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Proportional resonant current controller strategy in inverter application

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ABSTRACT

This paper presents the method of proportional resonant current controller strategy in inverter system application. In this study, the mathematical modelling of the controller is shown in detail. This is important for the modelling in Matlab Simulink. Nowadays, the decrement of power quality is easily found in this inverter system where inverter extensively used as interface circuits. To solve this problem, proportional resonant current controller is the solution. At resonant frequency, this controller has infinite gain which ensures a zero steady-state error in a stationary frame. This will result in minimized load current distortion as well as the harmonic contents. At the end, simulation result shows when using PR current controller, the unwanted harmonics injection are much reduced.

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1. INTRODUCTION

Nowadays, renewable energy sources such as wind, solar, hydraulic in power generation has become more important as energy consumption increases. The output current from the free energy sources are in direct current [1]. In order to convert the current into alternative current for transmission, inverter are used to convert and interface the current waveform. Inverter is usually pulse-width modulated. It occurs at a high switching frequency, either current controlled or voltage controlled and uses whether a linear or can be nonlinear control algorithm as well [2]. This synthesis method of inverter will produce harmonics spectra and as well as the non-linear loads that used in distribution.

For non-linear loads, its current waveform is not proportional to the voltage. This is different for linear loads where the current is proportional to the applied voltage [3]. Today, for most power networks, the major source of unwanted harmonic generations are from non-linear loads. It can degrade the power quality and cause resonance problems [4]. Rectifiers specifically which are broadly used as power electronic component to interface the system is one of the reason for degradation of power quality. For many domestic appliances which has rectifiers in its switched mode power supplies can degrade the quality of voltage supply [5-6]. One way to improve the power quality is by using filters, a power electronic device that has excellent task for performance filtering. Filters can be used either as a voltage controlled source or a current controlled source [7-11]. Two types of filter which is vital to consider for harmonics cancellation is the shunt and series active filter. Both have their own purposes; to inject currents so that it cancels harmonic currents directly and compensates distortion of voltage caused by non-linear loads respectively [12]. The performance of these filters are evaluated on the current control and the harmonic reference generation system.

For control system, the conventional proportional integral (PI) controller is easy to be implemented. However, one common drawback of PI controllers is they cannot track non direct current references without errors between the reference and output currents getting out from the filters [13]. The system will be unstable when the attenuation and resonant frequency of the filter varies significantly [14]. Thus, proportional resonant (PR) controller is used to reduce and even eliminate these harmonics disturbances. The characteristic of PR controller which has infinite gain at the resonant frequency will ensure zero steady-state error in a stationary frame. As a result, it minimize load current distortion, reduce unwanted harmonics, and will have better time domain response [15-25]. The connected filter is use to filter the inverter's switching frequencies [26].

This paper presents the method of proportional resonant current controller strategy in inverter system application. In this study, the mathematical modelling of the controller is shown in the next section. Previous researches in inverter application is discussed in brief in the following section. At the end, simulation result shows when using PR current controller, the unwanted harmonics injection are much reduced.

2. PROPORTIONAL RESONANT CONTROLLER

Figure 1 below shows the block diagram in a system using PR current controller. There are basically three block systems in the figure which are the controller block, the inverter block and the filter block. The current reference, I_i* will be compared with the output current I_i coming out after the filtering process. It is the resultant error which then be the input for controlling system.

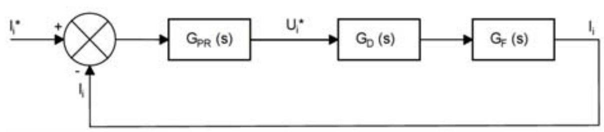

Figure 1. Block diagram of inverter system with PR current controller [27]

From the figure, the PR current controller $G_{PR}(s)$ is represented by:

$$G_{PR}(s) = K_P + K_I \frac{s}{s^2 + \omega_0{}^2} \quad (1)$$

where, K_P is the proportional gain term, K_I is the Integral Gain term and ω_o is the resonant frequency. The resonant term will basically provide infinite gain at the system frequency, ω_o and at other frequencies, there will not be occurring any phase shift and gai [28, 29]. The K_P term controls the system dynamic such as gain and phase margins as well as its bandwidth. Despite all this, (1) can allow stability problems to arise because of the infinite gain. Therefore, the control system can be made non ideal. For this to happen, damping is introduced. It is shown in (2) below;

$$G_{PR}(s) = K_P + K_I \frac{2\omega_c s}{s^2 + 2\omega_c s + \omega_0{}^2} \quad (2)$$

where, ω_c is the bandwidth around the system frequency of ω_o. From the equation, the gain of the controller at the system frequency ω_o is now restricted. Nevertheless, it is still large enough to give only a slightly small steady state error. The equation is actually making the controller more reliable in digital systems due to their rigorous limitation [30]. For simulating in Matlab purposes, based on (1), by using the Tustin transformation, the analogue equation above is changed to the z domain known as the discrete function. This is done by substituting $\boldsymbol{s}$ with $\frac{2}{T}\frac{1-z^{-1}}{1+z^{-1}}$. Based on that, it is then transformed to;

$$G_{PR}(z) = K_P + K_R \frac{\frac{2}{T}\frac{1-z^{-1}}{1+z^{-1}}}{\left(\frac{2}{T}\frac{1-z^{-1}}{1+z^{-1}}\right)^2 + \omega_o^2}$$

$$G_{PR}(z) = \frac{K_P\left[\left(\frac{2}{T}\frac{1-z^{-1}}{1+z^{-1}}\right)^2 + \omega_o^2\right] + K_R\left(\frac{2}{T}\frac{1-z^{-1}}{1+z^{-1}}\right)}{\left(\frac{2}{T}\frac{1-z^{-1}}{1+z^{-1}}\right)^2 + \omega_o^2}$$

$$G_{PR}(z)=\frac{K_P\left[\left(\frac{4}{T^2}\right)\left(\frac{1-2z^{-1}+z^{-2}}{1+2z^{-1}+z^{-2}}\right)+\omega_0^2\right]+\frac{2K_R}{T}\left(\frac{1-z^{-1}}{1+z^{-1}}\right)}{\left(\frac{4}{T^2}\right)\left(\frac{1-2z^{-1}+z^{-2}}{1+2z^{-1}+z^{-2}}\right)+\omega_0^2}$$

$$G_{PR}(z)=\frac{\left(\frac{4K_P}{T^2}\right)\left(\frac{1-2z^{-1}+z^{-2}}{1+2z^{-1}+z^{-2}}\right)+K_P\omega_0^2+\frac{2K_R}{T}\left(\frac{1-z^{-1}}{1+z^{-1}}\right)}{\frac{4(1-2z^{-1}+z^{-2})+T^2\omega_0^2(1+2z^{-1}+z^{-2})}{T^2(1+2z^{-1}+z^{-2})}} \quad (3)$$

In order to get a simpler transfer function, some adjustments are made. This is shows as below:

$$G_{PR}(z)=\frac{\left(\frac{4K_P}{T^2}\right)\left(\frac{1-2z^{-1}+z^{-2}}{1+2z^{-1}+z^{-2}}\right)+K_P\omega_0^2\left(\frac{T^2(1+2z^{-1}+z^{-2})}{T^2(1+2z^{-1}+z^{-2})}\right)+\frac{2K_RT}{T^2}\left(\frac{1-z^{-2}}{1+2z^{-1}+z^{-2}}\right)}{\frac{4(1-2z^{-1}+z^{-2})+T^2\omega_0^2(1+2z^{-1}+z^{-2})}{T^2(1+2z^{-1}+z^{-2})}}$$

$$=\frac{4K_P(1-2z^{-1}+z^{-2})+K_P\omega_0^2T^2(1+2z^{-1}+z^{-2})+2K_RT(1-z^{-2})}{4(1-2z^{-1}+z^{-2})+T^2\omega_0^2(1+2z^{-1}+z^{-2})}$$

$$=\frac{4K_P-8K_Pz^{-1}+4K_Pz^{-2}+K_P\omega_0^2T^2+2K_P\omega_0^2T^2z^{-1}+K_P\omega_0^2T^2z^{-2}+2K_RT-2K_RTz^{-2}}{4-8z^{-1}+4z^{-2}+T^2\omega_0^2+2T^2\omega_0^2z^{-1}+T^2\omega_0^2z^{-2}}$$

$$=\frac{(4K_P+K_P\omega_0^2T^2+2K_RT)+(2K_P\omega_0^2T^2-8K_P)z^{-1}+(4K_P+K_P\omega_0^2T^2-2K_RT)z^{-2}}{(4+T^2\omega_0^2)+(2T^2\omega_0^2-8)z^{-1}+(4+T^2\omega_0^2)z^{-2}} \quad (4)$$

By dividing the nominator and the denominator of the transfer function in (4) above with $(4+T^2\omega_0^2)$, the discrete form becomes:

$$G_{PR}(z)=\frac{\frac{(4K_P+K_P\omega_0^2T^2+2K_RT)}{(4+T^2\omega_0^2)}+\frac{(2K_P\omega_0^2T^2-8K_P)}{(4+T^2\omega_0^2)}z^{-1}+\frac{(4K_P+K_P\omega_0^2T^2-2K_RT)}{(4+T^2\omega_0^2)}z^{-2}}{1+\frac{(2T^2\omega_0^2-8)}{(4+T^2\omega_0^2)}z^{-1}+z^{-2}} \quad (5)$$

To simplify the above equation, it can be re-written as:

$$G_{PR}(z)=\frac{b_o+b_1z^{-1}+b_2z^{-2}}{1+a_1z^{-1}+a_2z^{-2}} \quad (6)$$

where;

$$b_o=\frac{(4K_P+K_P\omega_0^2T^2+2K_RT)}{(4+T^2\omega_0^2)}$$
$$b_1=\frac{(2K_P\omega_0^2T^2-8K_P)}{(4+T^2\omega_0^2)}$$
$$b_2=\frac{(4K_P+K_P\omega_0^2T^2-2K_RT)}{(4+T^2\omega_0^2)}$$
$$a_1=\frac{(2T^2\omega_0^2-8)}{(4+T^2\omega_0^2)}$$
$$a_2=1$$

K_P and K_R is the proportional gain and the resonance gain respectively, T is the sampling time and ω_o is the system frequency in rad/sec. With the resonance part added to the proportional controller, the system steady state error can be much reduced or nearly eliminated. Substituting T with 50μs and $\omega_o$with 2π x 50 Hz, the optimum gains for this control technique can be obtained by trial and error tuning. Figure 2 is the transformation of equation [6] that is modelled in Matlab Simulink. It is the resulting output signal that is used in the inverter switching process.

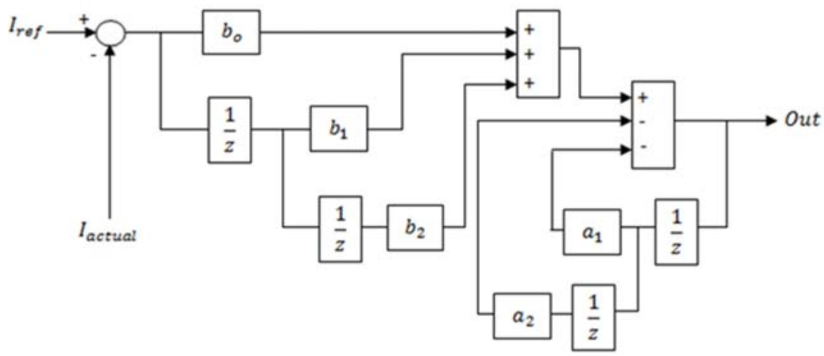

Figure 2. The parameters in the PR current controller system

3. PROPORTIONAL RESONANT CONTROLLER IN INVERTER APPLICATION

Inverter systems are very essential as a power generating method. Furthermore, the number of these inverter systems that are being connected to the grid is climbing. A paper by [31] has review the three phase inverters control to compensate an unbalanced load. Effectiveness of proportional resonant controller has been proved by many researchers where some of them can be found in [32-37]. To decrease the bad effects on the power quality, it is very important to maintain the harmonics injected by these inverters under certain limit. PR controller provides high gain at a certain resonant frequency and almost no gain exists at the other frequencies. Thus, it exhibits good transient response over the conventional PI controller when system subjected to load disturbance. The better performance is obtained using harmonic compensator along with the modelled PR controller. PR controller exhibits good transient response over the conventional PI controller when system subjected to load disturbance and better performance is obtained using harmonic compensator along with the modelled PR controller [38].

From [35], the inverter output current waveform are in acceptable sinusoidal shape when the system uses a PR current controller, as seen in the simulation results shown in Figure 3 It has still a steady state error but of small value. This is because of using a non-ideal PR controller mentioned earlier to avoid stability problems in the controller.

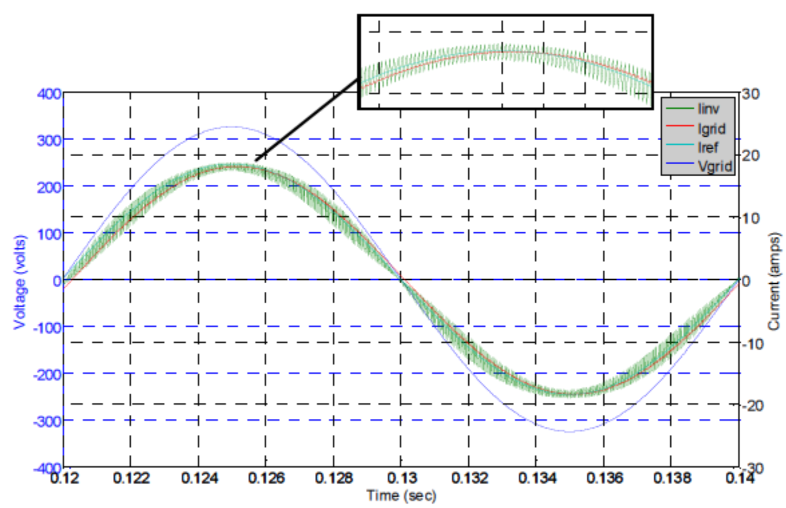

Figure 3. Grid voltage, grid current, reference current, inverter current in simulation with PR controller [35]

Figure 4 shows that the original harmonic spectrum without using PR current controller result simulation. It can be seen a big percentage number of amplitude in the 3rd, 5th, and 7th frequency. Whilst in Figure 5, it shows the grid current harmonic profiles when PR controller is used. From the figure, it also noticeable that the 1st harmonic of the grid current achieved 100%. This means the value is as expected. In addition, the 3rd, 5th and 7th harmonics reached around only 5% of current amplitude which shows better performance in term of unwanted harmonics injection.

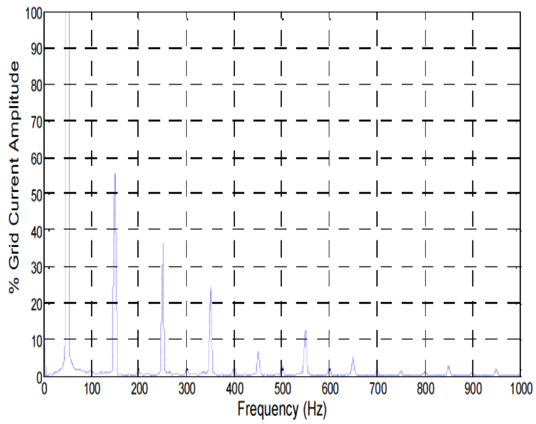

Figure 4. Harmonic spectrum without PR current controller [35].

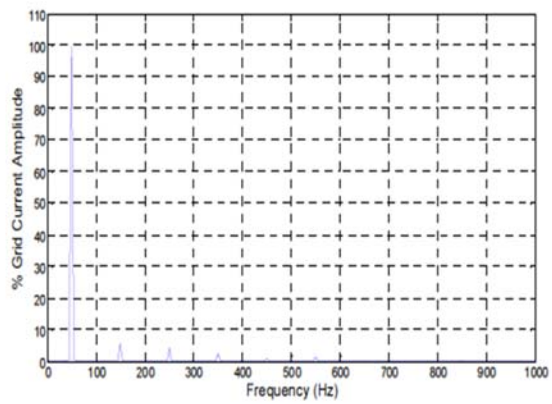

Figure 5. Harmonic Spectrum with PR current controller [35]

4. CONCLUSION

This paper has presented a method of proportional resonant controller used in inverter application. Mathematical function and modelling in Matlab of the PR controller is shown. An overview of this controller in inverter application has been done where in one of the research, using PR controller has reduce the error of fundamental current to zero, while 3rd, 5th, 7th harmonics in grid current also improved to around 5%. As a conclusion, from the review, it shows the good merit of using proportional resonant controller in inverter application.

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