Application note

Park or DQ Transform variants

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Opal-RT Technologies

Contents

Table 1 Document revision history

v 1.0	First version	May 16, 2018

1. Objective

This document objective is to explain the difference between various Park transforms used in SimPowerSystems and Opal-RT models

2. Software Requirement

To perform the parameter modification using the method described in this documentation, the following software is required to properly install on a computer that is used to conduct this operation.

Table 1 List of Software required

Software Names	Versions
MATLAB	R2015a

3. Introduction

The Opal-RT FPGA and SSN machine models are often derived and validated using SimPowerSystems models. One noticeable difference of implementation resides in the Park transform used in most machine models.

This document explains this difference of Park transform and its implications. One curious implication is that some Park transforms do NOT have the well-known 3/2 factor on torque.

4. Park transforms

For the purpose of this document we first define some 3-phase AC waveform of sequence A-B-C with the following equations:

$$V_{abc} = \begin{bmatrix} V_{as} \\ V_{bs} \\ V_{cs} \end{bmatrix} = \mathrm{Vm} \begin{bmatrix} \cos(wt) \\ \cos(wt - \frac{2\pi}{3}) \\ \cos(wt + \frac{2\pi}{3}) \end{bmatrix} \quad (1)$$

This voltage therefore has a cosine shape seen from phase A.

4.1 Park equations

Since R2012a, some SimPowerSystems machine models offer a choice of Park transform for the machine: 'Original Park transform' and 'Modified Park transform', referred in this document as the Krause variants of the Park transform.

For its part, Opal-RT models uses a power invariant Park transform. The power invariant form is usually recognisable by the sqrt(2/3) factors in it while the Krause variants has 2/3 or 3/2 factor in them.

4.1.1 'Classic' Park transform, used in SimPowerSystems

SimPowerSystems uses either the classic Park Transform, which is the original Park transformation published by Krause in [1].

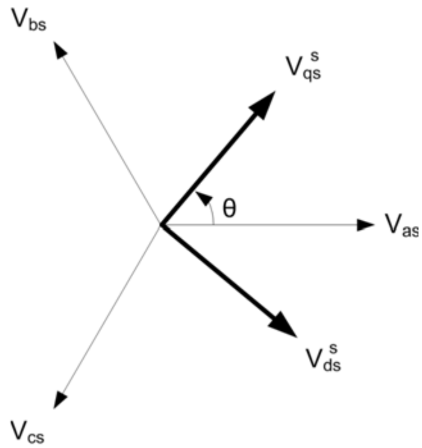

Fig. 1 Krause type Park transform definition

$$\begin{bmatrix} V_{qs} \\ V_{ds} \\ V_{0s} \end{bmatrix} = 2/3 \begin{bmatrix} \cos(\theta) & \cos(\theta - \frac{2\pi}{3}) & \cos(\theta + \frac{2\pi}{3}) \\ \sin(\theta) & \sin(\theta - \frac{2\pi}{3}) & \sin(\theta + \frac{2\pi}{3}) \\ 0.5 & 0.5 & 0.5 \end{bmatrix} \begin{bmatrix} V_{as} \\ V_{bs} \\ V_{cs} \end{bmatrix} \quad (2)$$

or the 'Modified Park transform' below.

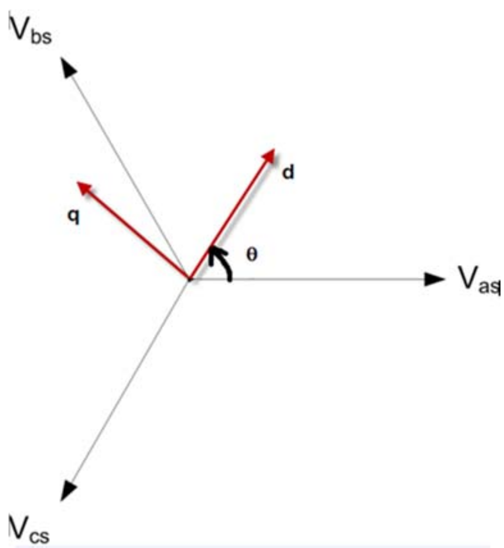

Fig. 2 Krause type Modified Park transform definition

The latter has a similar dq axis but with a different θ angle definition. Both these transforms produces torque equations with a 3/2 factor, show for PMSM below

$$T_e = 1.5pp\left[\psi i_q + (L_d - L_q) i_d i_q\right] \quad (3)$$

4.1.2 D-Q transform used in Opal-RT motor models.

In Japan and other places, the commonly used Park transform is different than the ones of Krause. First, it is orthonormal (sqrt(2/3) factor instead of 2/3) and secondly the angle θ is the phase shift between the direct axis d and phase A, which is the same as SimPowerSystems 'Modified Park transform' for angle definitions only.

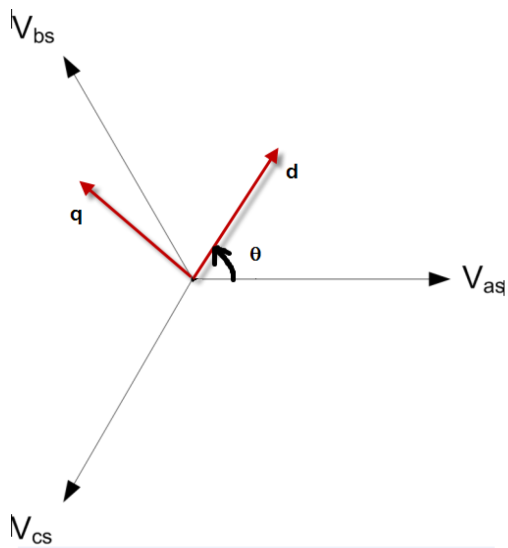

Fig. 3 Park transform definition of Opal-RT models

This transform can be conveniently expressed in this fashion:

$$\begin{bmatrix} V_{ds} \\ V_{qs} \end{bmatrix} = \sqrt{2/3} \begin{bmatrix} \cos(\theta) & \sin(\theta) \\ -\sin(\theta) & \cos(\theta) \end{bmatrix} \begin{bmatrix} 1 & -0.5 & -0.5 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} V_{as} \\ V_{bs} \\ V_{cs} \end{bmatrix} \quad (4)$$

(Note the different d-q order in the vector)

With this transform, using V_{abc} previously defined, for verification purposes, we obtain:

$\theta = 0$: $V_{ds} = \sqrt{3/2}$ $V_{qs} = 0$ (d-axis aligned on phase A)

$\theta = -pi/2$: $V_{qs} = \sqrt{3/2}$ $V_{ds} = 0$ (q-axis aligned on phase A)

The ARTEMiS demo model *ParkTransformVerification.xls* highlights these properties.

The torque equation, shown for PMSM below, is the same as before but without the 1.5 factor introduced by the 2/3 factor of the Krause Park transform:

$$T_e = pp\left[(\sqrt{\tfrac{3}{2}}\psi)i_q + (L_d - L_q)i_d i_q\right] \quad (5)$$

Note the $\sqrt{\frac{3}{2}}$ factor on the peak magnet flux ψ now. This is caused by the initial definition of ψ which is 'peak' on phase A.

The reader is invited to read [2] for more information on ARTEMiS SSN machine models.

4.2 Rotating (or not) Park transform

The most common usage of the Park transform is to view the machine quantities as seen from the rotor. This is the rotor Park referential'. This rotor park referential is used in SSN Synchronous machine and SSN PMSM. It is very useful for these 2 machines because the flux (generated by a magnet or field winding) is constant when seen from the rotor. Additionally, most inductances becomes constant in the DQ (or Park) referential, simplifying computation greatly.

To effectively use the rotor Park referential, the referential angle θ must be set equal to the actual rotor angle during simulation.

Park referential can also be used with $\theta = 0$ all the time. This is called a 'fixed reference frame' Park transform and it is used notably in the SSN induction machine. Combination are possible also; in the SSN-DFIM, a fixed reference frame is used for stator values while a rotating reference frame is used for rotor values.

4.3 Power invariance

One major advantage of using a power invariant Park transform is that power is invariant under the transform. This property can be expressed as:

$$V_{abc} I_{abc} = V_{dq} I_{dq}$$

Krause variants of the Park transform do NOT have this property. This is the reason of the 3/2 factor on torque equations of machine models using these transforms (like in SimPowerSystems).

4.4 Implications of the Park transform differences

The implication of this difference of referential is subtle but nevertheless important:

1- DQ amplitudes are different with different transforms. This can be important when one want to compare the internal ECU values of V_{dq}because the amplitude depends on the transform.

2- Torque equation is different.

3- The Back-EMF voltage profile is shifted by 90° in some Park transform.

5. References

[1] Krause, P.C., O. Wasynczuk, and S.D. Sudhoff. Analysis of Electric Machinery and Drive Systems. IEEE Press, 2002.

[2] Dufour C., "Highly stable rotating machine models in the state-space-nodal solver", unpublished, available in the Scientific Paper section of ARTEMiS.