Debugging with the Power Equilibrium Check in Simulations

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Abstract

This paper aims to help beginners of research students debug and analyse their models and simulations by checking the power equilibrium. Electric motor simulations are usually complicated for the beginners. Applying the continuous time models in discrete-time increase the confusion how to validate the simulations and how to debug. The power equilibrium is a good method for these purposes; however, checking it is not straightforward. This paper explains the details on a doubly-fed induction machine model, which is one of the most complicated electric motor models.

*Key* *words*: Power equilibrium, electric motor modelling, doubly-fed induction machine.



1. Introduction

Research studies frequently meet failures and disruptions due to wrong interpretations or applications of basic equations such as modelling errors in practical studies or bugs in software applications and simulations. In order to surmount these failures, research students are encouraged to measure or observe each quantity in equations and then to check if the equations are really satisfied as assumed theoretically. If not, then the researcher should go one step back or sometimes go back to the mid-stage between the last tested correct and wrong stages and check the equations for that stage similarly. This approach usually helps the researcher identify and solve the failure. A basic component might not work properly or the researcher might have thought its function or usage in a wrong way when designing or coding. However, sometimes there is no back stage practically, an equation is simply not satisfied. In such a case, which probably includes a modelling error, the researcher should go back to former equations yielding that equation checking if they really yield it under the operating conditions considered properly. The equation revision process may continue until reaching the very basic equations. We can call this well-known approach "*going back to childhood of the equations*", which requires and/or develops a strong educational background both theoretically and practically.

An example of this approach in computer simulations is to check the power equilibrium because more than physical, it is a mathematical rule. It is applicable in most engineering subjects and it must be satisfied exactly at every time step of the simulation; however, it is usually confusing for most research students because instantaneously considering, the energy goes into or come from various forms. In addition, even the simple law on a resistor may not be applied directly if the equilibrium is checked exactly in discrete-time solutions.

Electric machinery simulations are good examples to clarify such confusions because their dynamics include both electrical and mechanical power, both generating and motoring modes, both electromagnetic and kinetic energy storage, both fast and slow modes, and both active and reactive power definitions are available instantaneously. In addition, stationary or rotating reference frames and pulse-width modulated inputs increase the complexity in a research student's mind. Among the electric machinery, one of the most complicated models belongs to **d**oubly-**f**ed **i**nduction **m**achines (DFIM), which can be fed both from the stator and the rotor. In order to clarify these aspects, the application of the power equilibrium check is shown on a DFIM in this paper.

1. Model of Doubly-Fed Induction Machine (DFIM)

With the definitions of

 (1)

 (2)

the basic equations of the DFIM dynamics [1] are

 (3)

 (4)

 (5)

where among the parameters is the number of the pole pairs, is the friction constant,  is the inertia, and are the stator and rotor resistances, , and are the stator, rotor and mutual inductances, respectively; among the variables is the angular speed of the *dq* axes with respect to stator, and are the electromechanical and load torques, and are the stator and rotor flux linkages respectively; the inputs and are the stator and rotor voltages; and the state variables, and are the stator and rotor currents respectively and is the electrical angular speed of the rotor; hence is the mechanical angular speed of the rotor.

Defining the leakage constant , stator and rotor time constants and respectively, and

 (6)

state equations (3)-(5) can be rewritten as

 (7)

 (8)

When simulating the model in discrete-time with a time step of , denoting the next time step values with superscript “ + ”, (3)-(5) become

 (9)

 (10)

 (11)

1. Power Equilibrium

Since the effects of applied stator and rotor voltage are seen at the next time step, the instantenous stator and rotor input powers  and  should be calculated as multiplying by and from left respectively:

 (12)

 (13)

where  and  are the stator and rotor cupper losses respectively:

 (14)

 (15)

(12) and (13) are true if the multiplications of unbalance voltage and current components on both stator and rotor sides,  and  respectively, are zero, which is satisfied if a neutral line is not used. The multiplier 3/2 comes because the model used here assumes the equivalence of voltage and current amplitudes between three phase and two phase (*dq*) models. The sum of the middle terms in (12) and (13) is the power corresponding to the energy stored in the magnetic field:



 (15)

The sum of the last terms in (12) and (13) equals , where  is the electromechanical power and  is the discrete-time modelling error:

 (17)

In fact, if the present time values are used instead of the next time values in (17), the continuous-time  formula  is obtained. However, since the effects of and are seen at the next time step, the electromechanical power in discrete-time is

 (18)

which is composed of three components:

 (19)

 (20)

 (21)

which are the friction loss, the power corresponding to kinetically stored energy and the output power respectively.

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