USING THE TRANSIENT ENERGY FUNCTION TO ASSESS THE DYNAMIC STABILITY IN MULTI-MACHINE POWER SYSTEM

Luu Huu Vinh Quang

HCMUT HCMC Vietnam

lhv2uang@hotmail.com

ABSTRACT This paper mentions an algorithm to calculate the potential energy and kinetic energy levels within the frame of the center of inertia of the system, combining the use of transient energy function and time solution methods to determine the dynamic stability margin for the fault occurring at a specific position in multi-machine power system, considering the impacts of different torque components (accelerating, asynchronous, damping, braking torques) under condition of action of the automatic voltage regulation systems of generators and also of the action of automatic frequency regulation systems. Basing on the proposed algorithm this PC program uses the elements of the eigen-image matrix to bring the specific advantages for the simulation of the transient features of the state variables. Some tested numerical results of calculating the transient energy function for multi-machine power system are shown in this paper.

INTRODUCTION

The transient stability analysis is mainly performed through numerical simulations, where numerical integration is carried out step by step from an initial value to obtain dynamic response to disturbances. The transient energy function (TEF) methods assess system stability based on the transient energy. The progress has been made in the development and use of TEFs for multi-machine power systems, these developments has been the assessment of generator stability, determining whether all generators in the system remain in synchronism following a disturbance. The stability assessment is a comparison of the critical energy with the energy of the system at the beginning of the post-disturbance period.

This paper proposes a new mathematical model for transient stability analysis, considering the effects of the system automatic regulation, assessing the transient stability, dealing with the application of the TEF method in combination with numerical integration to assess the transient stability in multi-machine power systems. These are included:

1. Formulating the initial conditions of the transient problem.
2. Choosing the type of disturbance and implementing the numerical integration with rating clearing time and determining the transient state variables.
3. Identifying the stable energy point of post-disturbance condition.
4. Estimating the unstable equilibrium point.
5. Identifying the kinetic and potential levels at clearing instance and determining the transient energy margin (TEM) to assess the system stability.

MATHEMATICAL MODELLING

Numerical Integration Model:

The transient state of the power system is considered as the technical movement modelling by the differential equations following

$$\sum_{j=1}^{M}\left(A_{ij}\frac{d^2x_j}{dt^2} + B_{ij}\frac{dx_j}{dt} + C_{ij}x_j \right) = F_i(t); \qquad (1)$$

The real coefficients A_{ij}, B_{ij}, C_{ij} are determined by the system parameters and the nonlinear functions $G_i(x_j)$ describing the state of the system at any moment of time. $F_i(t)$ are external forces varying with time and characterizing the changes in the external conditions of the system. The transformation and solution of (1) are presented in (Luu H.V.Quang, 2015).

Transient Energy Function:

The TEF describes the transient energy at the t-th instance of time under transient conditions in the power system is

$$F_E = F_{KE}(\omega_i) + F_{PE}(\theta_{ij}); \qquad (2)$$

Referring (A.A.Fouad, V.Vital,1992), (P.Kundur,1993), the TEF can be written as follows

$$F_E = 0.5\sum_{i=1}^{n} 2H_i\,\omega_o\,\omega_i^2 \;-\sum_{i=1}^{n}\left(P_{mi}-E_i^2G_{ii}\right)\left(\theta_i-\theta_i^s\right)$$
$$-\sum_{i=1}^{n-1}\sum_{j=i+1}^{n}\left[C_{ij}\left(\cos\theta_{ij}-\cos\theta_{ij}^s\right)-\int_{\theta_i^s+\theta_j^s}^{\theta_i+\theta_j} D_{ij}\cos\theta_{ij}\,d\left(\theta_i+\theta_j\right)\right]; \quad (3)$$

The calculation of TEM is: $TEM = (F_E^{cr} - F_E^{clr});$

If TEM determined positive then transient oscillation can be attenuated, the power system state is stable; the power system will lose its transient stability if TEM determined negative. Regarding to critical clearing time, the TEM criterion is effective to comparatively assess the transient stability for different configurations of power system under transient condition, and may be effective to comparatively assess the transient stability for one type of disturbance at different locations.

NUMERICAL EXAMPLE

Let's survey the electro-mechanical transient process in a 45-bus power system consisting of 3 power plants with 6 synchronous generators, 1 synchronous condensers, 4 SVCs and 28 composite loads. The basic power is 100 MVA. The data of the synchronous machines and the SVCs are given in (Luu H.V.Quang, 2016). The positive-sequence line-data and load bus-data are given in the table 1 and table 2 following

Table 1. Line-data

Bus		R	X	0.5B
m	n	(pu)	(pu)	(pu)
2	33	0.0166	0.0347	0.0017152
32	6	0.0100	0.0208	0.0019602
32	4	0.0023	0.0048	0.0000448
6	3	0.0153	0.0319	0.0030062
3	2	0.0209	0.0437	0.0041188
4	2	0.0402	0.1024	0.0049913
5	2	0.0465	0.0972	0.0091670
2	7	0.0166	0.0347	0.0016311
2	9	0.0354	0.0739	0.0034788
2	34	0.0002	0.0248	0
7	8	0.0025	0.0052	0.0004903
8	1	0.0681	0.1423	0.0066966
10	34	0.0116	0.0625	0.0954835
11	34	0.0002	0.0009	0.0013262
12	13	0.0016	0.0879	0
12	20	0.0029	0.0154	0.0031678
12	34	0.0069	0.0325	0.0248897
13	14	0.0021	0.0055	0.0002662
13	1	0.0021	0.0055	0.0002662
14	15	0.0083	0.0174	0.0008168
14	16	0.0530	0.1108	0.0052157
15	30	0.0083	0.0055	0.0008168
16	17	0.0080	0.0137	0.0006467
16	27	0.0212	0.0539	0.0026287
17	18	0.0105	0.0176	0.0016095
18	22	0.0024	0.0061	0.0006010
19	20	0.0031	0.1002	0
20	21	0.0022	0.0117	0.0089177
21	22	0.0014	0.0503	0
21	34	0.0044	0.0234	0.0719708
22	23	0.0040	0.0067	0.0003055
22	26	0.0220	0.0371	0.0033789
22	28	0.0067	0.0171	0.0016655
23	24	0.0040	0.0067	0.0003055
24	25	0.0032	0.0066	0.0012415
25	26	0.0032	0.0066	0.0012415
27	28	0.0212	0.0539	0.0026287
28	29	0.0264	0.0552	0.0025973
29	30	0.0055	0.0115	0.0054069
30	1	0.0266	0.0555	0.0026136
31	1	0.0439	0.0741	0.0067591
5	35	0.0102	0.1308	0
32	36	0.0102	0.1308	0
27	37	0.0102	0.1308	0
25	38	0.0102	0.1308	0
1	39	0.0004	0.0921	0
1	40	0.0084	0.2008	0
1	41	0.0084	0.2008	0
34	42	0.0004	0.0921	0
34	43	0.0004	0.0921	0
2	44	0.0030	0.1114	0
2	45	0.0030	0.1114	0

Table 2. Load bus-data

Bus	Load			Bus	Load	
	MW	MVAR			MW	MVAR
3	6	3		18	16	6
4	10.5	5.1		22	4	1
5	125	15		23	6	3
6	4	2.5		24	8	3
7	5.5	4		25	20	10
8	18	8		26	8	3
9	38	16		27	37	10
10	47	32.8		29	16	6
11	30	9		31	68.4	4.8
15	18	11		32	4.9	2.5
17	6	3		33	4	1.9

Studying Cases:

Let's investigate the transient stability of system configurations with 4 SVCs locating on the buses counted from 35 to 38, the data of which are given in (Luu H.V. Quang, 2016).

Let's assess the transient stability of the power system by comparing the TEMs calculated under different conditions of short circuit occurring at some high voltage transmission line (i-j), connecting the buses i and j. Let's investigate three fault types: the fault of three-phase short circuit is designated by "F(3)"; the fault of phase-to-phase-to-ground short circuit is designated by “F(1,1)” and the fault of phase-to-phase short circuit is designated by “F(2)”. Let’s suppose that the faults will be cleared at 0.1 sec, the TEMs are calculated and shown in table 3 as follow

Table 3. Comparing the TEMs to assess the transient stability

Line		$TEM \times 10^{-4}$ (p.u.)			Ranking
Bus i	Bus j	F(3)	F(1,1)	F(2)	
1	30	4.3296	4.3213	4.1540	Strongest
2	3	4.2957	4.1865	4.1149	2nd
21	34	3.8805	3.7487	3.7440	3rd
12	34	3.2873	3.1531	3.1592	Weakest

The results, showing in the table 3, indicate that: the line (12-34) is weakest in view of transient stability of the power system because of its smaller TEMs. Having biggest TEMs, the line (1-30) is strongest in view of transient stability of the power system.

However, the TEMs will not be evermore effective to comparatively assess the transient stability of the power system of the different types of disturbance. We should combine the criterion of TEM with the use of kinetic energy level to comparatively assess the electro-mechanical transient process of the different types of disturbance regarding to one fault location: so, for the normal clearing time, the system is more stable if the kinetic energy is smaller.

The comparison of the changes of TEMs with the clearing time and the fault types, corresponding to the line ranking column of table 3, is allowed to assess the transient stability of the power system. The TEM is decreased if clearing time is augmented, but the kinetic energy levels will be augmented as demonstrating in next.

The results of studying case of line (1-30) are shown in the fig.1a, fig.1b, fig.1c and the fig.1d as follows

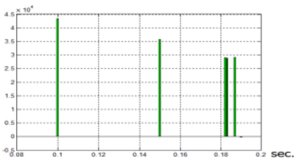

Fig.1a TEM with F(3)

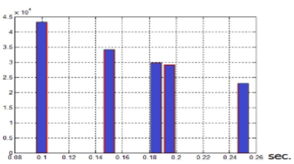

Fig.1b TEM with F(1,1)

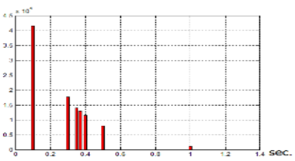

Fig.1c TEM with F(2)

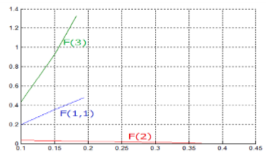

Fig.1d Kinetic Energies

In this case, the critical clearing time is 0.187sec for the fault type of F(3) and is 0.28sec for the fault type of F(1,1). Let’s choose the same clearing time of 0.19 sec. to compare the variations of the damping torques under conditions of the fault types of F(3) and of F(2). The unstable and stable states of damping torques are demonstrated in the fig.1e and the fig.1f, as follows

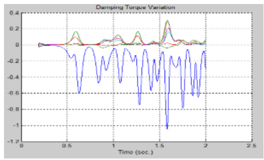

Fig.1e Damping Torques relating to F(3)

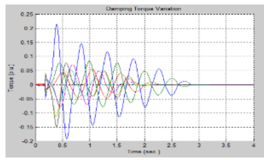

Fig.1f Damping Torques relating to F(1,1)

The results of studying case of line (2-3) is similarly shown in the fig.2a, fig.2b, fig.2c, fig.2d, fig.2e and the fig.2f, as follows

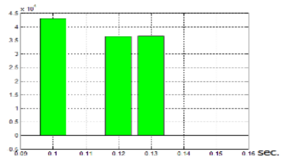

Fig.2a TEM with F(3)

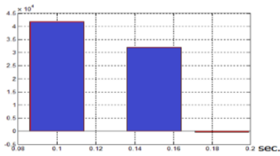

Fig.2b TEM with F(1,1)

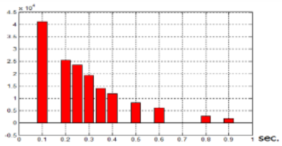

Fig.2c TEM with F(2)

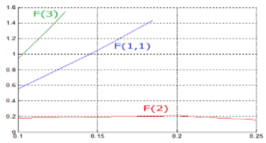

Fig.2d Kinetic Energies

The asynchronous torques are varied under fault condition of the same clearing time of 0.15 sec, as follows

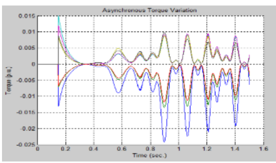

Fig.2e Asynchronous Torques relating to F(3)

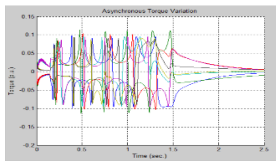

Fig.2f Asynchronous Torques relating to F(2)

The results of studying case of line (21-34) is similarly shown in the fig.3a, fig.3b, fig.3c, fig.3d, fig.3e and the fig.3f, as follows

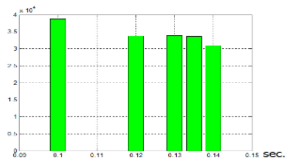

Fig.3a TEM with F(3)

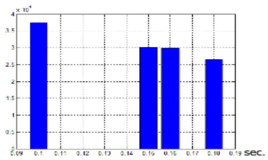

Fig.3b TEM with F(1,1)

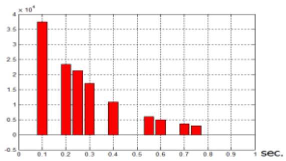

Fig.3c TEM with F(2)

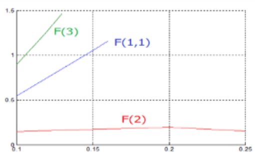

Fig.3d Kinetic Energies

The synchronous torques are changed under conditions of fault types of F(1,1) and of F(2), regarding to the same clearing time of 0.181 sec, as follows

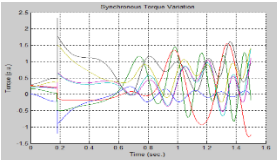

Fig.3e Synchron.Torques relating to F(1,1)

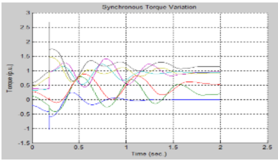

Fig.3f Synchron.Torques relating to F(2)

The results of studying case of line (12-34) is similarly shown in the fig.4a, fig.4b, fig.4c, fig.4d, fig.4e and the fig.4f, as follows

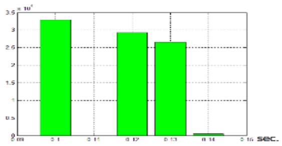

Fig.4a TEM with F(3)

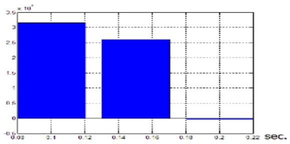

Fig.4b TEM with F(1,1)

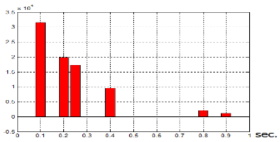

Fig.4c TEM with F(2)

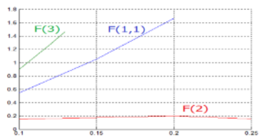

Fig.4d Kinetic Energies

The accelerating torques, regarding to the same clearing time of 0.18 sec, are shown as follows

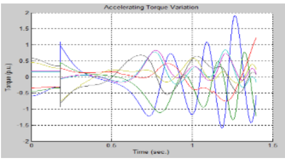

Fig.3e Accelerat. Torques relating to F(1,1)

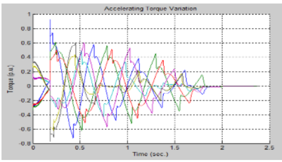

Fig.3f Accelerat. Torques relating to F(2)

The transient conditions of power system can be assessed by comparative checking the values of TEF corresponding to the critical clearing time (t_{TCC}). The content demonstrating in the table 4 confirms the outcomes relating to the assessment of transient stability of power system shown in the table 3 and in the figures belonging the above illustrative examples, as follows

Table 4. Comparing the t_{CCT} and the TEFs.

Line		$\frac{t_{\text{Critical Clearing Time}},(\text{sec.})}{\text{TEM}\times 10^{-4}(\text{p.u.})}$		
Bus i	Bus j	F(3)	F(1,1)	F(2)
1	30	$\frac{0.187}{2.91}$	$\frac{0.28}{1.706}$	$\frac{2}{0.0058}$
2	3	$\frac{0.139}{3.55}$	$\frac{0.175}{3.06}$	$\frac{0.9}{0.175}$
21	34	$\frac{0.139}{3.13}$	$\frac{0.175}{2.695}$	$\frac{0.9}{0.162}$
12	34	$\frac{0.139}{2.75}$	$\frac{0.175}{2.279}$	$\frac{0.9}{0.144}$

CONCLUSION

The transient energy margins allow to compare and to assess the different configuration of power system. Combination of TEF with the kinetic energy levels allows to assess the transient stability under condition of symmetrical or unsymmetrical disturbances in multi-machine power system. The critical TEF value provides an estimate of the maximum amount of energy that can be gained by the system during a disturbance without the system losing stability. If the system acquires less energy, stability will be guaranteed. However if the system acquires a greater amount of energy, it may be unstable.

REFERENCES

A.A.Fouad, Vijay Vital, Power System Transient Stability Analysis, *Prentice-Hall,Inc.*, 1992.

Prabha Kundur. *Power system stability and control*. *Mc Graw Hill, Inc*. 1993.

Luu H.V.Quang, Modeling the initial condition of P_power deficiency for multi-machine transient stability simulation, *Proceedings of the 8th Seatuc Symposium*, Malaysia 2014, [OS10], pp.74-79, ISBN 978-967-12214-1-9.

Luu H.V. Quang, Investigating the impacts of asynchronous torque affecting to the transient stability in multi-machine power system, 2014, *Science & Technology Development Journal VNU HCMC*, pp. 27-38, Vol.17-NºK3, ISSN 1859-0128.

Luu H.V. Quang, Simulating the transient stability in multi-machine power system considering the negative-sequence braking torques and the asynchronous tor*ques. 9th Seatuc Symposium*, Thailand 2015, ISSN 2186-7631.

Luu H.V. Quang, Comparing the impacts of the SVCs and the STATCOMs affecting to the electro-mechanical transient process in multi-machine power system, *Proceedings of 14th ISEE HCMUT*, Vietnam 2015.

Luu H.V. Quang, Comparing the impacts of SVCs and Synchronous Condensers to the transient stability in multi-machine power system, *Proceedings of 10th Seatuc*, Japan 2016.

NOMENCLATURE

$F_{KE}(\omega_i)$: kinetic energy function;
$F_{PE}(\theta_{ij})$: potential energy function;
F^{cr}_E : level of TEF calculated at UEP of post-disturbance state;
F^{clr}_E : level of TEF calculated at clearing time under fault condition;
C_{ij} : coefficient determined by $E_iE_jB_{ij}$;
D_{ij}: coefficient determined by $E_iE_jG_{ij}$;