ASSESSMENT OF POWER SYSTEM TRANSIENT STABILITY BY RKE METHOD[+]

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Abstract

The criterion for assessment is given in terms of the rate of change of kinetic energy of individual machines subsequent to fault clearance. The basic concepts and the mathematical formulation of the method are summarized. Practical test system is used to demonstrate the superior efficiency of the method relative to step by step given in the literature. Comparison of results between stability prediction of the step by step method and the RKE method shows good agreement.

The importance of this development may be judged by the saving it can make in the calculation of power system stability for large system.

المستخلص

أن معيار الحكم على استقرارية منظومة القدرة يعتمد على حساب معدل تغير الطاقة الحركية في لحظة إزالة العطل، تم تلخيص التمثيل الرياضي البسيط والمفصل للماكنة حسب الحاجة.تم اعتماد نماذج اختبارية تطبيقية معتمدة في الأدبيات لعرض مزايا الطريقة مع طريقة الخطوة خطوة، من مقارنة النتائج لاحظنا أن هناك تقارب كبير بين نتائج الطريقتين.يمكن استخدام طريقة معدل تغير الطاقة للحكم على استقرارية منظومات قدرة كبيرة من دون صعوبات أو تعقيدات قد تجعل الحل غير ممكن في بعض الأحيان أو يستغرق زمناً طويلاً كما يحصل في طريقة الخطوة- خطوة الكلاسيكية.

List of Symbols :

T = execution time, second.

I_i = vector of winding currents.

M_i = angular momentum of machine i.

δ_i = rotor angle of machine i.

P_{mi} = mechanical power input to machine i.

P_{ei} = electrical power output of machine i.

E_i = voltage behind the transient reactance of machine i.

G_{ii} = self conductance at the internal node of machine i.

B_{ii} = transfer conductance between ith and jth internal nodes.

δ_i^o = equilibrium state of the ith machine in the post fault state.

δ_i^s = equilibrium state of the ith machine in the pre fault state.

ω_i = rotor velocity or disturbance speed of machine i.

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ω_{ic} = rotor velocity at fault clearance of machine i.

ω_{icr} = rotor velocity at critical fault clearance of machine i.

δ_{ic} = rotor angle at fault clearance of machine i.

δ'_{im} = maximum angle of rotor advance of machine i.

T_{cr} = critical fault clearing time.

δ_{icr} = rotor angle at critical fault clearance of machine i.

ω'_{im} = velocity at δ'_{im} of machine i.

δ_{im} = maximum angle of rotor advance for critical stability of machine i.

ω_{im} = velocity at δ_{im} of machine i.

Introduction

An improvement has recently been proposed giving a mathematical justification of the method for single machine power systems: it is called the rate of change of kinetic energy (RKE) method. This method has been extended to multi machines systems using the fact that the critical machines of the system are responsible for system separation [1,2] .

Applications to stability problems and to systems with detailed machine representation are presented in 2 and 3.

This research presents a brief description of the RKE method and demonstrates its efficiency with respect to step by step direct method.

Model

The equations pertaining to this model, with damping and transfer conductances neglected, are [3] .

$$M_i \frac{d^2\delta_i}{dt^2} = P_{mi} - p_{ei} \quad \text{i = 1, 2… n} \qquad \text{… (1)}$$

The electrical power output P_{ei} is given by

$$p_{ei} = E_i^2\, G_{ii} + \sum_{j=1}^{n} E_i\, E_j\, B_{ij} \sin(\delta_i - \delta_j) \quad j \neq 1, \quad i = 1,2..........,n \qquad ...(2)$$

Solution of Eqn.1, with B_{ij} pertaining to the faulted state till the fault clearance, gives rotor angles and velocities of the machines [3, 4] .

From this information, a criterion for stability assessment can be developed.

11. Rate of change of kinetic energy (RKE) :

The kinetic energy $(KE)_i$ of machine i is

$$(KE)_i = \frac{1}{2} M\, \omega_i^2 \qquad \text{… (3)}$$

Differentiating Eqn.3 with respect to time, the RKE of machine i is

$$\frac{d(KE)_i}{dt} = \mathrm{M_i}\ \omega_{\mathrm{i}}\ (\mathrm{d}\omega_{\mathrm{i}}/\mathrm{dt}) \qquad \ldots (4)$$

Substituting eqn.1 into eqn.4, we obtain

$$\frac{d(KE)_i}{dt} = \omega_i\ (\mathrm{P_{mi}} - P_{ei}) \qquad \ldots (5)$$

At fault clearance, if the B_{ij} refer to the post-fault system, then $(\mathrm{RKE})_i$ is given by

$$(RKE)_i = \omega_{\mathrm{ic}}\ (\mathrm{P_{mi}} - P_{\mathrm{ei}}) \qquad \ldots (6)$$

The potential energy $(\mathrm{PE})_i$ gained during the post-fault state is given by

$$(PE)_i = \int_{\delta_{ic}}^{\delta_{im}} (\mathrm{p_{imax}} \sin \delta_i - P_{mi}) d\delta_i \qquad \ldots (7)$$

where $P_{i\max}$ is the maximum power fed by the machine to the infinite system. Since the total kinetic energy is constant, it is clear that

$$(d(KE)_i/dt) = -(\mathrm{d(KE)_i/dt}) \qquad \ldots (8)$$

Hence $(\mathrm{RKE})_i$ can be obtained by differentiating Eqn.7 with respect to time. This gives

$$(RKE)_i = \omega'_{\mathrm{im}}\ \mathrm{P_{imax}} \sin \delta'_{\mathrm{im}} - \omega_{\mathrm{ic}}\ \mathrm{P_{imax}} \times \sin \delta_{\mathrm{ic}} - \omega'_{\mathrm{im}}\ \mathrm{P_{mi}} + \omega_{\mathrm{ic}}\ \mathrm{P_{mi}} \qquad \ldots (9)$$

For a stable system, δ'_{im} will be less than the maximum angle of rotor advance for critical stability δ_{im}. Further, at δ'_{im} the rotor velocity W'_{im} is zero. Hence, $(\mathrm{RKE})_i$ is given by

$$(RKE)_i = W_{ic}(\mathrm{P_{im}} - P_{i\max} \sin \delta_{\mathrm{ic}}) \qquad \ldots (10)$$

For the unstable case, however, δ'_{im} is greater than δ_{im}, and ω'_{im} is not zero and is continuously increasing. In such a case, $(RKE)_i$ is given by (1)

$$(RKE)_i = -\omega'_{\mathrm{im}}\ \mathrm{P_{imax}} \sin \delta'_{\mathrm{im}} - \omega_{\mathrm{ic}}\ \mathrm{P_{imax}} \sin \delta_{\mathrm{ic}} + \omega'_{im}\ \mathrm{P_{mi}} + \omega_{ic}\ \mathrm{P_{mi}} \qquad \ldots (11)$$

It will now be shown that this rate of change of kinetic energy is a negative maximum for the critical machine at the critical clearing time and is given by

$$(RKE)_{icr} = \omega_{icr}\ (\mathrm{P_{im}} - \mathrm{P_{imax}} \sin \delta_{\mathrm{icr}}) \qquad \ldots (12)$$

Criterion

Assume that the fault is cleared at $(t_{cr} - \Delta t)s$. As a result, the system is stable, and the clearing angle and velocity will be less than δ_{icr} and ω_{icr}, by $\Delta\delta_i + \Delta\omega_{\mathrm{i}}$, respectively. RKE is then given by

$$\left[(RKE)_i\right]_{-\Delta t} = (\omega_{\mathrm{icr}} - \Delta\omega_i)(P_{mi} - P_{i\max} \sin(\delta_{icr} + \Delta\delta_i)) \qquad \ldots (13)$$

Clearly, the second term in Eqn.13 is less than the corresponding value at t_{cr}.

It is now assume that the fault is cleared Δt_s later. The rotor speed and angle are greater than those at t_{cr} by $\Delta\omega_i$ and $\Delta\delta_i$, and the system is unstable. Using Eqn.11, RKE at $(t_{cr} + \Delta t)$ is given by

$$\left[(RKE)_i\right]_{+\Delta t} = -\omega'_m\ \mathrm{P_{imax}} \sin \delta'_{im} - P_{i\max}(\omega_{icr} + \Delta\omega_c)$$
$$\sin(\delta_{icr} + \Delta\delta_c) + \omega'_{im} P_{mi} + (\omega_{icr} + \Delta\omega_c) P_{mi} \qquad \ldots (14)$$

Expanding the right hand side of eqn.14 and substituting $\Delta\delta_c$ and unity for sin $\Delta\delta_c$ and $\cos\Delta\delta_c$, one obtains

$$\left[(RKE)_i\right]_{+\Delta t} = \omega_{icr}(P_{mi} - P_{i\max}\sin\delta_{icr}) + \omega'_{im}(P_{mi} - P_{i\max}\sin\delta'_{im})$$
$$+ (P_{mi} - P_{i\max}\sin\delta_{icr})\Delta\omega_c - P_{i\max}\omega_{icr}\cos\delta_{icr}\,\Delta\delta_c$$
$$- P_{i\max}\Delta\omega_c\cos\delta_{cr}\Delta\delta_c \qquad \text{...(15)}$$

For $(RKE)_{i+\Delta t}$ to be less than $(RKE)_{icr}$, the sum of the last four terms on the right hand side of Eqn.15 must be positive. Thus, the highly positive value of the second term dominates, outweighing the third, fourth and the fifth terms together. Hence, $(RKE)_{i-\Delta t}$ is less negative than $(RKE)_{icr}$ this conclusion has also been verified by a number of simulations [5,6,7] .

Transient stability Computation Procedure

The integration method used for solving system differential equations is the modified Euler's method. Computing the critical clearing time (CCT) by the RKE method may be presented by the flowchart as in Fig.(1) [8,9,10] .

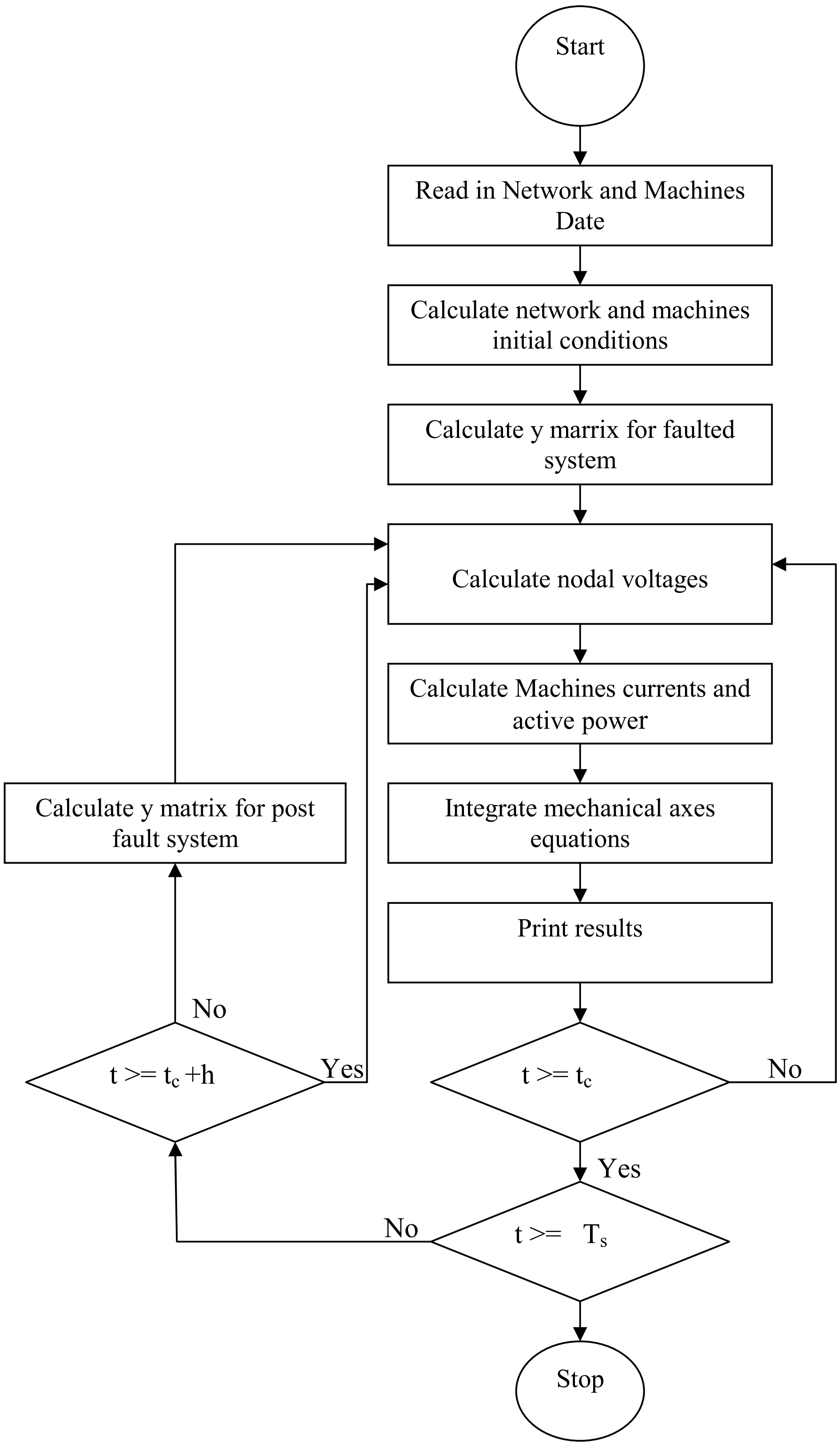


Fig.1. Simplified block diagram showing organistiom of transient stability calculation for a simple machine model

Results

For the purpose of comparison, the CCT_s s of all systems are calculated using the step by step method, the RKE method. The results obtained are as follows:

1- Three machines system (s_1)

The single line diagram of the three machine system is shown in Fig.2.a. A system consisting of three machines as shown in Fig.2.a. A short circuit near generator causes a deficit in the system power and accelerates this generator. RKE method suggests that machine 1is the critical machine and has the largest value of RKE compared to the other machines. RKE curve for machines 1 is shown in Fig.2.b,c,d.

2- Four machines system (s_2)

The single line diagram of four machine system is shown in Fig.3.a. At three phase-to- ground fault was applied near node one, then, at fault clearance the circuit breakers at both ends of line one-four were opened. Fig.3.b,c,d,e. shows the RKE versus time curve of the system for different fault clearing times, where it can be seen when the maximum RKE is taking place.

21. Conclusion

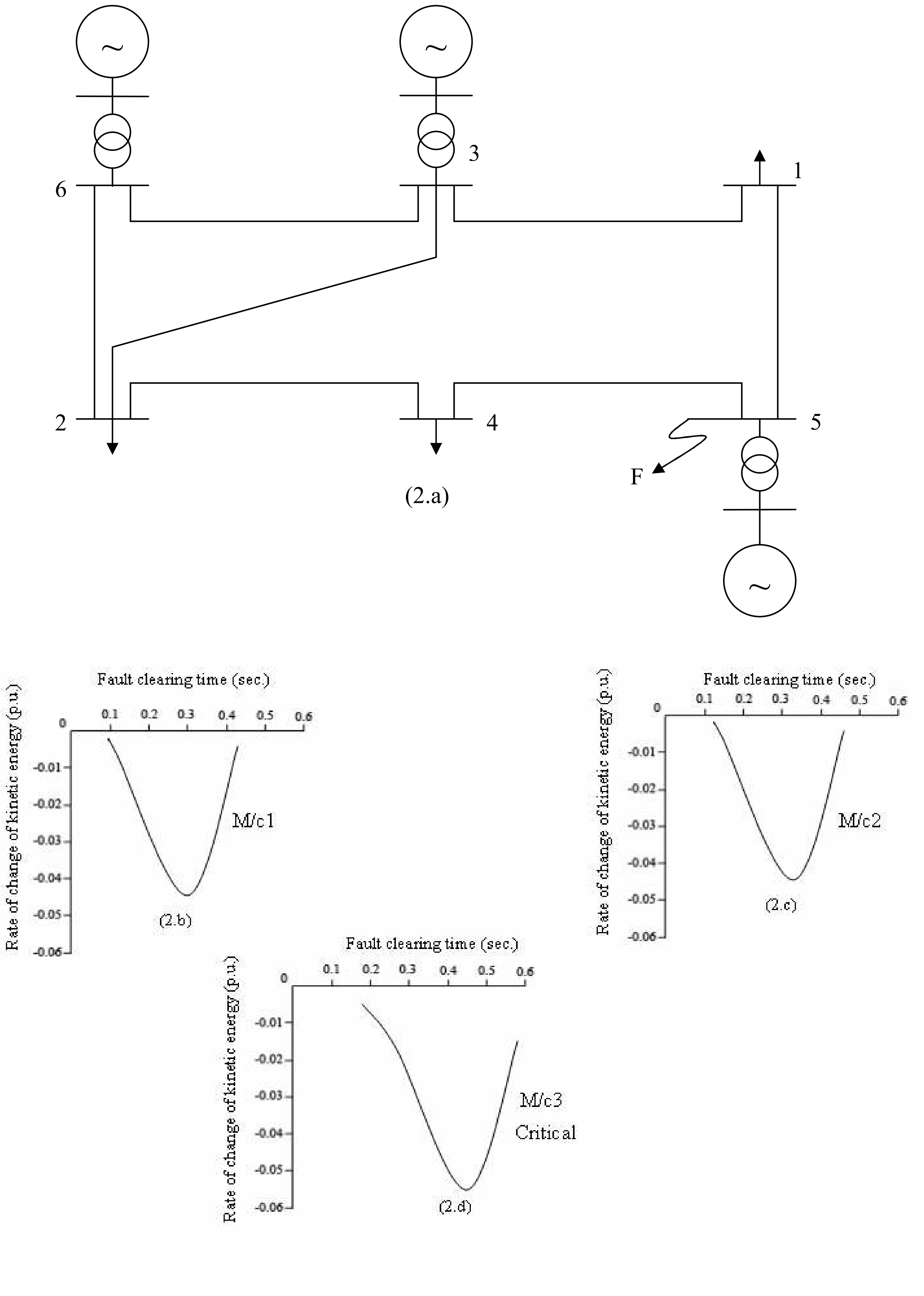
When the RKE method is applied to investigate the stability of a system, the time response of the state variables is not needed beyond the fault clearing time. The engineer making the study thus loses some information about the behavior of the various machines in the time domain. However, he will get an answer to the crucial question of whether the system is stable or not under the assumed conditions.

The method offers several practical advantages over existing method, in particular.

(i) Machines and network can be represented in any required detail without complicating the solution. Moreover, the more accurate the representation .
(ii) Stability or instability of a system is determined by integrating the system differential equation up to the fault clearing time only.
(iii) It provides a mean of determination of the critical clearing time without repetition of the full solution for several clearing times.
(iv) Shortening computation time, since calculation of the RKE at each is possible.

Clearance time involves insignificant effort compared with that for the Step by step computation, which must be continued well beyond the fault clearing time.

In effect, the RKE method yields more accurate estimates of CCT (Table 1), yet requires less execution time (Table 2). The RKE method thus offers itself as a promising tool for online stability investigations and transient security analysis.



6
3
1
2
4
5
F
Fault clearing time (sec.)
Rate of change of kinetic energy (p.u.)
0
0.1
0.2
0.3
0.4
0.5
0.6
-0.01
-0.02
-0.03
-0.04
-0.05
-0.06
M/c1
M/c2
M/c3
Critical

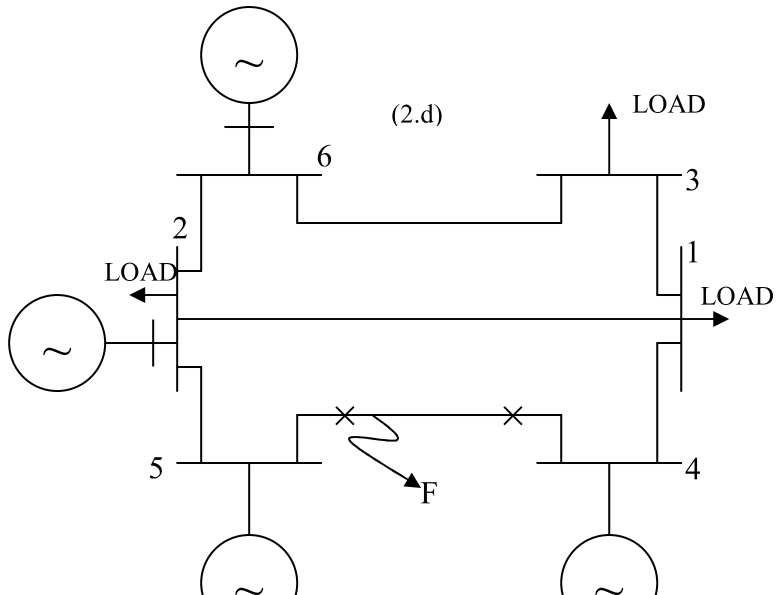
(2.a)

(2.b)

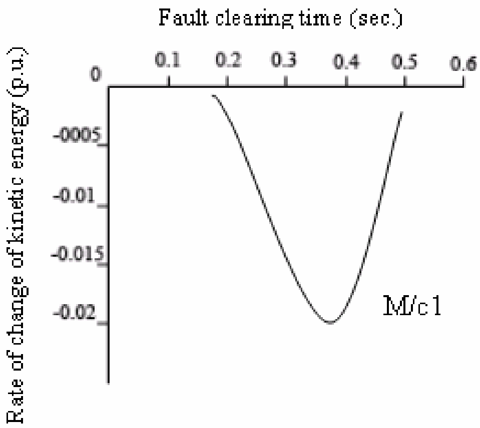
(2.c)

(2.d)

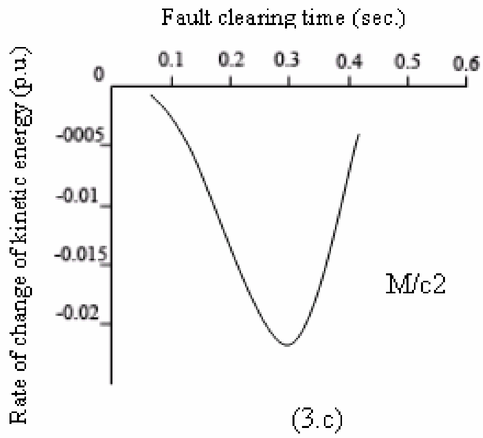
Fig. 1 single line diagram of 3-machines system with its RKE curve.



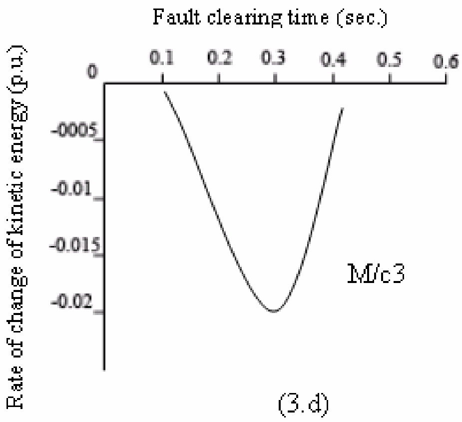
(3.a)



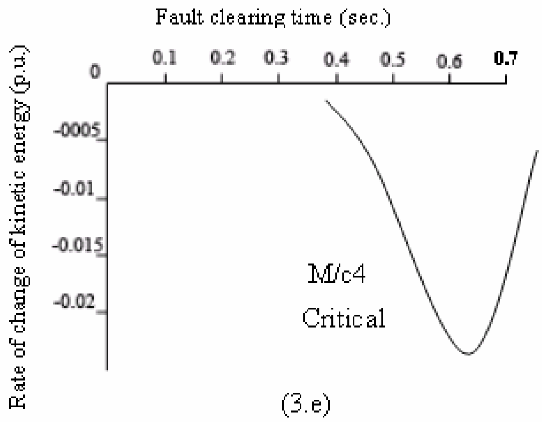
(3.b)



(3.c)



(3.d)



(3.e)

Fig. (2) One-line diagram of the 4-machines system with its RKE curve.

Table 1: results of study

System chosen	Critical clearing time, seconds by	
	Step by step method	RKE method
3 machine system S_1	0.43	0.42
4 machine system S_2	0.63	0.62

Table 2: Execution times by different methods*

System chosen	Execution, second, by	
	Step by step method **	RKE method
3machine system S_1	110.9	7.3
4machine system S_2	178.2	13.2

* Computer used is P_4

** The solution time taken is one second

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