Dynamic Phasors Modeling of the Wound Rotor Induction Generator for Electromagnetic and Electromechanical Analysis

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1. Introduction

Renewable energies have been object of major attention in the whole World. Some reasons are advances in technologies that have made those more achievable in different ways; we only mention four of them: cost, efficiency, reliability and quality. The first point is obtained due to mass production that permits low cost/kW generated. In the second one, the power electronics join with other research areas like materials science, have increased the efficiency in wind energy conversion system (WECS), PV systems and storage devices for example, permitting them to work in optimal values (MPPT). These two points are right now some of the most important requirements to implement these kinds of technologies in power electric system (e.g. distributed generation forming or not microgrids).

In the last years WECS are being installed widely, and the wound rotor induction generator (WRIG) is one of the most popular electric machines for this kind of technology, for its flexibility of operation. These systems present electromagnetic and electromechanical dynamics, which are very complex to analysis. To cover this necessity, different models have been developed to simulate them and be able to diagnostic electric system "health" and prevent blackouts or big variations in the parameters like voltages sags, dips, powers distortions, etc. These models are electromagnetic transient program (EMTP) and quasi stationary, but there is an area that is not covered for any case: simulate electromagnetic and electromechanical dynamics in high scale systems with accuracy and efficiency, to be able to take decisions and guaranteed stability and quality power system [1].

Key words: Dynamic phasors, WRIG, transient and permanent analysis, renewable energy.

2. Outlines of the dynamic phasors approach

In recent years dynamic phasors are being used for modeling different elements of power electric system, like generators, power electronics converters, transmission lines, transformers, loads, and Flexible AC Transmission System (FACTS). The main idea of dynamic phasors approach is to approximate a possibly complex time domain waveform $x(\tau)$ in the interval $\tau \in (\tau - T, t]$ with a Fourier series representation of the form [2]:

$$x(\tau) \approx \sum_{-\infty}^{\infty} X_k(t) \cdot e^{jk\omega\tau} \qquad (1)$$

$$X_k(t) = \frac{1}{T}\int_{t-T}^{t} x(\tau) \cdot e^{\cdot jk\omega\tau} d\tau = \langle x \rangle_k (t) \qquad (2)$$

Where $\omega = {2\pi}/{T}$ and $X_k(t)$ is the k_{th} time varying Fourier coefficient in complex form, also called dynamic phasors, and k is the set of selected Fourier coefficients which provide a good approximation of the original waveform (e.g. k=0,1,2). Some important properties of dynamic phasors are: the relation between the derivatives of $x(\tau)$ and the derivatives of $X_k(t)$, which is given in (3). This is obtained differentiating (1)

$$\left\langle \frac{dx}{dt} \right\rangle_k = \frac{dX_k}{dt} - jk\omega X_k \qquad (3)$$

The product of two time-domain variables equals a discrete time convolution of the two dynamic phasors sets of variables, which is given in (4)

$$\langle xy \rangle_k = \sum_{l=-\infty}^{\infty} (X_{k-l} Y_l) \qquad (4)$$

In this paper we focus in developing and analyzing the behavior of the WRIG with the two methodologies mentioned above, the instantaneous time domain model, and the dynamic phasors. Both are done in DQ0 reference frame.

3. WRIG dynamic phasors model

In this section we present the dynamic phasors model, which is developed from the state space model of the WRIG in DQ0 reference frame [3].

A. Proposed WRIG dynamic phasors model.

To obtain an accurate response of a model, it is important to take care of the selection of Fourier coefficients, because they represent the harmonics of the real signal, and depend of the analysis purpose, it should have more or less coefficients. In our case, we choose $k = \pm 1$ for the currents, at fundamental frequency, and $k = 0{,}2$ for the speed, having a dc and second harmonic components [4]. The resulting model is shown in (5). Note that $\bar{i}$ represents the conjugate of a complex number.

$$
\begin{aligned}
\frac{di^1_{ds}}{dt} &= (a_{11} - j\omega_s)i^1_{ds} - a_{12}(i^1_{qs}\omega^0_r + \bar{i}^1_{qs}\omega^2_r) - a_{13}i^1_{dr} \\
&\quad - a_{14}(i^1_{qr}\omega^0_r + \bar{i}^1_{qr}\omega^2_r) - b_1 v_{ds} + b_2 v_{dr} \\
\frac{di^1_{qs}}{dt} &= a_{12}(i^1_{ds}\omega^0_r + \bar{i}^1_{ds}\omega^2_r) + (a_{11} - j\omega_s)i^1_{qs} + \\
&\quad a_{14}(i^1_{dr}\omega^0_r + \bar{i}^1_{dr}\omega^2_r) - a_{13}i^1_{dr} - b_1 v_{qs} + b_2 v_{qr} \\
\frac{di^1_{dr}}{dt} &= -a_{21}i^1_{ds} + a_{32}(i^1_{qs}\omega^0_r + \bar{i}^1_{qs}\omega^2_r) + (a_{33} - j\omega_s)i^1_{dr} \\
&\quad + a_{34}(i^1_{qr}\omega^0_r + \bar{i}^1_{qr}\omega^2_r) + b_2 v_{ds} - b_3 v_{dr} \\
\frac{di^1_{qr}}{dt} &= -a_{32}(i^1_{ds}\omega^0_r + \bar{i}^1_{ds}\omega^2_r) - a_{31}i^1_{qs} \\
&\quad - a_{34}(i^1_{dr}\omega^0_r + \bar{i}^1_{dr}\omega^0_r) + (a_{33} - j\omega_s)i^1_{qr} + b_2 v_{qs} - b_3 v_{qr} \\
\frac{d\omega^0_r}{dt} &= \frac{P}{2J}\left[\frac{3}{2}PM\left(R(i^1_{qs}\bar{i}^1_{dr}) - R(i^1_{ds}\bar{i}^1_{qr})\right) - B\omega^0_r - T_L\right] \\
\frac{d\omega^2_r}{dt} &= \frac{P}{2J}\left[\frac{3}{2}PM\left(i_{qs}i_{dr} - i_{ds}i_{qr}\right) - B\omega^2_r) - j\omega_s\omega^2_r\right]
\end{aligned}
\tag{5}
$$

Where I_s, I_r and v_s, v_r are stator/rotor currents and voltages respectively and ω_r, T_L are the rotor electrical speed and the load aplied to the shift, respectively.

4. Results

In order to validate the model, it was simulated in Matlab/Simulink, with a 7.5 kW generator, 400 V, 50 Hz, 1440 RPM, and compared with asynchronous machine developed in SimPower Systems library. In figure 1, original and approximated dynamics from equation 7 and 8 are shown, respectively. It can be seen that module current, which is calculated from equation 6, follows the original follows the original signal when a step change is applied in mechanical load from -50 to -100 Nm at 0.4 seconds.

$$
\left|i_{ds}\right| = 2\sqrt{\left(i^{re}_{ds}\right)^2 + \left(i^{im}_{ds}\right)^2} \tag{6}
$$

5. Conclusions

Dynamic phasors approach offers a number of advantages over conventional methods: the selection and variation of Fourier coefficients *k,* gives a wider bandwidth in the frequency domain than traditional slow quasi-stationary models used in Transient Stability Programs and gives also the possibility of showing couplings between various quantities and addressing particular problems at different frequencies, however the number of differential equations increase.

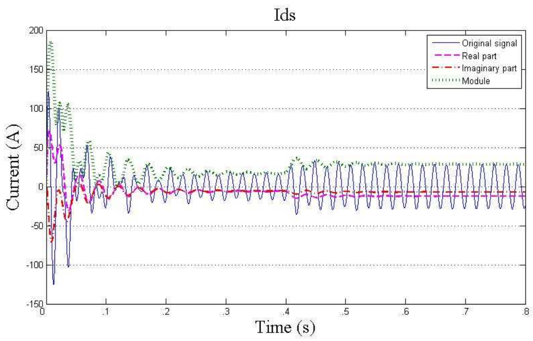

Fig. 1. Stator direct-axis current dynamic.

As the variations of dynamic phasors are slower than the instantaneous quantities, they can be used to compute the fast electromagnetic transients with larger step sizes, so that it makes simulation potentially faster than conventional time domain like EMTP simulation. The dynamic phasors approach also allows an analytical insight into system sensitivities used to design controllers or protection schemes. It is our interest continuous researching of dynamic phasors applications to model hybrid (DC-AC, continuous-discrete-continuous) systems with power electronics like transfer and conditioning powers elements, and renewable energies technologies like WECS, PV and storage systems.

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