

$$G_{res}(s) = K_p + \frac{K_r \omega_o s}{s^2 + \omega_o^2} \quad (6)$$

Kr is resonant gain, K_p is proportional gain, ω_o is resonant frequency. In non-ideal system some changes are considered. Here a new term Q was introduced, Q is called as quality factor and its value is as[8],

$$Q = f_{central} / (f_H - f_L) \quad (7)$$

The terms here are $f_{central}$ is the central resonance frequency, f_H is the upper level frequency f_L is the lower level frequency. These both upper and lower frequencies are selected so as the system gain drop to 0.707 of central resonance frequency. Normally it is recommended to have higher value of Q, for this purpose the values of both lower and upper frequencies are chosen closer to the value to fundamental or central resonant frequency[9]. We keep the value of Q high in order to achieve high gain. We can say for this purpose we choose a tiny band pass. On the contrary to have lower Q value gives us poor rejection of disturbances accompanied by lower gain. This will result in a higher steady state error. To efficiently reject the disturbances and to track the reference input, the value of Q is chosen larger keeping in mind the system's overall stability. The non-ideal transfer function of PR controller including Q is as below.

$$G_{res}(s) = K_p + \frac{K_r \omega_o s}{s^2 + (\omega_o / Q)s + \omega_o^2} \quad (8)$$

This is the equation for 1st harmonic, for each harmonic we add a separate block with the value of n equal to the value of prescribed harmonic.

$$G_{res}(s) = K_p + \frac{K_r \omega_o s}{s^2 + (\omega_o / Q)s + \omega_o^2} + \frac{K_{rn}(n\,\omega_o)s}{s^2 + (n\omega_o / Q)s + (n\omega_o)^2} \quad (9)$$

For example if we want to provide desired gain at 3rd and 5th harmonics then our desired equation will be as,

$$G_{res}(s) = K_p + \frac{K_r \omega_o s}{s^2 + (\omega_o / Q)s + \omega_o^2} + \frac{K_{3r}(3\omega_o)s}{s^2 + (3\omega_o / Q)s + (3\omega_o)^2} + \frac{K_{5r}(5\omega_o)s}{s^2 + (5\omega_o / Q)s + (5\omega_o)^2} \quad (10)$$

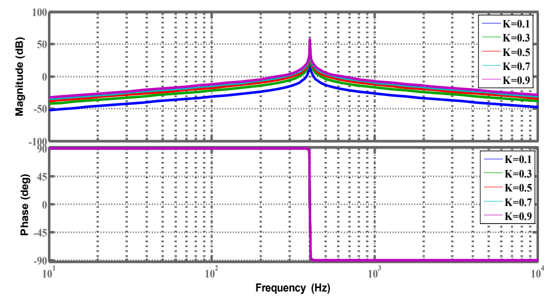

Figure 6. Bode of the Controller by changing the value K (resonant gain).

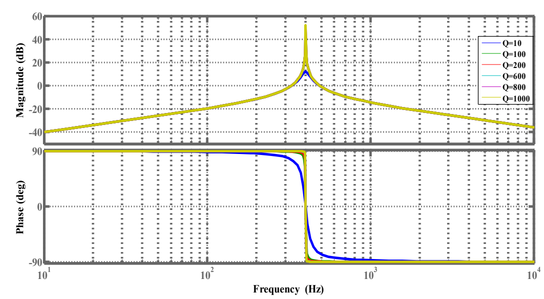

Figure 7. Bode of the Controller by changing the value Q.

Each new block for perspective harmonic there will be an addition of new block in the controller block depending upon the system requirements. For PR controller a linear second order controller designed through SI SO tool is use in conjunction with plant's transfer function. Here the only two controllers are applied at 1st and 3rd harmonics and it shown satisfactory results. Initially a controller at 5th harmonic has been applied as shown in the Figure (8) to note the changes in results due to the addition of new controller block. The gain is provided as shown in the Figure (8) at 400 Hz, 1200 Hz and at 2000 Hz.

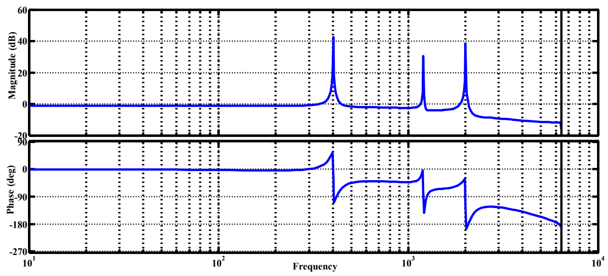

Figure 8. Bode of the system using 5th harmonic PR Controller.

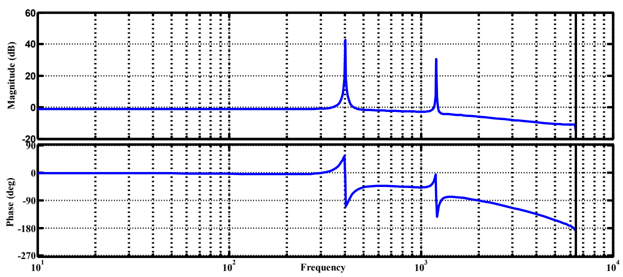

Figure 9. Bode of the system using 5th harmonic PR controller.

The gain margin is 11 dBs and phase margin is 54.4 degrees by selecting the value of Q=1000 and resonant gain value as 0.5. The results from bode and output wave shows that we already have enough gain. However this addition of controller block for 5th harmonic will further complicate our system and also will increase the price of overall controller development. The bode plot shown an increase in the gain at that very harmonic where a control block has been applied. In the sinusoidal tracking high gain is needed for periodic signals distortion. The sub-controller provides that desired gain at the applied harmonic. However, high gain may lead the system towards more error by increasing the magnitude of the output signal more than the desired level. From the Figure (7) below it is clear that controller provide desired at fundamental frequency (400 Hz) and at 3rd harmonic (1200 Hz).The output voltage signal with the reference tracking is shown in the below diagrams. By applying error signal initially even at 10 V magnitude our system shows stability. Due to the introduction of error initially it shows very less distortion before 0.02 seconds which then smoothens after 0.04 seconds as shown in the Figures below.

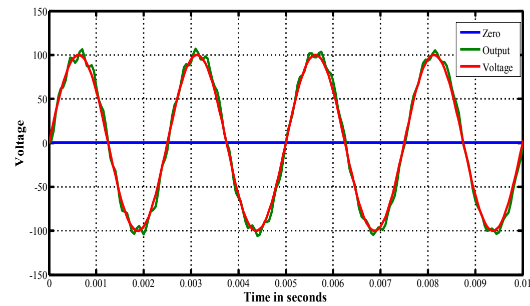

Figure 10. Output Voltage sine wave.

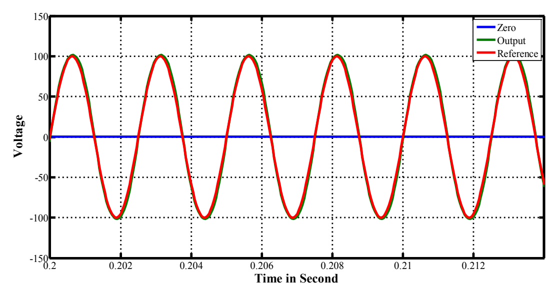

Figure 11. Output sine wave after 0.2 second.

5. Conclusion

For sinusoidal tracking in matrix converter it is strongly recommended to not apply PID controller. The main reason behind is for sinusoidal signal tracking a high gain is needed at the desired time for harmonics distortion. The PR controller on the other hand provides better results and better reference sinusoidal tracking as compared to PID controller. The total harmonics distortion is PR controller is also less than the 5% as required per international standards and the gain margin is 11 dBs and phase margin is 54.4 degrees already. Therefore it is suggested to use PR controller for matrix converter control as compared to PID controller.

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