SIMPLIFIED DYNAMIC EQUIVALENTS FOR MULTI-MACHINE POWER SYSTEM STABILITY STUDIES

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بسم الله الرحمن الرحيم

« وما أوتيتم من العلم إلا قليلا »

« صدق الله العظيم »

بسم الله الرحمن الرحيم

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S U M M A R Y

Multi-machine power system stability computation necessitates the dynamic representation of each component in the system. As the size and complexity of the system increases , the order of the describing differential equations becomes extremely high . Consequently high cost and long computing time are usually involved when running such stability study on a digital computer . Reduction of the computer time involved , besides cutting the study cost down , is a must for on-line computer applications where fast control decisions have to be taken .

Efforts for reducing stability computation time were first devoted towards lowering the order of representation for each component in the system . The question of how far this order can be reduced for a certain component in the system directs these efforts towards the development of linear dynamic equivalents . In this approach the power system is divided into a study sub-system , which contains the site of disturbance and thus severely affected by it , and an external sub-system , which includes the remainder of the original system . The study system is represented in details , while the dynamics of the external system are simplified by a linearized set of equations derived from the dominant eigen-modes of the external system.

L_{ss}, L_{rr}, M_{sr}, M_{rs}	Stator and rotor : self and mutual inductance matrices for the a,b,c,fd,kd,and kq windings.
C_p	Park's transformation matrix .
$x_{fd\ell}, x_{kd\ell}$, $x_{kq\ell}, x_{a\ell}$	Field , d-axis damper , q-axis damper , and stator winding leakage reactances .
x_{ad}, x_{aq}	d,q-axis mutual reactances .
x_{ffd}, x_{kkd}, x_{kkq}	Field , d,q-axis damper winding self reactances.
x_d, x_q ..	Stator d,q-axis winding reactances .
r_a, r_{fd}, r_{kd}, r_{kq} ..	Stator , field , d , and q-axis damper winding resistances
x'_{ad}	Stator direct axis mutual transient reactance.
x'_d	Stator direct axis transient reactance .
x''_{ad}, x''_{aq}	Stator d, and q-axis mutual subtransient reactances .
x''_d, x''_q ..	Stator d, and q-axis subtransient reactances .
x''_m	Introduced subtransient matrix .
z'_a, z''_a ..	Introduced transient and subtransient impedance matrix .
v_D, v_Q .., i_D, i_Q	D,Q-axis bus voltage and current .
v''_d, v''_q ..	d,q-axis subtransient voltages .

v_m, i_m .. v_N, i_N	Introduced bus voltage and current vectors in d,q,and in D,Q coordinates .
v'_m, v''_m .. v'_N, v''_N	Introduced transient and sub-transient machine voltage vectors in d,q-coordinates and in D,Q-coordinates .
S-System	Study system.
E-system	External system .
H	Inertia constant in MWS/MVA .
T_m	Perunit mechanical input torque .
T_g	Perunit electrical generating torque .
D	Coefficient of mechanical damping .
k_d	Damping factor of damper windings .
P,Q,S ..	Bus active , reactive , and apparent powers .
T'_{do}, T''_{do} .. T''_{qo}	Open stator d-axis transient , d- , and q-axis subtransient time constants .
I,V	Bus current and voltage vectors .
Y	Total network bus admittance matrix .
Y_N, Y'_N, Y''_N	Reduced network admittance matrices ; at the machine terminals (Y_N) , after appending the transient (Y'_N) , and the subtransient (Y''_N) reactances at the machine terminals .
ψ_{sm} ..	Introduced stator flux linkage vector .
ψ_r	Rotor flux linkage vector.
$C_f, r_r, Y_{r\ell 2}$	Introduced rotor constant matrices .

i_o	Introduced initial stator current vector .
u_{NH}	Introduced intial su[illegible]sient vector .
δ	Constant coefficient ; introduced .
Y_R , Y_T ..	Introduced constant admittance matrices .
I^o, I^o_m ..	Introduced constant vectors for E-system .
Ψ^o, Ψ^o_m	Introduced constant flux linkage matrices .
Ω..	Vector of $[\omega]$.
T_G	Vector of $[T_g]$.
M	Vector of $[M]$.
F_{e1}, F_{e2} , F_{A1}, F_{A2}	Diagonal matrices of $[1/T_e]$, $[K_e/T_e]$, $[1/T_A]$, and $[K_A/T_A]$.
V_t	Vector of machine terminal voltage ; $[v_t]$.
V_T	Vector of S, E-system terminal voltages .
C	Introduced initial machine terminal voltage vector .
X	E-system state vetcor .
X'..	Subvector of X .
A, B	State space form constant matrices .
A_I, B_I ..	Constant matrices of ΔI_T equation ; introduced.
z	Transformed E-system states .
V_r	Eigenvectors matrix .
Λ	Diagonal matrix , whose diagonal elements are the eigenvalues .

$\Lambda_1, \Lambda_2, \Lambda_3$	Sub-matrices of Λ .
β	Introduced constant matrix .
$\beta_1, \beta_2, \beta_3$ ..	Subvectors of β .
U	Unit matrix.
z_1, z_2, z_3 ..	Subvectors of the z vector .
S_1, S_2	Constant matrices used for computation of I_T .
I_S, V''_S ..	S-system machine currents , and sub-transient voltages .
I_E, V''_E ..	E-System machine currents and subtransient voltages .
$Y_{SS}, Y_{TS}, Y_{ST}, Y_{TT}$	Submatrices of the Y''_N matrix of the E-system.
X_E	E-system state vector .
X_S	S-system state vector .
$A_{EE}, A_{ES}, A_{SE}, A_{SS}$	Constant submatrices of the whole system A-state matrix .
Y_S, Y_{SE}, Y_{ES}, Y_E	Submatrices of the Y''_N matrix of whole system.
I_{SE}	Introduced constant current vector .
C_{ri}, C_{vi} ..	Introduced constant matrices .
T'_i, T''_i	Submatrices abstracted from V_r

C_{LE1}, C_{LE2}, C_{LE3}, B_S	Introduced constant matrices for I_S computation .
C_{TS}, C_{TE}, V_{TO}, a_1, a_2, a_3 , B_V	Introduced constant matrices for V_T computation .
t	Coordinate transformation matrix . The matrix transposition symbol . The time in seconds .
p	$\frac{d}{dt}$
$e_{fd} = \frac{x_{ad}}{r_{fd}} v_{fd}$	Unsaturated open circuit excitation voltage referred to the stator side .
o	Initial condition indication .
δ..	Vector of [δ].

Some of capital letters , that are used for vectors or matrices , are composed of elements or diagonals taken as the corresponding defined small letter variables .

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Chapter 1

INTRODUCTION

The power system stability problem was firstly recognized for the synchronous machines connected through long transmission lines. Such machines suffer from a difficulty in maintaining synchronism, not only during the events of faults or loss of excitation but also under certain conditions of normal operation.

The first stability studies aiming at the determination of the highest power that can be transmitted without losing synchronism were limited to one machine-infinite bus system. As the size and complexity of interconnections in power systems to-day are getting too large, and considering the new trend of designing synchronous machines with large capacity and high per unit reactances for economical reasons, the stability of a synchronous generator in a network should be evaluated from a multi-machine model.

At the begining, multi-machine stability studies were conducted by considering only the swing equations of the different machines. The solution of these equations were performed using long hand calculations for systems of up to 3 or 4 machines at maximum. However, by using a-c network analyzer for obtaining the initial conditions and the accelerating torque under transient conditions , multi-machine calculations up to 12 machines have been done . Then , the numerical difficulties associated with the solution of the system differential equations were overcome by the use of integrating machanical means called the differential analyzer ; [5] .

As more accurate synchronous machine dynamic models become available ; multi-machine stability solution is first done on analogue computers . Analogue simulation has the advantages of flexibility in changing the system parameters , high speed , accuracy and repetitive operations . But large networks containing more than 5 machines , cannot be easly simulated because of the required large number of analogue components . However , these components may be limited using analogue computers and network analyzers in a combined scheme , where the analyzer is used to simulate the power network ; thus saving their analogue components ; [20,21,23] .

For most realistic system stability studies ; micro-machines and micro-systems are used for system modelling , but this procedure needs expensive equipments and consumes , an appreciable amount of power ; [20,23] .

Later , digital computers are used as an excellent aid in simulating power systems for their different studies.