Reliable Modelling of Electromechanical Systems using Macromodell Approach for Control Purposes

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To my parents

Abstract

The macromodelling, the theme of this thesis, is a new modelling approach for the electromechanical systems. This approach depends on describing the studied system using some high reduced data defined the system behaviour. The key point is the use of the finite element analysis to generate this data required to accomplish high accuracy modelling methodology. Due to this scope, the macromodelling presents a technique to replace the large dimension discrete data, stored in look-up tables, with an analytical formulation. On the other hand, the macromodelling approaches serves as a topology to link two simulation environments: The finite element method tool (with its high accuracy) and the system simulator (with its high flexibility).
Generally, the macromodelling procedure can be divided into two tasks: Reducing the amount of the data required to describe the studied system and finding the appropriate analytical formulation of the reduced data.
To perform the new methodology, linear algebra is pointed as a mathematical framework to perform the macromodelling algorithms. Otherwise, the energy function method covers the physical framework which is used to derive the main system equations.

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Nizar Khateeb
May 2010

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List of Notation

General Acronyms

AnROM	Analytic ROM
BF	Basis Functions
CAnROM	Concentrated ROM
CV	Curve Fitting
FEA	Finite Element Analysis
FEM	Finite Element Method
MOR	Modell order Reduction (equivalent to macromodell and ROM in literature)
OP-ROM	Orthogonal Projection based ROM
PM	Permanent magnet Motor
ROM	Reduced Order Modell (100 % equivalent to Macromodell)
SRM	Switched Reluctance Motor
SVD	Singular Value Decomposition
TTRR	Three term recurrence relation

Symbols and Definitions

General notice: When a letter use to describe two signals (or variables): physical and mathematical then the physical signal is recognized with the sign [~] upon it, e.g., $\tilde{u}$ is a physical signal (source voltage), where u is a basis function. $\tilde{R}$ and $\tilde{i}$ are also Resistance and current respectively.

A	Matrix contains the coefficients of the Fourier series resulted from curve fitting
a_0, a_i	Fourier coefficients
B	Coefficient of friction
b_i	Fourier coefficients
c	The coefficients matrix of the spectral decomposition
c_r	Macromodell matrix (reduced order modelled c)

c_{ij} Coefficients of the macromodell matrix c_r or the coefficients matrix c

C Matrix of the concentrated polynomials $C_0(i), C_1(i)$ …

dW_e The differential change in the electrical energy

dW_f The differential change in the magnetic field energy

dW_m The differential change in the mechanical energy

e Intermediate macromodell

E Back emf factor

$f(x)$ Mathematical modell of 1-Dimension data (1 variable function space)

$f(x,z)$ Mathematical modell of 2-Dimension data (2 variable function space)

f Vector contains the function values $f(x_k)$ or matrix contains the function values $f(x,z)$

f_r Approximated function vector or matrix by reducing the number of the basis function.

$\mathbb{F}$ Studied function space.

FI Basis functions matrix of the co-energy –current look-up table

FI_r Reduced basis function matrix of the co-energy –current look-up table

FIo Orthonormal basis function matrix the co-energy –current look-up table

FIt Upper triangular matrix of the co-energy –current look-up table

FX Basis functions matrix of the co-energy –angle look-up table

FX_r Reduced basis function matrix of the co-energy –angle look-up table

FXo Orthonormal basis function matrix the co-energy –angle look-up table

FXt Upper triangular matrix of the co-energy –angle look-up table

F_{el} Electromagnetic force

F_r Friction coefficient

$\tilde{i}$ Current variable or current vector

i Index of a coefficient in a matrix or vector

I Identity matrix

j Index of a coefficient in a matrix or vector

J Concentrated macromodell

$\tilde{J}$ Moment of inertia.

k Index of a coefficient in a matrix or vector

l Index of a coefficient in a matrix or vector

L Inductance

m Constant refers to the dimension of vectors in the columns space of $\mathbb{F}$

n Constant refers to the dimension of vectors in the row space of $\mathbb{F}$

p Reduced numbers of the basis functions of the columns space

P Matrix contains the coefficients of the fitting polynomials
q Reduced numbers of the basis functions of the row space
Q Orthogonal matrix (in QR orthonormalization)
R Upper triangular matrix (in QR orthonormalization)
$\tilde{R}$ Phase winding resistance
S A diagonal matrix containing the singular values of studied matrix
S_r A diagonal matrix with the r nonzero singular of studied matrix
t Time variable
T Electromagnetic torque
T_p Period of a function
T_l Load torque
T_{mech} Mechanical angle [°]
T_{el} Electrical angle [rad]
$\tilde{u}$ Source voltage
u_j Basis function of function space
u_{ind} The induced voltage
U Basis functions matrix (U in SVD is a orthonormal matrix)
U_r Reduced basis functions matrix
Uo Orthogonal matrix from U_r
Ut Upper triangular matrix from U_r
v_i Basis function of function space (with 2 or more dimensions)
V Basis functions matrix (V in SVD is a orthonormal matrix)
V_r Reduced basis functions matrix
Vo Orthogonal matrix from V_r
Vt Upper triangular matrix from V_r
Wco_{FEM} FEM simulated co-energy look-up table
Wco_{ROM} Reduced order modelled (macromodelled) co-energy look-up table
$WI(i)$ Co-energy as function of the current
WI_r Reduced co-energy -current function matrix
$WX(\alpha)$ Co-energy as function of angle
WX_r Reduced co-energy -angle function matrix
$\tilde{WIX}(i,\alpha)$ Co-energy as function of both angle and current

Wco_{AnROM} Analytic reduced order modelled (macromodelled) co-energy look-up table

Wco_{CAnROM} Concentrated analytic reduced order modelled (macromodelled) co-energy look-up table

x A general variable of a function f or vector in the 1-dimension function space $\mathbb{F}$

Y The studied look-up table (measured or FEM-simulated data) whose dimension is $m \times n$ matrix

z A second variable or vector in the 2 or more dimensions function space $\mathbb{F}$

Greek letters

α Rotor position or a vector of 1-dimension angle values

ψ Flux linkage (in literature also λ)

ω Angular speed

Algorithm Names and Acronyms

[TTRR_Poly] The Gram-Schmidt orthogonalization based three term recurrence relation

[Poly_Norm] Orthonormalization the TTRR-generated polynomials

[Coe_Orth_Poly] Computing the coefficients of the orthogonal polynomials

[Coe_Orth_Norm_Poly] The coefficients of the orthonormal polynomials