

## PI control of a phase tracking loop

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### ABSTRACT

In this work, the Proportional-Integral PI control implemented in a PLL (Phase Tracking Loop) is presented, with the purpose of synchronizing an external phase coming from a renewable energy generation system to the phase of an electrical network. MATLAB® and PSIM® software are used to simulate the results obtained.

**KEYWORDS;**-Control PI, electrical network, phase tracking loop (PLL), renewable energy generation system.

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### I. INTRODUCTION

In recent years, the growth in the use of renewable energies has been considerable, due to the increase in global warming. Among the renewable energies we find solar, wind, hydraulic, geothermal energy, etc.; these energies are used so that, together with a generation system, electrical energy is produced. The electrical power generation system from renewable energy is shown in Fig. 1. It is observed that the energy obtained goes through a conversion process to obtain an Alternating Current (AC) signal.



Fig. 1. Electric power generation system from a renewable energy source.

Within the electrical energy generation systems, there are those of the type connected to the network, where the electrical energy from renewable sources is injected into the conventional electrical network with the purpose of reducing the consumption of the conventional network and having an economic benefit in the receipt of electricity consumption.

In order to inject energy into the electrical network, it is necessary that the energy generated is at the same phase and frequency as that established by the electrical network, for this reason it is necessary to use a PLL Phase Tracking Loop. The PLL connection is made between the power grid and the inverter, as shown in Fig. 2, since the inverter signal is coupled to the power grid signal.

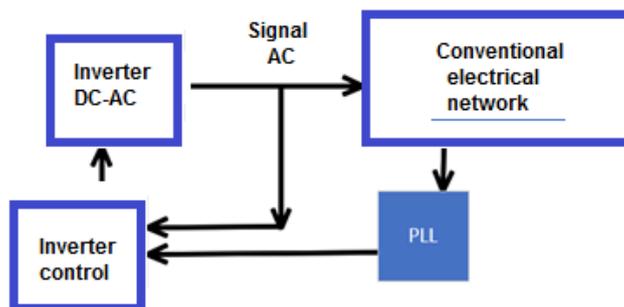


Fig. 2. Connection of the PLL to the inverter and the electrical network.

A PLL is a phase tracking loop, that is, it manages to keep an output signal synchronized with an input reference signal, in such a way that the error of the output phase with respect to the input phase is almost zero; The first investigations of the PLL were carried out in 1923 and it began to be used in 1970. The applications of the PLL are:

- Frequency synthesizers.
- Signal reconstitution (signal filtering).
- Control of a motor by monitoring phase and frequency.
- Electric power generation systems.

Fig. 3 shows the block diagram of the phase tracking loop structure, which is made up of a filter that maintains the amplitude of the signals; the phase detector is in charge of finding the phase of  $V_{red}$ ; the PI controller makes the output phase angle follow the input phase reference, as well as maintaining robustness against noise and distortions and finally there is the oscillator part, which allows the variation of frequency and phase.

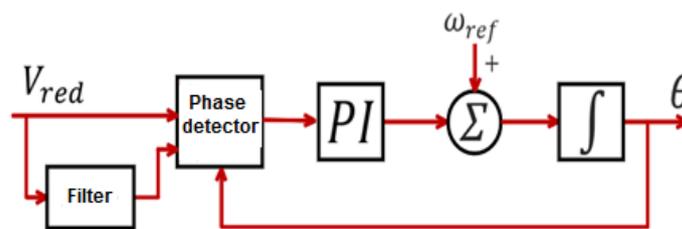


Fig. 3. General block diagram of the PLL.

Phase detection is performed by means of the Clarke and Parke transform. The Clarke transform converts the components of a system of type abc into two components of a stationary frame  $\alpha$  and  $\beta$ . The Park transform converts the  $\alpha$  and  $\beta$  components to a d and q synchronous reference frame. Because the conventional single-phase electrical network is considered, and because there is only one  $\alpha$ -type signal, it is necessary to generate the missing signal  $\beta$  by a proposed signal.

Fig. 4 shows the conversion of the  $\alpha$  signal coming from the single-phase electrical network, then the  $\beta$  signal is generated, to finally convert the signals to the synchronous reference frame d and q. The phase detection process allows knowing the frequency, phase and amplitude at which the electrical network is working.

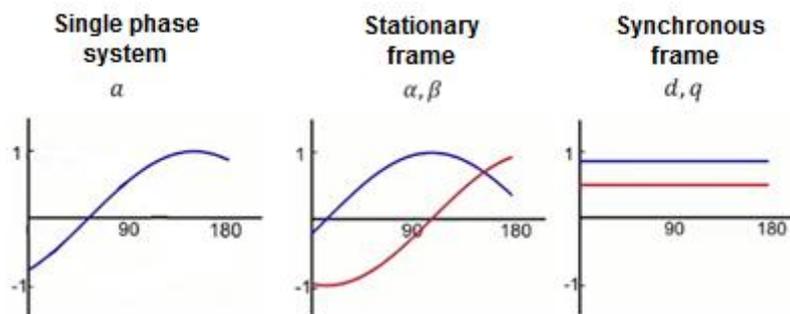


Fig. 4. Transformation from a single-phase system to a synchronous frame with d and q components.

## II. DEVELOPING

For the development of the PLL control, the MATLAB software is used, where the programming is carried out. Filter programming is done using equation 1, where  $\omega_{red}$  corresponds to the angular frequency of the network.

$$Filter = \frac{\omega_{red} - s}{\omega_{red} + s} \quad (1)$$

$$\omega_{red} = 2\pi * f_{red} \quad (2)$$

Considering  $f_{red}=60$  Hz and substituting in equation 2, we have:  $\omega_{red} = 377$  and substituting  $\omega_{red}$  in equation 1, the Filter equation is obtained:  $Filter = \frac{377-s}{377+s}$ .

The  $\alpha$  and  $\beta$  coordinates are given by equations (3) and (4), where the value of the conventional electrical network is 127 V, and the generated signal, in this case  $V_{\beta}$ , maintains the same amplitude as  $V_{\beta}$  but with a  $90^\circ$  offset.

$$V_{\alpha} = V_{red} = 127V \quad (3)$$

$$V_{\beta} = V_{red+90^\circ} = 127V \angle 90 \quad (4)$$

The coordinates  $V_d$  and  $V_q$ , according to the literature, are described below:

$$V_d = V_{\alpha} \cos \theta + V_{\beta} \sin \theta \quad (5)$$

$$V_q = -V_{\alpha} \sin \theta + V_{\beta} \cos \theta \quad (6)$$

Fig. 5 shows the programming in MATLAB to later obtain the controller, where the network voltage is equal to 127 V, PI corresponds to the controller and  $T_{pll}$  is the closed-loop transfer function.

```

1 - set (cstprefs.tbxprefs, 'FrequencyUnits','Hz');
2 - s=tf('s'); %Declaración de la variable compleja s
3 - w=logspace(1,3,2000);
4 - Vred=127 %Voltaje de la red
5 - fred=60 %Frecuencia de la red
6 - G=1/s; %Funcion de transferencia del integrador
7 - Vd=Vred*sqrt(2) %Valor de la componente Vd
8 - G1=Vd*G; %Reducción del bloque
9 - wred=2*pi*60; %Frecuencia angular de la red
10 - PI=s+58.3/s % Controlador PI del PLL
11 - Tpll=Vd*PI*G; % Funcion a transferencia del lazo cerrado
12 - figure (1);
13 - margin(Tpll);
14 - grid;
```

**Fig. 5. Programming in MATLAB of the PLL.**

The value of the proposed controller is given by equation 7. Once the controller is selected, the PLL circuit is made in PSIM Software, in order to subsequently analyze the signals obtained.

$$PI = \frac{s + 58.3}{s} \quad (7)$$

Fig. 6 shows the electrical circuit of the PLL, in this case no reference frequency is placed, therefore, the controller together with the PLL will be in charge of searching for both the phase and the frequency of the electrical network.

For the case of Fig. 7, we have the same electrical circuit of the PLL, with the difference that a reference frequency of 60 Hz is added, since it is known that the conventional electrical network in Mexico works at 60 Hz.

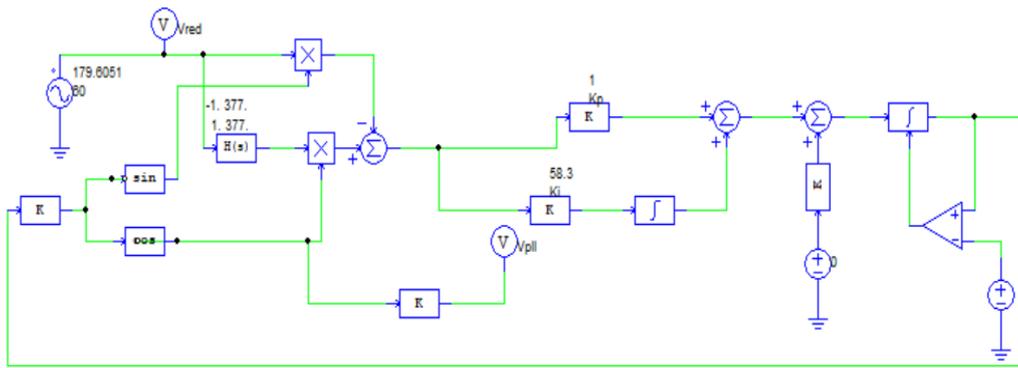


Fig. 6. PLL electrical circuit.

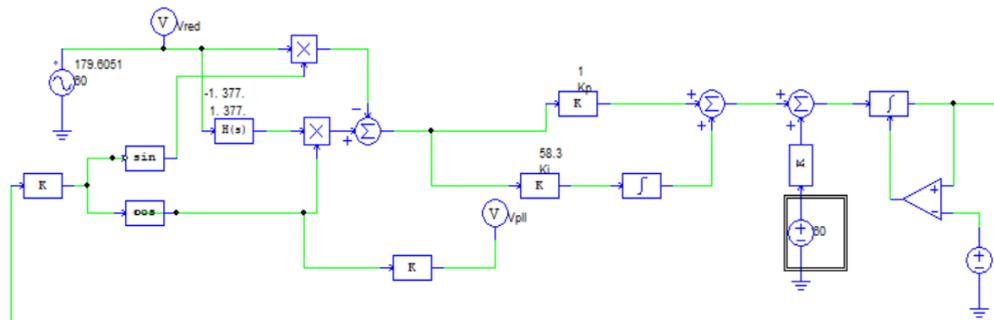


Fig. 7. Electrical circuit of the PLL with a reference frequency of 60 Hz.

### III. RESULTS OBTAINED

The response of the proposed controller in equation 7 is shown in Fig. 8, where it is observed that according to the Nyquist criteria the system is stable and the proposed controller makes the system comply with the phase and gain margins established by the bibliography.

Also, in the step response, the controller responds in 0.06 seconds, being a small time, and the overshoot is less than 20%. The aforementioned answers were obtained by means of MATLAB software.

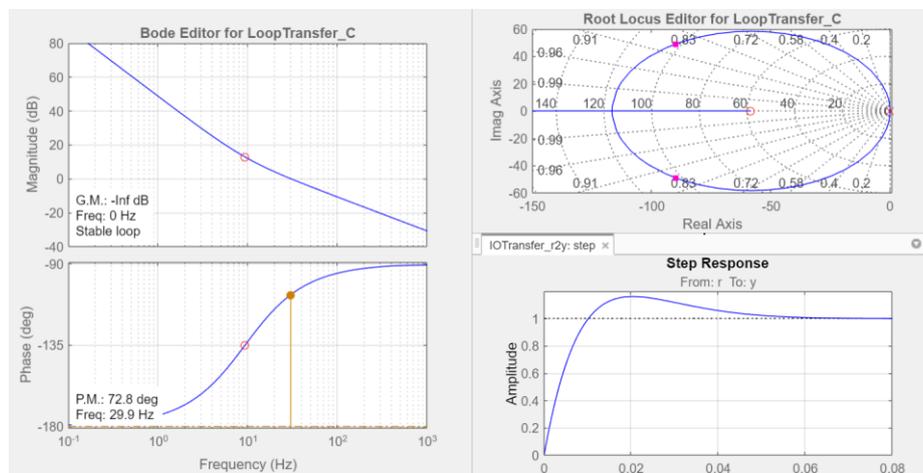
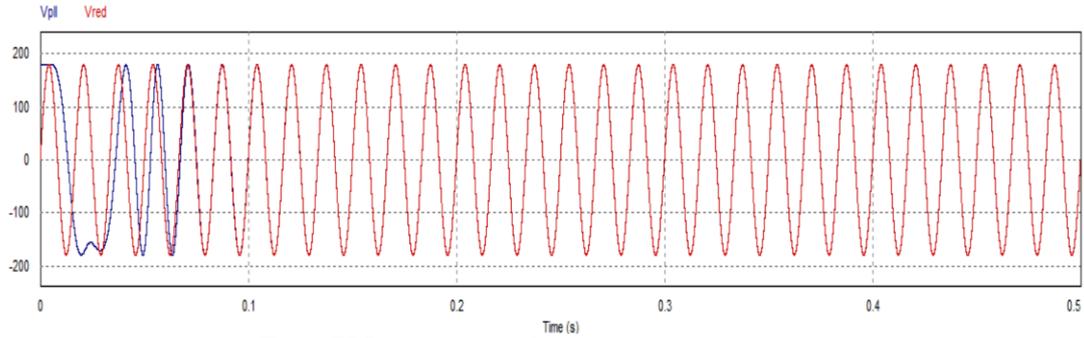


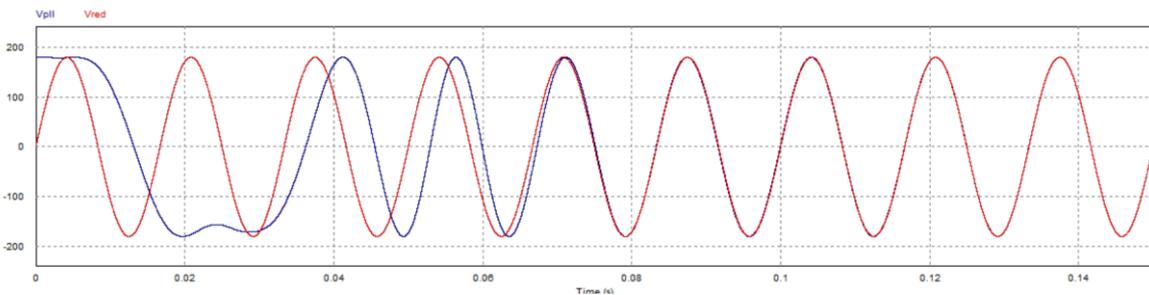
Fig. 8. System response with the proposed controller.

To verify the functionality of the PLL, the signals  $V_{pll}$  and  $V_{red}$  are obtained from the electrical circuit, where  $V_{pll}$  corresponds to the signal generated by the PLL and  $V_{red}$  to the voltage signal of the conventional electrical network. Fig. 9 shows the signal obtained from Fig. 6, where no reference frequency was placed.



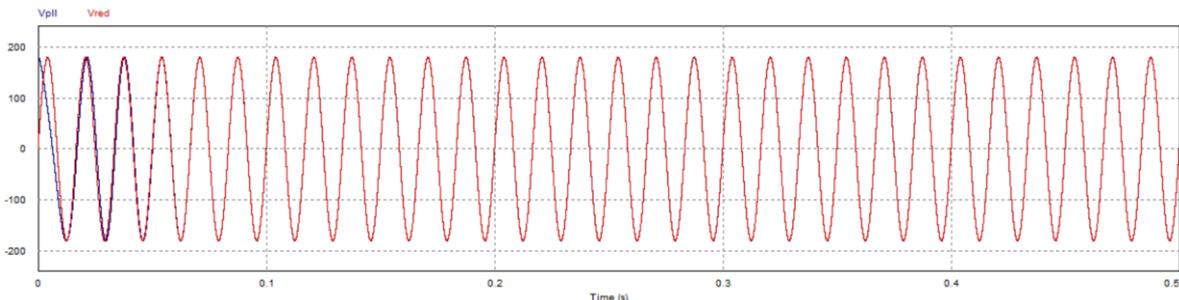
**Fig. 9. PLL response without frequency reference.**

Making an approach to the signals obtained in Fig. 9, it is observed that the PLL at the beginning looks for the signal of the electrical network to synchronize to it and after 0.08 seconds it achieves it maintaining the same amplitude, the same frequency and the same phase both signals (See Fig. 10).



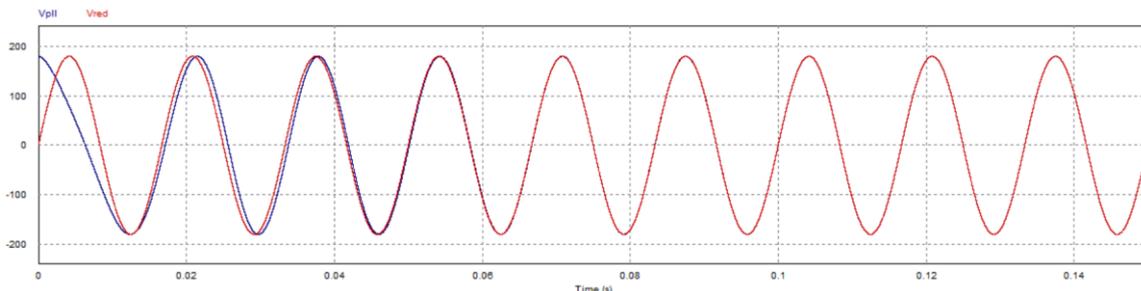
**Fig. 10. PLL response without frequency reference with zoom.**

Fig. 11 shows the behavior of the PLL when a reference frequency is added to it.



**Fig. 11. PLL response with frequency reference.**

Making an approach to Fig. 11, Fig. 12 is obtained, where it is observed that the response of the PLL is a little faster compared to the previous one, due to the fact that it managed to synchronize with the electrical network in a time of 0.045 seconds.



**Fig. 12. PLL response with zoomed frequency reference.**

#### IV. CONCLUSION

With this writing, it is shown that the PLL is of great importance when it is required to synchronize one signal with respect to another, since, by means of it, two signals can be maintained at the same phase and the same frequency; therefore the PLL has various applications as mentioned in the introduction. There are several phase search techniques, such as those shown in the bibliography, but one of the most used is the one used in this paper, due to its practicality and ease of implementation.

The application used in the present work focuses on renewable energy generation systems, where the generated energy is injected into the already established conventional electrical network.

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