State Space Modelling of Induction Generator for Dynamic Stability and THD Analysis Using SPWM Technique

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Abstract: Earlier approaches to stability analysis induction machinery were based on estimations and ideal expectations with little predictive accuracy. The emergence of computers with a quick-acting memory opens the door to accurate research by expanding the space for complex modelling. The previous procedures are based on the same range criterion or on a changed shape or on a swing equation. The methods now use a day now to explain the state field using the dynamic equations. This paper presents the development of the transient stability State space model, THD analytic, linearisation techniques and models for dynamic instability tests operating point model (with current and flow linkage states). Two case studies have shown the techniques.

Keywords: dynamic stability, swing mathematical form, THD, state-space.

INTRODUCTION

Computer induction is seldom used in isolated mode. In a power plant, they operate in tandem and the power plants are connected by a power system to a grid. The load given by an induction machine is negligible in a wide grid system [1,2]. Thus, by serial impedance, they are collectively viewed as one unit connected to the infinite bus. The induction generator is designed such that the device's axis is very wide and unyielding. The induction generator can be a cylindrical (steam turbine) or salient polarity type (driven by water turbine). The generators and power system components are synchronized with the moving magnetic field produced by the number of layers winding [3]. The classical analysis shows the inductive generator as a source of emf behind impedance (or merely because the resistance effect is too small, the armature reaction effect summarizes the armature leakage effect. We use one single inductive reactant for cylindrical pole machines and two inducing reactants for polar or direct axes as well as the inter polar or square axis [4] for salient polar machines. This effect can be explained by the substitution for fast transient conditions with inductive reactance for sluggish transients of latent reactance. Enhanced empirical techniques have now improvised the effects of transient and sub-transient importance to give better assessments of transient phenomena [5].

ILLUSTRATION OF INDUCTION GENERATOR

The variable step model [4, 9, 12] in which an Induction Generator can be described

i) There are two concentric coils in the scattered damper winding: one along the d axis and one along the q axis.
ii) A concentrated winding in the d-axis is the field winding.
iii) For the three stages, the armature is denoted by three coils, each of which is 120°.

In such systems, the inductance adjusts time as well as the analytical equations are nonlinear, since the angles of coupling of moving coils with fixed coils are constantly different. These non-linear equations are hard to solve. For this sort of model, the machine has a fantastic runtime and memory requirement.

A transformation matrix is used to eliminate this issue by Park and Gorev to translate process amounts to axis expanses as seen in the following:

$$\begin{bmatrix} V_d \\ V_q \\ V_o \end{bmatrix} = \sqrt{(2/3)} \begin{bmatrix} \cos\theta & \cos(\theta - 2\pi/3) & \cos(\theta + 2\pi/3) \\ \sin\theta & \sin(\theta - 2\pi/3) & \sin(\theta + 2\pi/3) \\ 1/\sqrt{2} & 1/\sqrt{2} & 1/\sqrt{2} \end{bmatrix} \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} \quad (1)$$

where, V_d, V_q etc. are transformed quantities and V_a, V_b etc. are phase quantities. The existing factors have a close relationship. The following inverse transformation is done to get phase quantities from the axis quantities:

$$\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} = \sqrt{(2/3)} \begin{bmatrix} \cos\theta & \sin\theta & 1/\sqrt{2} \\ \cos(\theta - 2\pi/3) & \sin(\theta - 2\pi/3) & 1/\sqrt{2} \\ \cos(\theta + 2\pi/3) & \sin(\theta + 2\pi/3) & 1/\sqrt{2} \end{bmatrix} \begin{bmatrix} V_d \\ V_q \\ V_o \end{bmatrix} \quad (2)$$

An orthogonal transformation is the park. It reduces a system to one with fixed axis variables with time-varying inductions. Similar and much easier to solve is the resulting model. D, Q is pseudo-stationary in this model, i.e. they are set in space but have the potential to induce emf by the speed action of the rotor. The real and transformed machine's circuit representation is shown in Fig. 1 (a) and (b). As a T-circuit, it illustrates the transformer. In this T—representation, the shunt factor consumes very little current. So we typically neglect and portray the transformer as serial impedance. The impedance of the engine is coupled with this impedance. The reaction and time constants are amended accordingly.

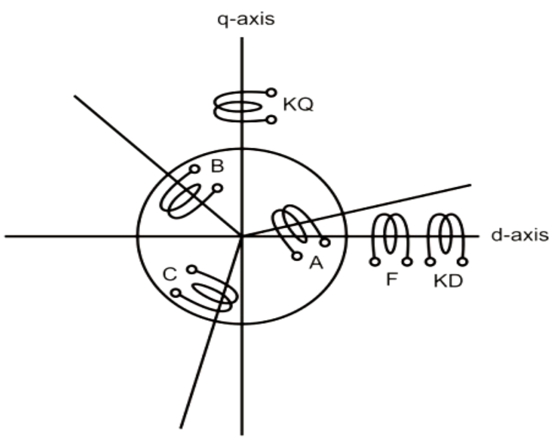

Figure 1(a). Induction Generator Variable Phase Model

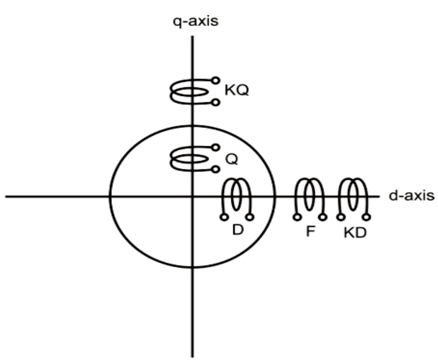

Figure 1(b). Machine converted d-q axes

QUANTITIES FOUNDATION, P.U. MATRIX WITREN AND TRANS-FORMIES

It's customary to use p.u in power system research. In terms of the relevant basic quantities, parameters and variables. The nominal voltage/current etc. of a single machine is used as a basis quantity for analysis. We choose the basis for equal flux relation for rotor quantities [10, 13, 18].

The impedance matrix transformed is derived from:

$$[Z'] = [CT]\ [Z]\ [C] \qquad (3)$$

Where the transformation matrix is [C] and it is transposed by $[C]^T$. We get the transformed impedance matrix through algebraic manipulation. This is a (4x4) matrix for a poly phase induction machine and a (5x5) matrix for a poly phase induction machine with one coil per axis representing the damper winding.

There is no inductance in the converted Z-matrix and can be tracked considerably more effectively. For most machine problems, it is a closed solution which forms the basis of the classic concept of the induction machine.

The drawbacks in the generalized model are as follows:

a. It cannot be used for double-salient devices such as the inductive induction generator.
b. It should not be extended to unbalanced winding machines such as single-phase induction generators.
c. External effects like equilibrium, heavy iron propagation of eddy currents and commutation phenomena are crucial to understand independently.

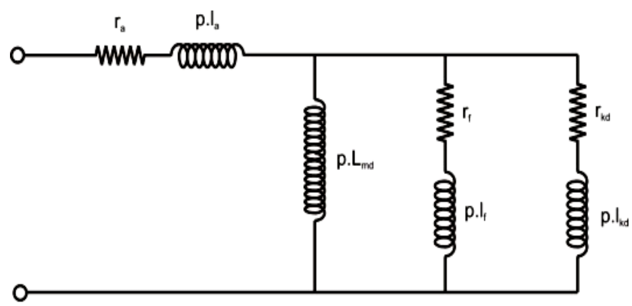

Figure 2(a). equivalent network of d-axis

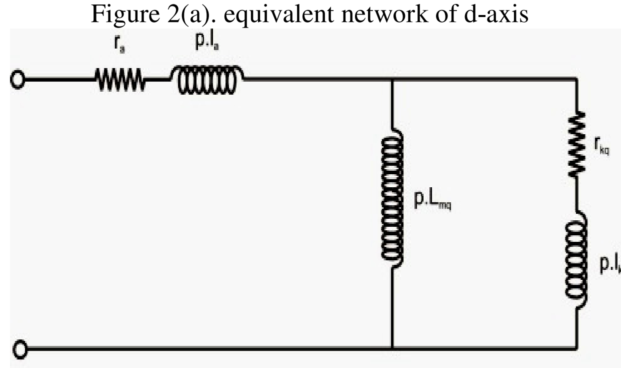

Figure 2(b). equivalent network of q-axis

COMPOSITION OF EQUIVALENT NETWORK

In Fig 2(a) for the d-axis and 2(b) for the q-axis, the equivalent circuits for the transformed machine are given. The coil F is the ground coil, KD and KQ are the damper coils, and D and Q are the pseudo-stationary counterparts of the 3-phase armature coils. The nomenclature of the other criteria is below [16, 19]:

L_{md} = Magentising D-axis inductance
L_{mq} = Magentising Q-axis inductance

l_a = Inductance of the armature leakage
r_a = Armature resistance
l_f = The field's leakage inductance
r_f = The field's resistance
l_{kd} = Inductance of d-axis damper leakage
r_{kd} = Resistance of the d-axis damper

In the steady state of the induction motor, p can be replaced by jω, as in the case of lack of excitation.

DEVICE PARAMETERS BY DATA OF THE MANUFACTURER

Manufacturer data is provided to power station operators through which the equivalent circuit for the d and q axes can be calculated using the following equation sequence [20].

$$X_{md} = X_d - x_a ;\; X_{mq} = X_q - x_a \tag{4}$$

$$1/X_f = 1/\left(X_d^{'} - x_a\right) - 1/X_{md} ;\; X_f = x_f + X_{md} \tag{5}$$

$$1/X_{kd} = 1/\left(X_d^{''} - x_a\right) - 1/x_f - 1/X_{md} ; \quad X_{kd} = x_{kd} + X_{md} \tag{6}$$

$$1/X_{kq} = 1/\left(X_q^{''} - x_a\right) - 1/x_f - 1/X_{mq} ; \quad X_{kq} = x_{kq} + X_{mq} \tag{7}$$

$$r_f = X_f \,/\, (\omega T_{do}^{'}) ;\quad T_{do}^{'} = T_d^{'}\left(X_d / X_d^{'}\right) \tag{8}$$

$$r_{kd} = \left(x_{kd} + \frac{X_{md} x_f}{X_{md} + x_f}\right) / (\omega T_{do}^{''}) \tag{9}$$

$$T_{do}^{''} = T_d^{''}\left(X_d^{'} \,/\, X_d^{''}\right) \tag{10}$$

$$r_{kq} = X_{kq} / (\omega T_{qo}^{''});\; T_{qo}^{''} = T_q^{''}\left(X_q^{'} / X_q^{''}\right) \tag{11}$$

These parameters apply to Park, Concordia, and Adkins' classical model. However, some of the data for current devices, such as q-axis magnetisation data or sub-transient reactance data, may not be usable. In any case, by referring to regular tables and textbooks, acceptable values can be inferred for the missing data.

EXTENSION OF THE CLASSICAL MODEL

It is possible to expand the classical model to include [4, 22]:

a. Mechanical parameters: Movable Z-matrix inertial and damping effects.
b. Strong iron effects: by reflecting more than one coil of damper per axis. As suggested by Anderson and Fouad, at least one more q-axis coil can be used, giving rise to transient q-axis reactance and time constants.
c. Saturation: by the use of saturated reactance values referring to the O.C.C. quieting limit.
d. Harmonics: As demonstrated by Kopylov, by the theory of superposition.

INCLUSION OF EFFECTS HITHERTO NEGLECTED

The measurement of electromechanical transients accounts for inertial and damping effects. The turbo-induction generator's inertia is given as the inertia constant H and the p.u. damping, just as D. The equation for the toque balance (known as the swing equation) is given [21] as:

$$T_m - T_e = \frac{2H}{\omega}\frac{d^2\delta}{dt^2} + \frac{D}{\omega}\frac{d\delta}{dt} \tag{12}$$

The consequence of saturation is that, based on the degree of saturation, the value of Xmd (also Xmq to a lesser degree) is diminished. For conditions at or close CMR and an unsaturated value under small/capacitive load, a saturated value of inductive reactance (Kingslay's method) is standard practice. If the O.C.C./S.C.C for the computers is available, either graphically or by computer software, the required value for the reactance will be found. The Frolick method or exponential method can be implemented using the curve-fitting technique for more detailed saturation analysis.

In the classical model, the influence of induced eddy currents in the solid iron rotor is not accounted for. The classical model is only suitable for laminated rotors that are seldom seen today. For dynamic performance analysis, the various electromagnetic models which account for the induced eddy currents in the solid iron sections of the rotor and in the retaining rings are not suitable. The solid iron rotor has been found to act as a q-axis damper, and two damper circuit coils for the q-axis are adequate to reflect the effect. This gives rise to the idea of a transient q-axis reaction.

In addition, between the field and the damper, there is a reciprocal coupling which may be expressed by an additional X_{fkd} parameter. By the system of Takeda and Adkins, the parameter can be experimentally figured out. There is no detail on this parameter in the manufacturer's results. In order to reduce complexity, the effect of harmonics is not accounted.

EQUIVALENCE MODEL OF MACHINE ON INFINITE BUS

A multi-machine system can be reduced to a 2-machine system by circuit analysis [16] for disruptions at a given spot. With regard to the grid power, if the rating of the defective machine is relevant, then the two-machine representation must be adopted. But if the rating of the generator is limited relative to the power of the system, then it becomes desirable to equate the 2-machine system via series impedance of one machine linked to an infinite bus. The circuit representation of a single device of a computer is given in Fig.1.

THE REACTANCE AND TIME CONSTANTS OF INDUCTION MACHINES

The above expressions have been found for p.u., neglecting the limited influence of resistances in the equivalent circuit. Induction System reactance and time constants [4, 11].

From, $X'_d = x_1 + X_{md} \Updownarrow x_f$; $\Updownarrow \rightarrow$ *in parallel* (15)

We get:

$$x_f = \left(X_d - X'_d\right) / \left\{X_{md}\left(X'_d - x_1\right)\right\} \quad (16)$$

where, X'_d = transient reactance of d-axis and x_f = Ground reactance leakage

From, $X''_d = x_1 + x_{md} \Updownarrow x_f \Updownarrow x_{kd}$ (17)

We get:

$$x_{kd} = x_{md} x_f . \left(X''_d - x_1\right) / [\, X_{md} x_f - X_f \left(X''_d - x_1\right) \,] \quad (18)$$

Where,

X''_d = d-axis sub transient reactance and x_{kd}= d-axis damper leakage reactance

From, $X''_q = x_1 + x_{mq} \Updownarrow x_{kq}$ (19)

We get: $x_{kq} = \left(X_q - X''_q\right) / \left\{X_{mq}\left(X''_q - x_1\right)\right\}$ (20)

Where, X''_q = q-axis sub transient reactance and x_{kq}= q-axis damper leakage reactance

From, $T'_{do} = X_f / (\omega_0 r_f)$ (21)

We get: $r_f = X_f / (T'_{do}\omega_o)$; (22)

Where, T'_{do} = d-axis O.C. transient time constant and r_f = field resistance.

The corresponding short circuit time-constant is given by: $T'_d = T'_{do} X'_d / X_d$

From $T''_{do} = (\, x_{kd} + x_f \Updownarrow X_{md}) / (\omega_o r_{kd})$ (24)

We get: $r_{kd} = \left(x_{kd} + x_f X_{md} / X_f\right) / (\omega_o T''_{do})$ (25)

Where, T''_{do} = d-axis sub transient time constant and r_{kd}= d-axis damper resistance.

The corresponding short circuit time-constant is given by: $T''_d = T''_{do} X'_d / X''_d$ (26)

From, $T''_{qo} = X_{kq} / (\omega_o r_{kq})$ (27)

We get, $r_{kq} = X_{kq} / (T''_{qo}\omega_o)$ (28)

Where, T''_{qo} = q-axis O.C. sub transient time constant and r_{kq} = q-axis damper resistance.

The corresponding S.C. time constant is given by: $T''_q = T''_{qo} X''_q / X_q$ (29)

The induction process data from the manufacturers includes induction, latent and sub-transient reactance and time constants. The other similar circuit reactance used in a state space model can be determined by means of the above formulae. If the generator is anticipated to operate on an infinite bus by series impedance, the reactance and time constants are changed.

STATE SPACE METHODOLOGY AND TRANSFER FUNCTION

The block diagram and transfer function method [23] (or signal flow graph) provides a mechanism's input/output relationship or free response, but does not take initial conditions into account before a disruption occurs. It is also incapable of treating non-linear functions. But for both linear and non-linear functions, the state space solution can run and can account for the original conditions. The interrelationship within the system of variables can also be discussed. Some benefits are also provided by the transform functionality strategy. More area data is used in this. It is important because it can provide input information that affects inter-area oscillation modes and can work without any modeling on calculated device data being needed. In a dynamic manner, a generator's parameters and functions are interrelated. It is necessary to decrease the uncertainty of mathematical expressions to evaluate such a method. The State Space approach to machine analysis is optimally adapted from this perspective.

MATHEMATICAL REPRESENTATION OF STATE SPACE TECHNIQUE

The following expressions are obtained by minimizing the governing differential equations of a system to their natural shape [17]:

$$\begin{aligned} X_1 &= f_1\left(X_1, X_2, \ldots\ldots\ldots, X_n, u_1, u_2, \ldots\ldots\ldots., u_m, t\right) \\ X_2 &= f_2\left(X_1, X_2, \ldots\ldots\ldots., X_n, u_1, u_2, \ldots\ldots\ldots., u_m, t\right) \\ &\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \\ X_n &= f_n\left(X_1, X_2, \ldots\ldots\ldots, X_n, u_1, u_2, \ldots\ldots\ldots., u_m, t\right) \end{aligned} \quad (30)$$

or, in a compressed state:

$$X = f\,(\,X, u, t) \quad (30(a))$$

The equation reduces to the following shape if the coefficients are linearized across the desired form as:

$$\dot{X} = Ax + Bu \quad (31)$$

A is a matrix of (n x n) and B is a matrix of (n x n) (n x m). The state variables reflect the scheme's complicated states. The above equations describe a first order sequence of differential equations in the form of state space. The state variables are not unique; there are several options for the choice of state variables. To reflect electrical machines, we usually choose either of the following:

i) As state variables, a set dependent on the currents, i.e.

$$X^T = \left[\, i_d \ i_q \ i_F \ i_{KD} \ i_{KQ} \,\right] \qquad (32)$$

Where,

i_d, i_q: d & q axis constituents of the armature current ;

i_F: field current

i_{kd}, i_{kq}: d & q axis constituents of the damper current.

This method has the advantage of having straightforward relationships in terms of voltages v and state variables.

ii) As state variables, a collection based on flux linkages, i.e.

$$X^T = (\lambda_d \ \ \lambda_f \ \ \lambda_{kd} \ \ \lambda_q \ \ \lambda_{kq}) \qquad (33)$$

where, λ_d, λ_q : d & q axis armature flux-linkages; λ_f: field flux linkages ;

λ_{kd}, λ_{kq}: d and q axis damper flux-linkages.

The collection to be picked depends on the relevant area of analysis.

MODELLING OF CURRENT IN THE STATE SPACE FORM

In terms of normalized quantities, the matrix model in Park's reference frame [14] for a machine is given as:

$$\begin{bmatrix} V_d \\ -V_f \\ 0 \\ V_q \\ 0 \end{bmatrix} = \begin{bmatrix} r_a & & & \omega L_q & \omega L_{mq} \\ & r_f & & & \\ & & r_{kd} & & \\ -\omega L_d & -\omega L_{md} & -\omega L_{md} & r_a & \\ & & & & r_{kq} \end{bmatrix} \text{x} \begin{bmatrix} i_d \\ i_f \\ i_{kd} \\ i_q \\ I_{kq} \end{bmatrix}$$

$$+ \begin{bmatrix} L_d & L_{md} & L_{md} & & \\ L_{md} & L_f & L_{md} & & \\ L_{md} & L_{md} & L_{kd} & & \\ & & & L_q & L_{mq} \\ & & & L_{mq} & L_{kq} \end{bmatrix} \begin{bmatrix} \dot{i}_d \\ \dot{i}_f \\ \dot{i}_{kd} \\ \dot{i}_q \\ \dot{i}_{kq} \end{bmatrix}$$

Using notation for matrix:

$$[V] = -(R + \omega N)[i] - L[\dot{i}] \qquad (34)$$

Where, R = Resistance matrix; N=Matrix for speed voltage inductances, L = Inductance matrix

Therefore, we get:

$$[\dot{i}] = -[L]^{-1}(R + \omega N)[i] - [L]^{-1}[V] \, p.u. \qquad (35)$$

This equation is in the space of the necessary state and is used for transient analysis. To incorporate the effects of inertia and damping, additional equations can now be included.

STANDARDIZING THE SWING CALCULATION

The following expression is obtained by normalizing the swing equation [14]:

$$\frac{2H}{\omega_B}\frac{d^2\delta}{dt^2} = T_m - T_e = \tau\frac{d\omega}{dt} \qquad (36)$$

The electric torque is defined as:

$$T_e = (1/3)(i_q\lambda_d - i_d\lambda_q) \ , \quad \text{where}$$

$$\lambda_d = X_d i_d + X_{md}(i_f + i_{kd}) \ ; \ \lambda_q = X_q i_q + X_{mq} i_{kq} \qquad (37)$$

The swing equation becomes: for higher accuracy, including the damping coefficient D.

$$T_a = T_m - T_e - T_D = T_m - T_e - \omega D \qquad (38)$$

PRESENCE OF MECHANICAL CONSTRAINTS AS STATE -SPACE FORM

The following motion state space model, including mechanical parameters, is obtained for the Induction machine [12]:

$$\begin{bmatrix} \dot{i}_d \\ \dot{i}_f \\ \dot{i}_{kd} \\ \dot{i}_q \\ \dot{i}_{kq} \\ \dot{\omega} \\ \dot{\delta} \end{bmatrix} = \left[\begin{array}{ccccc|cc} \multicolumn{5}{c|}{} & & \\ \multicolumn{5}{c|}{L^{-1}(R+\omega N)} & & \\ \multicolumn{5}{c|}{} & & \\ \hline -L_d i_q/\tau & -L_{md} i_q/\tau & -L_{md} i_q/\tau & L_q i_d/\tau & \omega & -D/\tau & \\ 0 & 0 & 0 & 0 & \delta & 1 & 0 \end{array}\right] \begin{bmatrix} i_d \\ i_f \\ i_{kd} \\ i_q \\ i_{kq} \\ \omega \\ \delta \end{bmatrix} + \begin{bmatrix} \\ \\ \mathbf{L^{-1}V} \\ \\ \\ T_m/\tau \\ -1 \end{bmatrix}$$

Where,

$$\tau = 3\tau_j \qquad (39)$$

It is in the ideal shape of State Space: $X = f(X, u, t)$. The inputs are $[V]$ and T_m. It is referred to as the state's current room. The result has nonlinearities in this model. The use of flux relations as state variables is an alternative approach.

THE ALTERNATIVE TACTIC OF FLUX LINKAGE IN STATE SPACE FORM

The use of the flux linkage state space model is an alternate method [10]. In this model, the variables of the state are:

$$X^T = (\lambda_d \ \ \lambda_f \ \ \lambda_{kd} \ \ \lambda_q \ \ \lambda_{kq}) \qquad (40)$$

Mathematical manipulation may achieve a comparable expression [12].

UNDER SMALL PERTURBATION OF LINEARISATION

1) **State-space form of current:**

If the state variable at time t_0 has an initial value of X_0 and the disturbance is X_Δ, then after linearization, we get

$$\dot{X}_\Delta = A(X_0)X_\Delta + B(X_0)U \qquad (41)$$

The A-matrix elements depend on the state vector's initial value, kept set for a particular case analysis, and the limitations of the infinite bus. The system's complex behavior is determined by the state matrix's eigenvalues. In the n-dimensional hyper-space of state variables, the operating conditions describe the hyperplane. We get the form below by linearizing the non-linear present state space model:

$$V = -Kx - Mx \tag{42}$$

For the induction generator, the state equation that does not include the load equation is given as:

$$\dot{X} = -(M^{-1}K)x - M^{-1}V = Ax + Bu \tag{43}$$

This is the sort of State Space that is required. Here are the terminologies explicitly attached to an infinite bus for the M-matrix and K-matrix components of an induction generator:

M=

<table>
<tr><td>L_d</td><td>L_{md}</td><td>L_{md}</td><td colspan="2" rowspan="3">0</td><td colspan="2" rowspan="3">0</td></tr>
<tr><td>L_{md}</td><td>L_F</td><td>L_{md}</td></tr>
<tr><td>L_{md}</td><td>L_{md}</td><td>L_D</td></tr>
<tr><td colspan="3" rowspan="2"></td><td>L_q</td><td>L_{mq}</td><td colspan="2" rowspan="2">0</td></tr>
<tr><td>L_{mq}</td><td>L_Q</td></tr>
<tr><td colspan="3" rowspan="2">0</td><td colspan="2" rowspan="2">0</td><td>$-T_j$</td><td>0</td></tr>
<tr><td>0</td><td>1</td></tr>
</table>

(44)

K=

R	0	0	$\omega_o L_q$	$\omega_o L_{mq}$	λ_{qo}	$-K_q$
0	r_F	0	0	0	0	0
0	0	r_D	0	0	0	0
$-\omega_o L_d$	$-\omega_o L_{md}$	$-\omega_o L_{md}$	R	0	$-\lambda_{do}$	K_d
0	0	0	0	r_Q	0	0
$(\lambda_{qo}-L_d.i_{qo})/3$	$-L_{md}.i_{qo}/3$	$-L_{md}.i_{qo}/3$	$(L_d.i_{do}-\lambda_{do})/3$	$L_{mq}.i_{do}/3$	D	0
0	0	0	0	0	-1	0

(45)

Where, infinite bus constants

$$K_d = -\sqrt{3}.V_\infty.\sin\delta_0 \tag{46a}$$

$$K_q = \sqrt{3}.V_\infty.\cos\delta_0 \tag{46b}$$

b) State space model of Flux-linkage:

The following form by algebraic modification by comparable treatment on the non-linear flux-linkage model. [18]

$$TX = CX + D$$

or, $$X = (T^{-1}C)X + T^{-1}D = AX + BU \tag{47}$$

This is in the type of State Space that is required. As in the previous case, the terms can be obtained by algebraic manipulations for the components of the A-matrix and B-matrix and are given in ref.

CASE STUDY

Case Study 1 (Current State Space Analysis)

The methods proposed by Mazumdar, Ghosh, Sanyal, etc. are being followed for the estimation of the results [17-19]. At present, the turbo generator with capacity of 250 MW, 11 kV, 50 Hz is being considered in the Purulia district of West Bengal (Santaldih TPS). Below are the function parameters, time constants and factors under operating conditions related to the system:

The Inductive Reactance of the d-axis, $X_d = 1.6$ p.u.

The Inductive Reactance q-axis, $X_q = 1.53$ p.u.

The transient reactance d-axis, $X_d^{'} = 0.122$

The subtransient reactance of d-axis, $X_d^{''} = 0.173$

The transient time constant of d-axis, $T_d^{'} = 1.021$ s

The subtransient time constant of d-axis, $T_d^{''} = 0.031$ s

The subtransient time constant of the q-axis, $T_q^{''} = 0.021$ s

For a minor disturbance that neglects the effects of exciter and governor power, we conduct dynamic stability analysis of the induction generator. It combines the boundary conditions.

Axis elements of the voltages and currents (in p.u.):
$V_d = -0.726$ $V_q = 0.8574$
$I_d = -0.9374$ $I_q = 0.3057$
$E = E_{FD} = 2.358$ $I_{FD} = 3.658$
Infinite bus const, K = 1.432

For defined operating conditions, the state matrix elements using the current state space representation are listed below:

Table I: Parameters of the state matrix

-36.081	**0.440**	**14.131**	**-3489.0**	**-2548.4**	**-2445.9**	**1752.3**
12.516	**-4.999**	**77.722**	**1210.3**	**884.02**	**848.47**	**-607.86**
22.757	**4.402**	**-96.868**	**2200.6**	**1607.3**	**1542.7**	**-1105.2**
3588.8	**2648.9**	**2648.9**	**-36.052**	**90.107**	**1776.2**	**2386.6**
-3504.2	**-2586.4**	**-2586.4**	**35.202**	**-123.37**	**-1734.3**	**-2330.3**
-0.008	**-0.203**	**-0.203**	**-0.799**	**-0.442**	**0.000**	**0.000**
0.000	**0.000**	**0.000**	**0.000**	**0.000**	**1000.0**	**0.000**

The characteristic matrix equation was developed by the Fadeev-Leverrier process. The matrix's characteristic polynomial is given below:

$x^7 + 0.29737\,x^6 + 1.0279\,x^5 + 0.22621\,x^4 + 1.384532\text{e-}02\,x^3 + 2.331442\text{e-}04\,x^2 + 1.026837\text{e-}05\,x + 3.074246\text{e-}08 = 0$

The actual roots have been defined by the Newton-Raphson technique and developed as shown below:

$R_1 = -3.264\text{e-}03$; $R_2 = -0.1534$;
$R_3 = -8.749\text{e-}02$

Adjacent pair (1): -6.5707e-03 ± j 1.7423e-02
The related oscillation frequency in Hz.= 1.698 ; damping ratio= 4.605
Adjacent pair (2): -3.5948e-02 ± j .99826

Corresponding oscillation frequency in Hz.=59.9; damping time const.= 7.379e-02
The system is stable since there is no positive real root, or no root with a positive real part.

Case study 2 (Flux Linkage State Space Analysis)

Another measurement of dynamic stability using a flux-linkage state space model is now being made for a 250 MW induction generator. The stability analysis was carried out using both Routh's own value method and parameters. The parameters marked below are:

Synchronous Reactance of the d-axis, $X_d = 2.225$p.u.

Synchronous Reactance of the q-axis, $X_q = 2.11$p.u.

The latent reactance in the d-axis, $X_d^{'} = 0.305$

The transient reactance of the d axis, $X_d^{''} = 0.214$

The transient time constant of d-axis, $T_d^{'} = 1.0$ s

The transient time constant of the d-axis sub, $T_d^{''} = 0.125$ s

The transient time constant of the q-axis sub, $T_q^{''} = 0.06$ s

At generator terminals, the boundary limitations are given.
Power rated by the generator = 250 MW;
Voltage rated by the generator = 11 kV
Control of the generator P = 0.85p.u.
Control calculation for the generator (lag) = 0.85
Terminal voltage of the engine $V_g = 1.0$
The limitless voltage of the bus V_{inf}= 0.9307
W.r.t limitless bus phase angle = -7.0030°
Power angle = 40.307°
The voltages and currents are given below with the axis quantities:
V_d= -0.758 V_q= 0.784 I_d= -0.9478
I_q= 0.4125 $E=E_{fd}$= 3.254 I_{fd}= 2.654
Infinite Continuous Bus, K= 1.745

Table II: Parameters of the state matrix

-16.428	9.4412	6.1628	-878.42	246.28	-730.18	667.16
1.7833	-4.5154	2.6013	0.0000	0.0000	0.0000	0.0000
12.788	11.766	-25.4917	0.0000	0.0000	0.0000	0.0000
1138.4	-166.43	-263.86	1.1717	-3.7078	762.04	823.34
0.0000	0.0000	0.0000	59.078	-63.6638	0.0000	0.0000
0.5988	0.2500	-0.3964	-0.7486	0.4956	0.0000	0.0000
0.0000	0.0000	0.0000	0.0000	0.0000	1000.0	0.0000

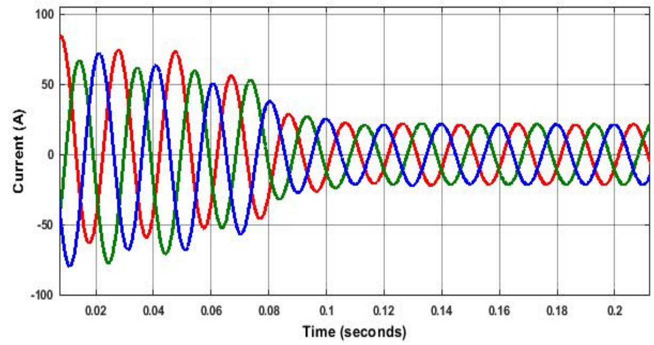

Fig.3 Three phase stator current with SPWM technique

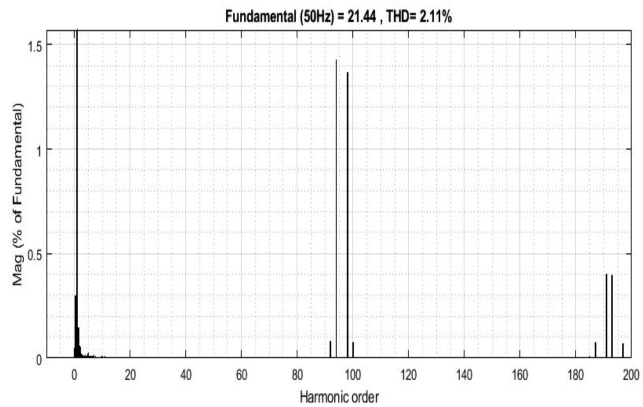

Fig.4 THD analysis of stator current

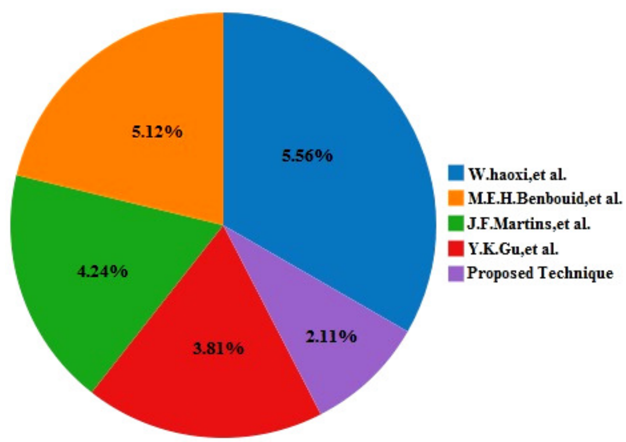

Fig.5 THD comparison with other technique

The Fadeev-Leverrier technique was used to determine the characteristics equation, as given below:

$$x^7 + 0.10893x^6 + 1.0045\,x^5 + 7.399E\text{-}02\,x^4 + 2.3252E\text{-}03\,x^3 + 6.1547E\text{-}05\,x^2 + 8.4629E\text{-}07\,x + 8.1277E\text{-}10 = 0$$

Equilibrium research is performed according to the parameters of Routh. The tabulation of Routh is given below:

Table III: Parameters of Routh's criterion

1.0000000000000	1.0045360000000	0.0023251500000	0.0000008462933
0.1089272000000	0.0739918900000	0.0000615473300	0.0000000008128
0.3252573000000	0.0017601180000	0.0000008388317	
0.0734024400000	0.0000612664100	0.0000000008128	
0.0014886370000	0.0000008352302		
0.0000200824800	0.0000000008128		
0.0000007749825			

Though the elements are presents in the first column are having the same sign and positive in value, hence the system is stable. The primary roots of the system are defined by NR criterion:
r_1=-1.0354e-03 ; r_2= -1.412e-02 ;
r_3= -3.235e-02
The oscillating frequency of the system = 1.5 Hz
The damping ratio = 0.9

CONCLUSION

Mathematical simulation of a system helps to understand the behavior of a system and predict its results. The most difficult part is designing the induction motor in this exercise. The general technique is to use the Park-Gorev transition along d-q axes to reduce the system into a number of coupled coils. For the model, this makes it simple and tractable. It also removes the computer's need for runtime and memory space. A number of synchronous generators swing around equally in different types of agitation. It is assumed that a cohesive culture like that is a collection of swinging machines. The coherent category can be defined by a single big machine with equivalency parameters in order to minimize the dimension of the resulting model. In the block diagram and transfer function method, there are some important limitations, once common. In the State Space system, such limits are missing. However, the State Variable Model was used. There are two kinds of state variables widely used. The existing state variables and the state variables of the flux linkage. The consequences of the mechanical parameters of inertia and damping, the effects of the turbine (and boiler, if any) and, ideally, the secondary effects of saturation, etc., need to be included in the state variable model. It also lowers THD by as much as 2.11%. Eventually, its utility is demonstrated by the complex stability of the suggested solution

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