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Use of a Series Active Filter Applied to a Wind Turbine

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Abstract- The use of fixed speed wind turbines in an electrical network leads to problems of power fluctuations during variations in wind speed through torque. The disturbances affect the quality of energy. The principle of the system proposed in this article concerns the association of a wind turbine and an active filter FAS series supplied by a DC bus. The objective is to filter the variations of the voltage of the network thus protecting the nonlinear loads sensitive to the disturbances generated by the asynchronous generator. The FAS control strategy is based on linear control which uses the PWM technique for the synthesis of the regulators of the different loops. The system was simulated with Matlab/ Simulink software. The simulation results are presented and commented on.

Keywords:- electrical network, FAS series, PWM technique etc.

I. INTRODUCTION

For centuries wind power has been used to move ships, grind grain, or pump water. This source of energy is now used to generate electricity. [1] [2].

In recent years, the importance of wind power generation has steadily increased. It has a number of advantages: first of all, it is a non-polluting renewable energy that contributes to better air quality and to the fight against the greenhouse effect. [3].In a constant speed wind turbine, the variation in wind speed has a rapid impact on the grid voltages. These variations can lead to a deterioration in the quality of the energy (flickers) [2] [4], even to a destabilization of the network and the systems connected to it.

For this reason, we propose in this article to add in series to the asynchronous generator an active compensator dedicated to the compensation of voltage harmonics, it is composed of a voltage-controlled voltage inverter to act as a voltage source. This is a usual application which represents a fairly important preliminary step to highlight the compensatory effect.

The series active filter is divided into two: the power part and the control part. In the first part, we will detail the different constituents by presenting its modeling.

In the control part we will present a method for identifying the harmonic components of the voltage of the polluted network. This is a method based on the calculation of instantaneous active and reactive power (PQ). The controllers offered are linear PID type. [3]

II. PROPOSED STRUCTURE

The wind turbine model proposed in this article is shown in Fig. 1. In this system, the wind turbine is at almost fixed speed. The structure is composed of an asynchronous generator connected to the network in series with a bidirectional DC / AC converter supplied by a DC bus (battery).

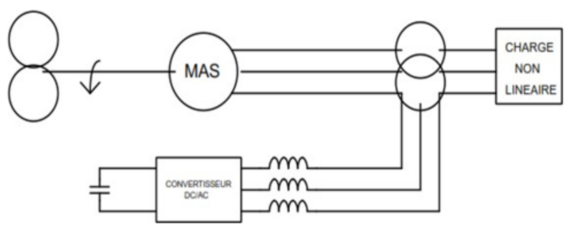

Fig 1. Proposed wind energy system.

In our study, we did not take into account the mechanical part of the wind turbine so we can consider the proposed wind power system as a polluted voltage source supplying a nonlinear load sensitive to harmonics.

Figure I.2 simplifies the power structure of the system and shows the structure of the two-level inverter operating as a series active filter. This series compensator injects a voltage in phase opposition with the harmonic voltage coming from the wind generator through three injection transformers (with a unity transformation ratio). [4] [5]

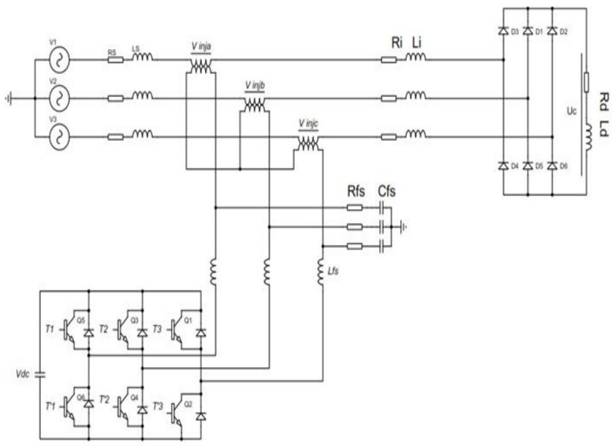

Fig 2. Power structure of the FAS connected to the wind energy system.

1. FAS control strategy:

- Identification of harmonics
- The filtering quality lies in the efficiency of the method used for the identification of harmonic currents. There are several algorithms which vary in complexity, among which we quote:
- The instantaneous power P-Q method,
- The synchronized reference frame method, The method of synchronized detection, The Fourier method,
- The method based on the active current,
- The method based on the regulation of direct voltage,
- The three-phase method.

III. METHOD OF INSTANTANEOUS POWERS

The identification method is used to calculate the disturbing voltages that are injected by the inverter, in phase opposition, to depollute the voltage at the terminals of the load to be protected [4].

In our case, the harmonics extraction method used is the active and reactive power (PQ) method; This method offers the advantage of choosing the disturbance to be compensated with precision, speed, and ease of implantation [5] [6]. In the event that the mains voltage is polluted, a PLL-based system is added after measuring the voltages at the connection point of the active filter. Another effective solution to this problem may be the insertion of a filter called a multivariate filter (FMV) after measuring or estimating these voltages. [7] [8]

This method exploits the transformation of the parameters of the system in the three-phase frame abc into two-phase in the stationary frame. Let us denote by () and) the voltages measured at the connection point of the active filter and the currents absorbed by the polluting load, respectively: [8]

$$\begin{bmatrix} v_{s\alpha} \\ v_{s\beta} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} v_{sa} \\ v_{sb} \\ v_{sc} \end{bmatrix} \quad (I.1)$$

$$\begin{bmatrix} i_{l\alpha} \\ i_{l\beta} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} i_{la} \\ i_{lb} \\ i_{lc} \end{bmatrix} \quad (I.2)$$

If we make the α and β axes coincide with the real and imaginary axes of the complex plane, the three-phase systems of voltages and currents are written:

$$\begin{bmatrix} v_{s\alpha} \\ v_{s\beta} \end{bmatrix} \begin{bmatrix} i_{l\alpha} & i_{l\beta} \\ -i_{l\beta} & i_{l\alpha} \end{bmatrix} \begin{bmatrix} p_l \\ q_l \end{bmatrix}$$

Harmonic voltages are calculated by:

$$\begin{bmatrix} v_{h\alpha} \\ v_{h\beta} \end{bmatrix} = \begin{bmatrix} v_{s\alpha} \\ v_{s\beta} \end{bmatrix} - \begin{bmatrix} \tilde{v}_{s\alpha} \\ \tilde{v}_{s\beta} \end{bmatrix}$$

Finally, the disturbing reference voltages in the abc reference are given by:

$$\begin{bmatrix} v_{fa} \\ v_{fb} \\ v_{fc} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & 0 \\ -\frac{1}{2} & \frac{\sqrt{3}}{2} \\ -\frac{1}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} v_{h\alpha} \\ v_{h\beta} \end{bmatrix} + \begin{bmatrix} \Delta v_{la} \\ \Delta v_{lb} \\ \Delta v_{lc} \end{bmatrix}$$

or Δv_l represents the voltage drop across the load.

The diagram in Figure (I.3) illustrates the different steps for obtaining the harmonic components of the current of a non-linear load [5] [8].

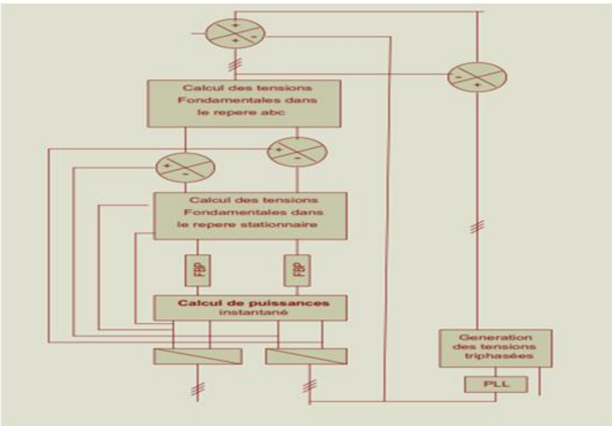

Fig 3. Identification algorithm.

To estimate the phase, it is assumed that the three network voltages are sinusoidal, defined by:

$$\begin{bmatrix} v_{sa} \\ v_{sb} \\ v_{sc} \end{bmatrix} = V_{max} \begin{bmatrix} \sin(\omega t) \\ \sin(\omega t - \frac{2\pi}{3}) \\ \sin(\omega t) + \frac{2\pi}{3} \end{bmatrix}$$

By doing the transformation in the synchronous coordinate system, one obtains:

$$v_{s\alpha} = \sqrt{\frac{3}{2}} V_{max} \left[\sin \omega t - \frac{1}{2} \sin(\omega t - \frac{2\pi}{3}) - \frac{1}{2} \sin(\omega t + \frac{2\pi}{3}) \right]$$

$$v_{s\beta} = \sqrt{\frac{3}{2}} V_{max} \left[\frac{\sqrt{3}}{2} \sin(\omega t - \frac{2\pi}{3}) - \frac{\sqrt{3}}{2} \sin(\omega t + \frac{2\pi}{3}) \right]$$

v_{ldes} represents the desired voltage across the load, in our case v

$$v_{ldes} = \sqrt{2}\, 220V$$

The diagram of the PLL adopted based on an FMW filter is given in figure (I.4).

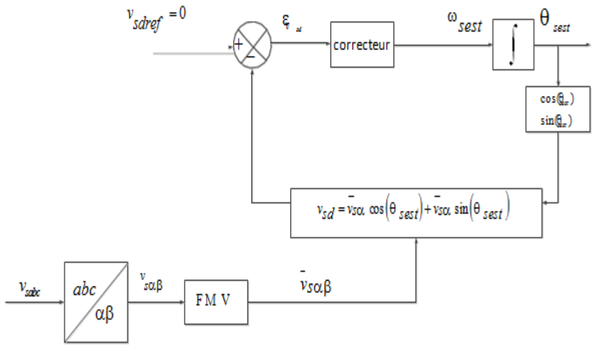

Fig 4. Structure of a three-phase PLL based on FMV.

By simplifying relations (I.6) and (I.7) we find:

$$v_{s\alpha} = 3\sqrt{\frac{3}{2}} V_{max} \sin(\theta)$$

$$v_{s\beta} = -3\sqrt{\frac{3}{2}} V_{max} \cos(\theta)$$

And in the synchronous frame:

$$\begin{bmatrix} v_{sd} \\ v_{sq} \end{bmatrix} = \sqrt{\frac{3}{2}} \begin{bmatrix} \cos(\theta_{sest}) & \sin(\theta_{sest}) \\ -\sin(\theta_{sest}) & \cos(\theta_{sest}) \end{bmatrix} \begin{bmatrix} v_{s\alpha} \\ v_{s\beta} \end{bmatrix}$$

θ_{Sets} is the estimated angular position of the three-phase voltage vector.

By replacing the relation (I.8) in (I.9) we obtain:

$$v_{sd} = 3\sqrt{\frac{3}{2}} V_{max} \left[\sin(\theta) \cos(\theta_{sest}) - \cos(\theta) \sin(\theta_{sest}) \right]$$

$$v_{sq} = 3\sqrt{\frac{3}{2}} V_{max} \sin(\theta - \theta_{sest})$$

Assuming that $\theta - \theta_{Sets}$ is very small, then the previous expression can be expressed as:

$$v_{sq} = 3\sqrt{\frac{3}{2}} V_{max} (\theta - \theta_{sest})$$

The estimated angular pulsation is given by:

$$\omega_{sest} = H(s) 3\sqrt{\frac{3}{2}} V_{max} (\theta - \theta_{sest})$$

the PI regulator transfer function defined by:

$$H(s) = k_p + K_i/S$$

The angular position is given by:

$$\omega_{sest} = \frac{\theta_{sest}}{s}$$

The closed loop transfer function of this system is given by:

$$\frac{\theta_{sest}}{\theta} = \frac{(k_p s + k_i)3\sqrt{\frac{3}{2}}V_{max}}{s^2 + (k_p s + k_i)3\sqrt{\frac{3}{2}}V_{max}}$$

We thus obtain the simplified model of the PLL, illustrated in figure (I.5)

$$k_p = \frac{2\sqrt{2}}{3\sqrt{3}}\frac{\omega_n \xi}{V_{max}}$$
$$k_i = \frac{1}{3}\sqrt{\frac{3}{2}}\frac{(\omega_n)^2}{V_{max}} \qquad (I.15)$$

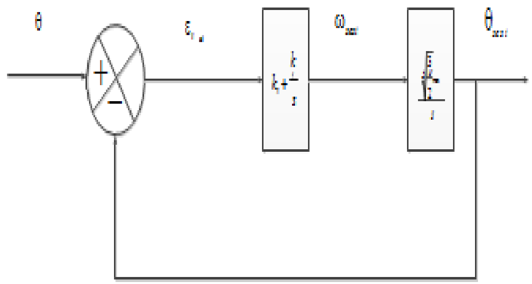

Fig 5. Diagram of a PI regulator of the PLL.

IV. SIMULATION RESULTS

The simulation of the command by SVM of the FAS with identification of harmonics by the PQ method was carried out with the following parameters:

- DC voltage source at the capacitor terminal is equal to 900V
- desired value of the load voltage is equal to $V_{Idés} =$ 2220
- voltage of the disturbed source is defined by the system (I.6).

$$v_{sa} = \sqrt{2}v_d \sin(\omega_t t) + \sqrt{2}v_d/5\sin(5\omega_t t) + \sqrt{2}v_d/7\sin(7\omega_t t)$$
$$v_{sb} = \sqrt{2}v_d \sin(\omega_t t - \frac{2\pi}{3}) + \sqrt{2}v_d/5\sin(5\omega_t t + \frac{2\pi}{3}) + \sqrt{2}v_d/7\sin(7\omega_t t - \frac{2\pi}{3})$$
$$v_{sc} = \sqrt{2}v_d \sin(\omega_t t + \frac{2\pi}{3}) + \sqrt{2}v_d/5\sin(5\omega_t t - \frac{2\pi}{3}) + \sqrt{2}v_d/7\sin(7\omega_t t + \frac{2\pi}{3}) \qquad (I.12)$$

Figure (I.6) represents the block diagram of the PWM control of the FAS with identification of the harmonics by the PQ method.

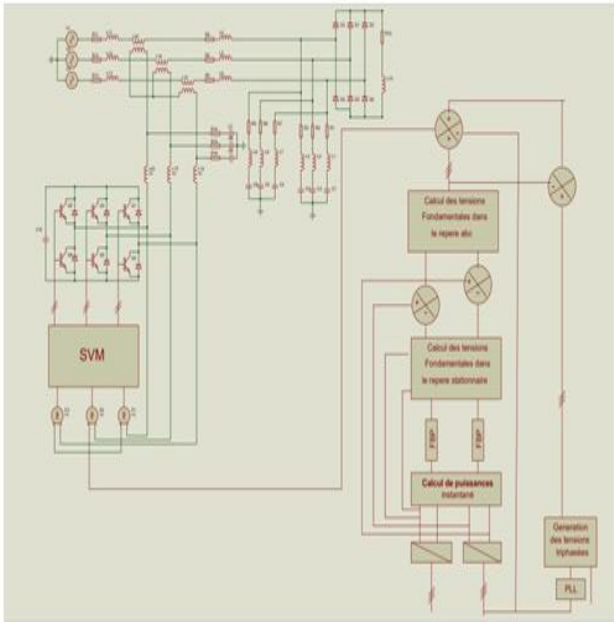

Fig 6. Block diagram of the control by SVM of the FAS with identification of harmonics by the PQ method.

1. The results presented in this section correspond to the compensation of disturbances affecting the load voltage.

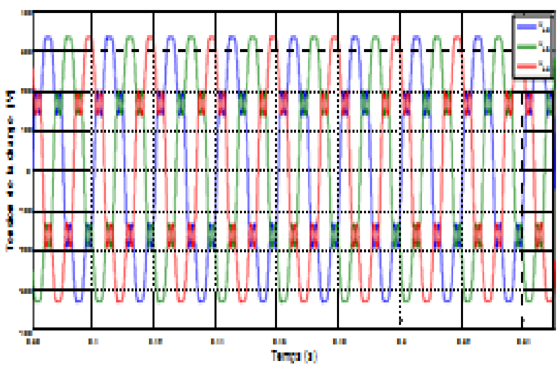
Fig 7. Load voltage before filtering.

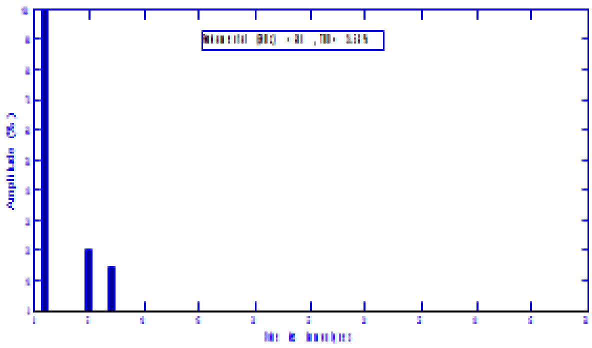

Fig 8. Harmonic spectrum of the voltage after filtering.

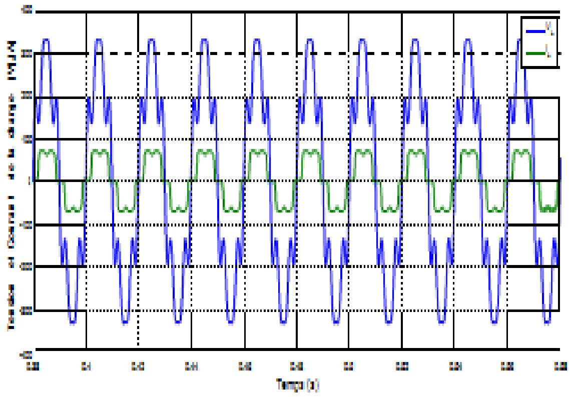

Fig 9. Voltage and current of the first phase of the source.

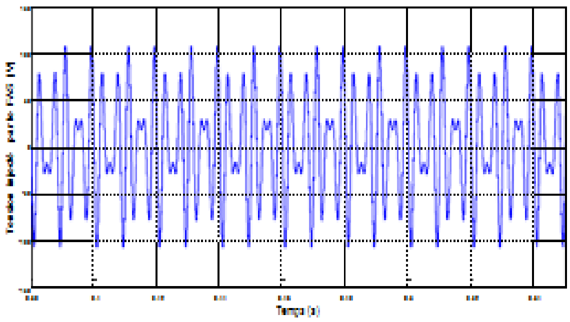

Fig 10. Voltage injected by the first phase.

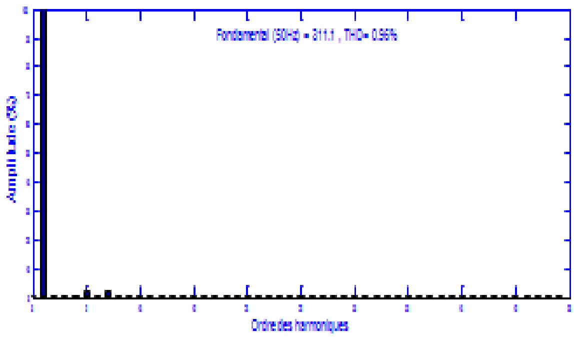

Fig 11. Harmonic spectrum of the load voltage after filtering.

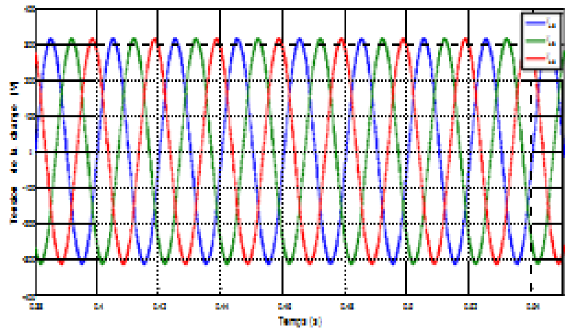

Fig 12. Load voltages after filtering.

2. The results presented in this section correspond to the compensation for a three-phase voltage dip with a depth of 23% and a duration of 60ms.

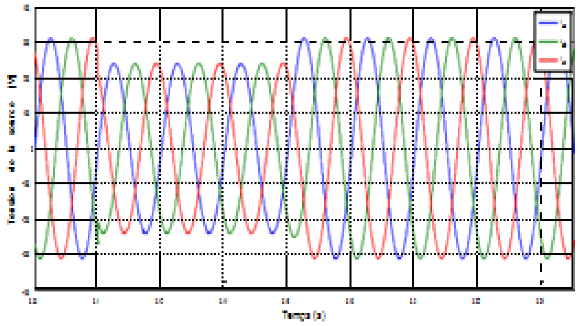

Fig 13. Source voltages during a voltage dip.

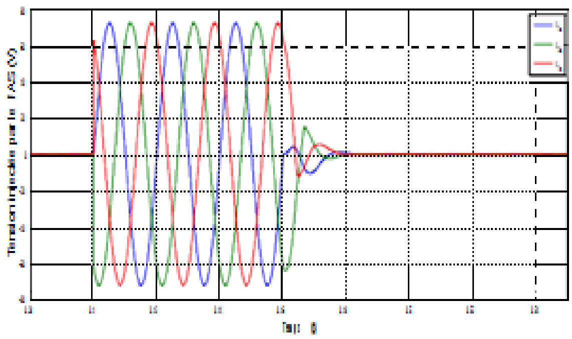

Fig 14. Voltages injected by the FAS during a voltage dip.

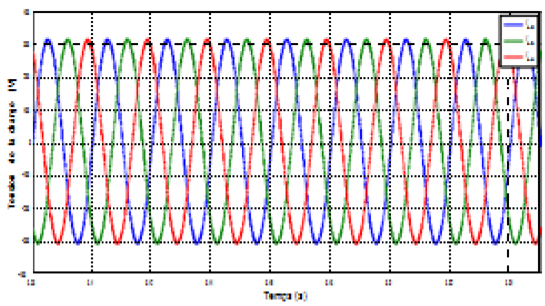

Fig 15. Voltages at the terminals of the load during a voltage dip.

V. INTERPRETATION OF THE RESULTS

Figure) I.7) shows us the effect of harmonics on the load voltage before filtering. This effect is represented in the form of disturbance at the level of the sinusoidal waves and consequently a significant increase of to a value of 24.59% according to its harmonic spectrum represented in figure (I.8).

After inserting the series active filter, it is noted that there is a compensating voltage generated by this to that of the harmonics present in the network, see figure (I.10), this has the effect of a breakage reduction of 24.58% at 0.96%, see figure (I.11) this value of the is a value compatible with the IEEE STD 519-1992 standard which imposes a value less than 5%. Figure (I.12) shows the appearance of the effect of FAS on the load voltage which is now sinusoidal.

Figure (I.13) shows the effect of a voltage dip within 60ms on the network voltage. Figure (I.14) shows the role of series active compensation in compensating for the voltage drop during a voltage dip. Figure (I.15) shows us that the voltage across the load is always sinusoidal.

VI. CONCLUSION

In this article, we have proposed a modern solution to remedy the disturbances and harmful harmonics generated by the wind generator. This modern solution consists of installing an active filter in series with the network. For the proper functioning of this filter, the method of extracting voltage harmonics based on active and reactive power is adopted. In order to improve the harmonic quality of the source current, the following article will be devoted to a hybrid solution combining the series active filter with passive filters.

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