# Research on Frequency Adaptability of Permanent Magnet Synchronous Generator

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**Abstract**. In this paper, a study on frequency adaptability of permanent magnet synchronous generator (PMSG) is carried out, the influence mechanism of the frequency changes on PMSG is revealed. It is proposed that setting the converter protection setting value and PLL parameters reasonably can ensure that the grid frequency change has little effect on the PMSG. The simulation of frequency adaptability of PMSG is realized on Matlab/Simulink, and the simulation results verify the correctness of the conclusion.

## 1 Introduction

After asynchronous networkin between Yunnan power grid and China Southern Power Grid, the system capacity becomes smaller and the anti-disturbance ability becomes worse[1-2]. The issue of frequency has replaced the transient stability issue as its main problem[3]. By 2019, the installed capacity of renewable energy in Yunnan has reached 11. 57 million kilowatts, and in the dry season, the highest proportion of power generation in some regions has reached nearly 50%. With the change of power grid characteristics and high proportion of the renewable energy grid connected[4-7], the adaptability of renewable energy to frequency has become a problem that must be studied.

Based on the MATLAB / Simulink platform, this paper mainly studies frequency adaptability of PMSG. Through a large number of theoretical research and simulation verification, it is concluded that the response characteristics and performance parameters of PLL will affect the response characteristics of PMSG when the frequency changes, reasonable setting of converter protection setting value and PLL parameters can make the grid frequency change has little impact on PMSG.

## 2 Analysis frequency adaptability of PMSG

### 2.1 Analysis of the influence of PLL on PMSG frequency adaptability

When the frequency changes, if change is within the hold-in range, PLL can track frequency change and enter the phase-locked state quickly. If the frequency change is out of pull-out range, the capture time is long, and it takes some time to recover to the steady due to the inherent response speed of PLL.

During the period when PLL is in the hold-in range, the adjustment of the converter is in a dynamic change process, and the parameters of the converter also have a transient change process. Taking the sudden drop of frequency as an example, the relationship between the output frequency of the phase-locked loop and the actual frequency is shown in Figure 1.

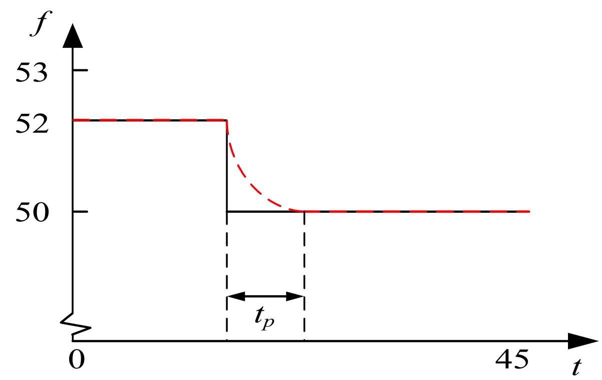


**Figure 1.** Response characteristics of PLLwhen frequency changes

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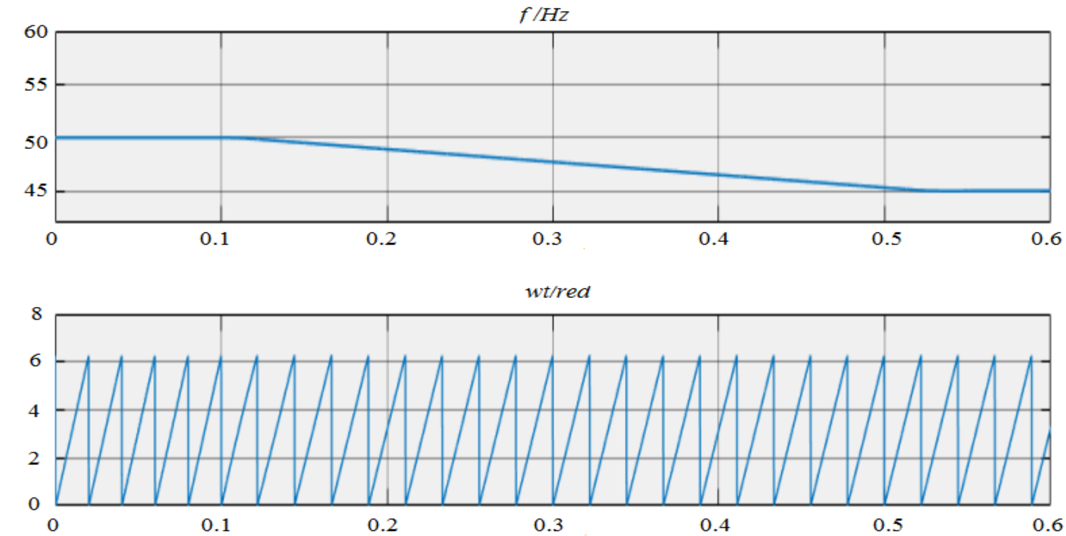



**Figure 2.** Simulation waveform diagram of frequency down step

When the actual grid frequency fluctuates, it takes a period of $t_p$ for PLL to fully lock the grid frequency, as shown in Figures 1 and 2. The magnitude of $t_p$ depends on the frequency variation of grid and the response speed of PLL. Therefore, within $t_p$, the frequency output by PLL gradually changes, and the current and voltage under the dQ axis coordinate obtained also changes, which leads to the active and reactive power output by the grid side converter gradually changes. However, since the frequency change of the grid is usually small, the power output of the PMSG may not change significantly.

### 2.2 Analysis of the influence of filter on PMSG frequency adaptability

At the moment of frequency changes, the filter resistance Rg and the inductance Lg connected in series on the AC side of the grid-side converter and the impedance of the filter connected in parallel on the AC side will change. The grid-side converter is connected to the grid as shown in the figure below.

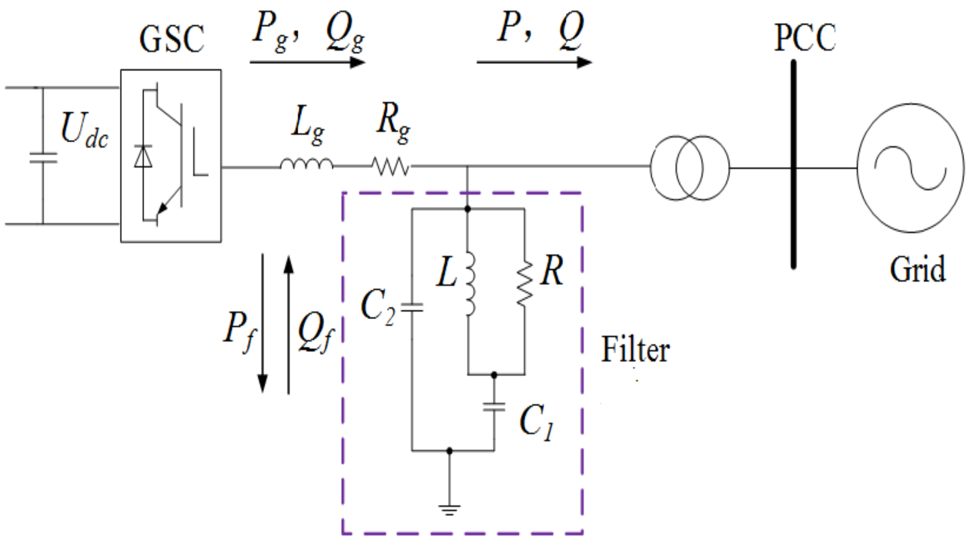



**Figure 3.** Grid-side converter and grid

As shown in Figure 3, the AC filter is first composed of a resistor R in series with an inductor L, and then a capacitor $C_1$ in series, and finally in parallel with a capacitor $C_2$. According to the basic principle of the circuit, the impedance of the AC filter can be obtained.

$$Ztotal=\frac{Z_1}{Z_2} \tag{1}$$

$$Z_1=\left(\frac{R^2\omega L}{(R^2+\omega^2L^2)\cdot\omega C_2}-\frac{1}{\omega^2C_1C_2}\right)-j\frac{R\omega^2L^2}{(R^2+\omega^2L^2)\cdot\omega C_2} \tag{2}$$

$$Z_2=\left(\frac{R\omega^2L^2}{(R^2+\omega^2L^2)\cdot\omega C_2}-\frac{1}{\omega^2C_1C_2}\right)-j\frac{R\omega^2L^2}{(R^2+\omega^2L^2)\cdot\omega C_2} \tag{3}$$

In Figure 3, ω is the grid frequency R, L, C1, C2 correspond to the resistance, inductance and capacitancerespectively.

According to formula (1), the impedance of the AC filter is related to the grid frequency ω. When ω decreases, the AC filter impedance Ztotal will increase. On the contrary, when the grid frequency increases, Ztotal will decrease. Changes in the impedance of the filter will cause changes in the power flowing into it. The power flowing into the AC filter can be expressed as formula (4).

$$S_f = P_f - jQ_f = \frac{U^2}{Z_{re}} - j\frac{U^2}{Z_{im}} \approx j\frac{U^2}{Z_{total}} \tag{4}$$

The AC filter mainly emits reactive power, and the actual active power absorbed can be ignored. It can be seen from formula (4) that when frequency decreases, Ztotal increases, the reactive power output by the AC filter will decrease. Conversely, when the grid frequency increases, the power flowing into the AC filter will increase.

When frequency changes, the active power flowing into the AC filter can be ignored relative to the active power output by the converter, and the reactive power output by the AC filter will decrease. According to the grid-side power flow shown in Figure 3, the power injected into the grid can be calculated.

$$\begin{cases} P = P_g - P_f \approx P_g \\ Q = Q_g + Q_f \end{cases} \tag{5}$$

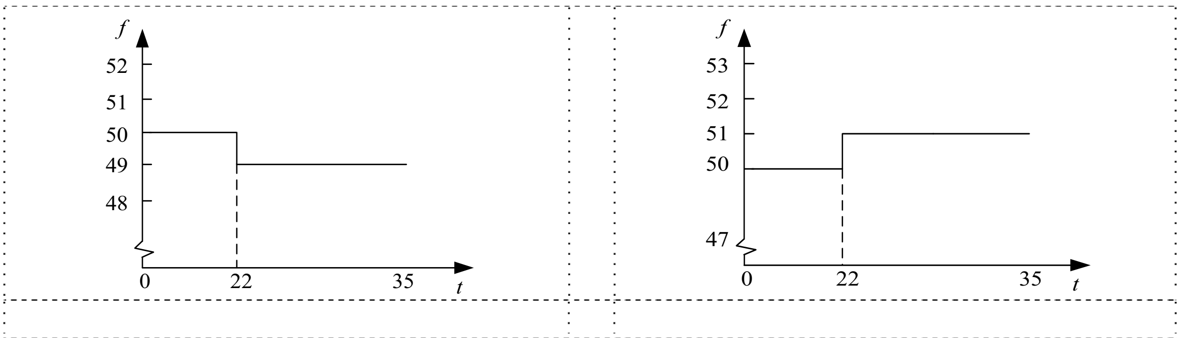
According to equation (5), it can be known that when frequency decreases rapidly, the active power injected by PMSG is almost unchanged, while the reactive power output by the filter will drop, because the grid-side converter adopts double closed-loop vector control, the reactive current command is calculated from the difference of reactive power through PI. Therefore, the reactive power deviating from the reactive power reference value caused by the sudden drop in frequency will cause the reactive current command to change, and further this reduces the reactive power injected into the grid. When PLL is within the hold-in range, the converter control returns to normal, and the reactive power is gradually adjusted to 0. At this time, the reactive power gradually attenuates and returns to the rated value. The value is 0, and finally stabilizes at the new grid frequency. When frequency rises suddenly, the reactive power change is opposite to the frequency drop, while the active power and DC voltage remain almost unchanged.

When the frequency changes gradually, the PMSG response is similar to the response when the frequency changes rapidly. However, due to the frequency changes slowly, PLL can always follow the frequency change, so the reactive power will not change suddenly, and will always follow the frequency change smoothly. When the frequency decreases gradually, the reactive power injected into the power grid slowly decreases. After the frequency drops to a new stable value, it remains unchanged, and the reactive power quickly returns to 0. When the frequency rises, the variation characteristics of the reactive power injected into the grid are exactly the opposite of the frequency decreases, and the reactive power will rise slowly with the frequency. In addition, the active power is almost unchanged during the frequency change and always remains at the rated value, so that the DC voltage will not change significantly.

In summary, when the frequency changes, if the amplitude of the frequency change is small and within hold-in range of PLL, PLL can always completely lock the frequency after a period of tracking process. Under the regulation of the converter, PMSG can be stabilized to maintain grid-connected operation at the new grid frequency. However, when the frequency changes greatly in some extreme cases, it may beyond hold-in range of PLL, thus making the converter on the grid side cannot output accurate network voltage and current signals, and the output power oscillate, which will affect the normal grid-connected operation of PMSG.

## 3 Simulation analysis

Using MATLAB/Simulink, this paper combines the power grid frequency variation range of Yunnan power grid after the occurrence of ac/dc locking fault, and dynamically simulates and validates the response characteristics of PMSG.



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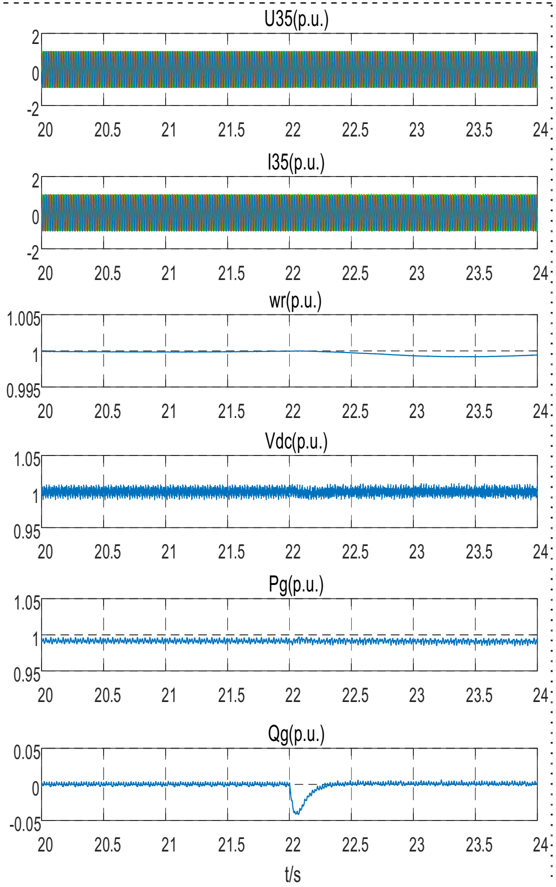


**Figure 4.** Simulation of frequency reduces

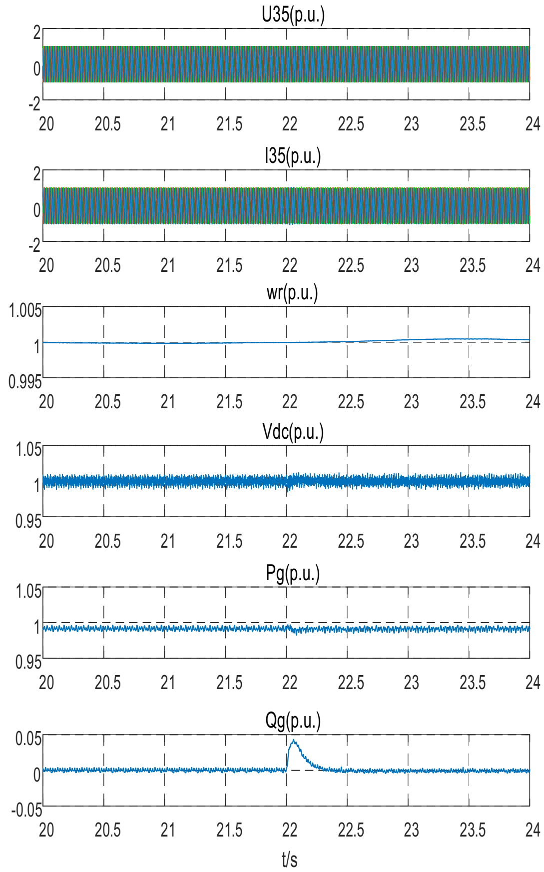


**Figure 5.** Simulation of frequency increases

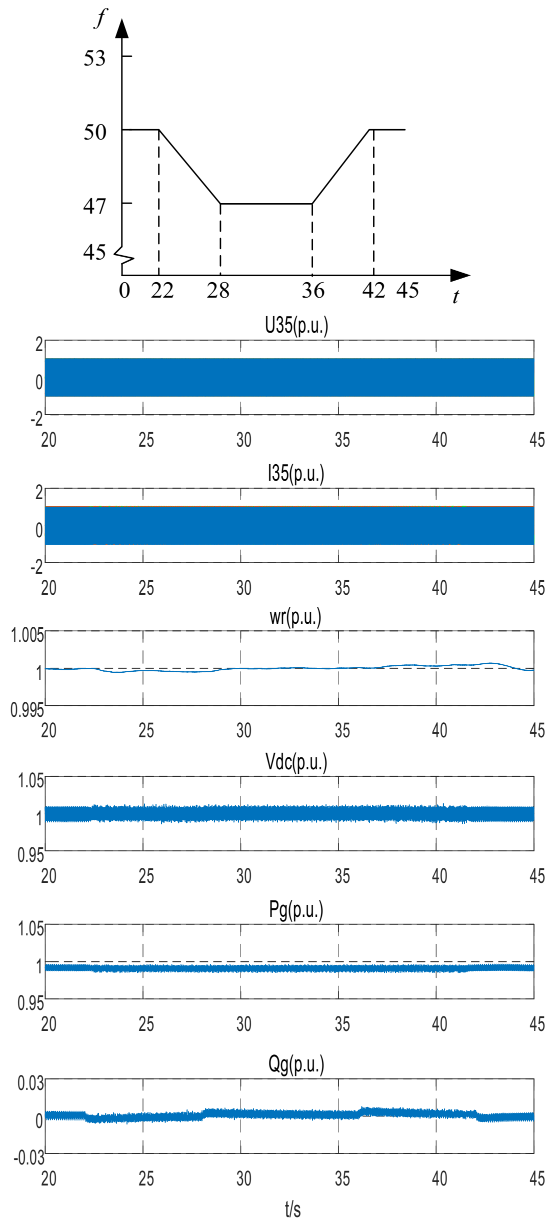


**Figure 6.** Simulation of frequency reduces

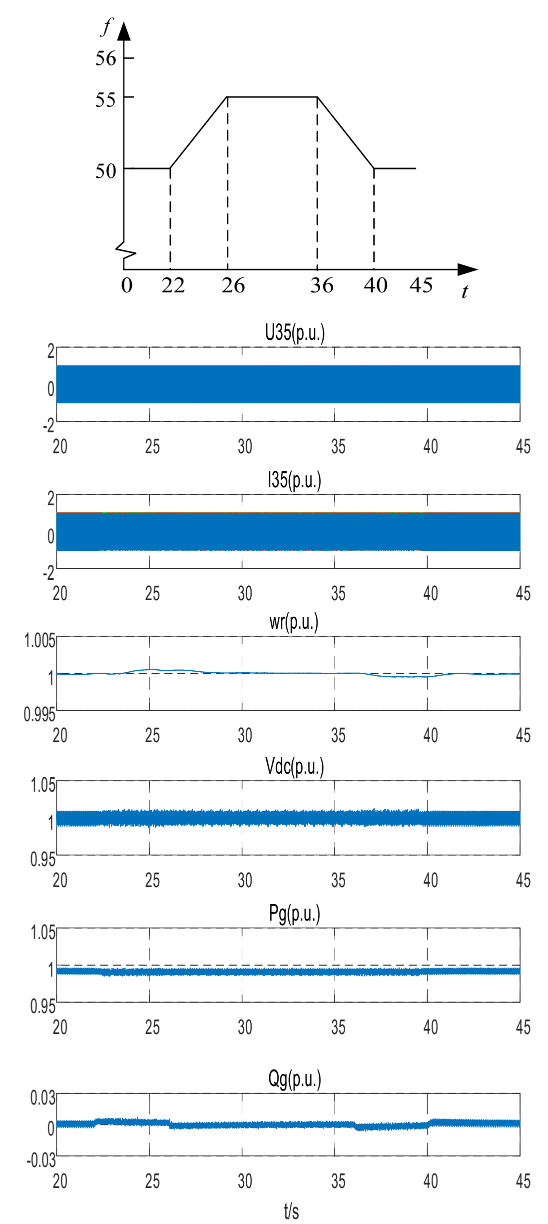


**Figure 7.** Simulation of frequency increases

From Figure 4 to Figure 7, when the frequency is reduced, the inductive reactive power output by the filter is reduced significantly, so that the reactive power injected into the grid will also be reduced, and even the reactive power will be absorbed into the grid. When the frequency increases, the change rule of PMSG is opposite to that when the grid frequency reduces.

In addition, the active power injected by the PMSG remains unchanged when the frequency changes, and the DC side voltage also remains the same. This is because the frequency change is small, the active power change caused by the frequency difference in the phase lock process is small, and the active power flowing into the AC filter is negligible, so the total active power injected into the grid remains the same,  The DC side voltage also remains the same.

## 4 Conclusion

The frequency response characteristics of PMSG are affected by the operating characteristics of the PLL and the control of the converter under different frequency ranges. different power grids can ensure the frequency adaptability of PMSG by setting corresponding inverter protection limits and PLL parameters according to the characteristics of their respective power grids.

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