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A SINGLE MACHINE EQUIVALENT APPROACH FOR THE AMELIORATION OF CRITICAL CLEARING TIME LIMIT

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ABSTRACT
In this present paper, a computationally realistic algorithm is adopted in order to obtain the critical clearing time (CCT) by means of one machine infinite bus (OMIB) equivalent system which has been derived from an equal area criterion (EAC). The CCT is defined as the highest time intermission by which the fault ought to be cleared with the aim of preserving the power system stability. The computation of CCT entails an essential numerical formulation derived from the three fault conditions, which are; pre-fault, during fault and post-fault conditions. The significance of CCT becomes considerably less whilst transient instability is induced by a three phase fault occurred at the bus bar next to the substation connected with a sensitive generator. By setting the protection relay with the obtained value of CCT, it is sufficient to maintain the transient stability albeit fault occurred at other locations. Throughout the occasion of fault, a circuit breaker which is in service earlier than the smallest CCT will not agitate to a transient instability. The IEEE Reliability Test System 1996 (RTS-96) is used to validate the robustness of the proposed methodology in determining the CCT.

Keywords: CCT, dynamic system cascading collapse, transient stability assessment.

INTRODUCTION
Intricacy of operating and planning a contemporary power system is persistently escalating due to the large power transfers over long distance, superior interdependence among interconnected systems, more complex coordination, and intricate interface amongst various system controllers and less power reserves. These demands have forced systems to be managed closer to their dynamic security limits, such that instability has become a main intimidation for system operation, as evidenced by the recent increase in power system blackouts (Pizano-Martianez *et al.*, 2010). Large area blackout or cascading collapse of a power system typically could cause to a severe impact towards the society and economy of the country. For that reason, it is significant to seek for an elucidation that provides precautionary action so that it could be implemented in order to avoid from occurrence of a cascading collapse in power system (Salim *et al.*, 2014). Transient stability assessment (TSA) is a most important obligation for secure operation of power systems. The transient stability is examined taking into account the effects of the system due to instability for instance line switching, loss of generators or demand and also fault (Ayasun *et al.*, 2006). A power system is transiently stable for a particular steady-state operating condition and for a particular large disturbance if, following that disturbance; it reaches a satisfactory steady-state operating condition (Pavella *et al.*, 1994).

To date, several methods have been developed and discussed in the literature for studying the transient stability assessment in the determination of accurate value of the CCT. The direct methods and hybrid methods are the two methods commonly used in transient stability studies. The direct method provide a stability index which gives stability margin of an operating point in terms of energy stored in the system (A. A. Fouad *et al.*, 1991; F. Wu *et al.*, 1985; H. D. Chiang *et al.*, 1995). On top of that, there are several variants of the direct method for example potential energy boundary surface (PEBS) method (H. D. Chiang *et al.*, 1988), boundary of stability region based controlling unstable equilibrium point (BCU) (H. D. Chiang *et al.*, 1994) method and EAC (Y. Xue *et al.*, 1989). The hybrid method of transient stability assessment proposed in (Roy *et al.*, 2009; T. S. Chung *et al.*, 1995) have produced astonishing evolution in fast computation of CCT. The hybrid method of TSA takes advantage of Lyapuno's type energy function and combines it with the normal time domain simulation method. In most cases, the hybrid TSA method determines some stability index value where it reflects the security status of power systems. In (D. Z. Fang *et al.*, 2005), the authors proposed a normalized energy function approach for fast computation of CCT for TSA where it normalizes the inertia by using an average center angle instead of center of inertia.

Based on the literature review that has been performed, it is imperative to investigate the CCT due to its considerable impact to a power system operation. Therefore, this paper offers a prompt computational method to find out the CCT by means of one machine infinite bus equivalent technique. The RTS-96 is used as the case study to confirm the success of the proposed technique considered in the analysis of CCT. The following subsection will discuss on the mathematical transformation from a multi-machine system to an OMIB equivalent system used in determining the CCT specified for the tripping of transmission line.

Multi-Machine System to a Single Machine Equivalent TSA of a power system is part of planning and operation planning studies where it emphasizes on the ability of a system to resist severe interruption whilst ensuring continuity of service. The computational challenges of a multi-machine system can be minimized by simplifying the original large scale system to a dynamic equivalent model. The simplest dynamic equivalent model of a multi-machine system can be obtained by means of OMIB model. Once a multi-machine system is represented by the OMIB equivalent model, its modification can be used to determine the transient stability condition of the system. This will be explained in the next section.

Methodology of one machine infinite bus (OMIB)

The dynamic response of an overall system is performed in the time domain simulation of TSA in order to investigate either the inter-machine rotor angle deviations falls under a specific range. However, the evaluation of transient stability for a multi-machine system using the time domain simulation is computationally challenging due to its non-linear nature (Bhat *et al.*, 2006). Therefore, the computation of multi-machine system is simplified while retaining the essential features of a system. This can be achieved by applying the concept of single machine equivalent (SIME) where its purpose is to obtain a single machine equivalent from a multi-machine system. SIME is a direct method which is derived from the equal area criterion combined with the time-domain stability program that transforms the multi-machine power system into an OMIB system. For each step of the time domain simulation, SIME segregates the multi-machine system into two groups which are the critical machines and non-critical machines. Then, the OMIB model is calculated based on the two equivalent machines decomposed from the two clusters of critical machines (cm) and non-critical machines (ncm). The procedure that used to determine the rotor angle associated with OMIB is explained as follows:

a) Identify the critical machine (CM) and non critical machine (NCM) associated with the transient stability limit as defined in equation (1). For a given disturbance on a large system, only few machines are identified as the severely distributed machines. The stability of the entire system can also be verified through the dynamic response of the severely disturbed machines. This requires the assessment of transient stability that can be obtained based on the deviation between relative rotor angles with regard to the center of inertia (COI) given by equation (1a) and (1b) (Busan *et al.*, 2012). The machine is said to be critically unstable, cm, if the angle deviation, Δδ_n (t), exceeds 180o and vice-versa for the non-critical machine, ncm (Busan *et al.*, 2010).

$$ncm \cup cm = \begin{cases} ncm & , if\ \Delta\delta_n(t) \le 180^o \\ cm & , if\ \Delta\delta_n(t) > 180^o \end{cases} \quad (1)$$

$$\Delta\delta_n(t) = |\delta_n(t) - \delta_{COI}(t)| \quad (1a)$$

$$\delta_{COI}(t) \triangleq \left(\sum_{n=1}^{G} H_n\right)^{-1} \left(\sum_{n=1}^{G} H_n \delta_n(t)\right) \quad (1b)$$

Basically, the rotor angle of OMIB is constructed based on the two equivalent rotor angles of $\delta_{cm}(t)$ and $\delta_{ncm}(t)$ converted from two rotor angle clusters of critical and non-critical machines, respectively. Hence, the basic formulation of rotor angle of OMIB can be obtained from equation (2) (Xue *et al.*, 1989).

$$\delta_{OMIB}(t) = \delta_{cm}(t) - \delta_{ncm}(t) \quad (2)$$

$$\delta_{cm}(t) \triangleq \frac{1}{M_{cm}} \sum_{n \in cm} M_n \delta_n(t) \quad (2a)$$

$$\delta_{ncm}(t) \triangleq \frac{1}{M_{ncm}} \sum_{n \in ncm} M_n \delta_n(t) \quad (2b)$$

M_{cm} : total inertia coefficient of cm given by $\sum_{n \in cm} M_n$
M_{ncm} : total inertia coefficient of ncm given by $\sum_{n \in ncm} M_n$
M : OMIB inertia coefficient defined by 2×H.

However, the basic formulation of δ_{OMIB} in equation (2) will not be used in the subsequent analysis due to its complexity in computing the generator real output power, P_{e_n} consisting of large matrix size of n×k at every time interval required by $\delta_n(t)$ in equations (2a) and (2b). Therefore, utilizing equation (2) to compute the basic formulation of $\delta_{OMIB}(t)$ may yield to a computational burden occurred in the following analysis. This predicament can be solved by using a simplified formulation of $\delta_{OMIB}(t)$ resulting to a less computation time which will be explained in the next step.

b) Calculate the rotor angle of OMIB at each time interval, $\delta_{OMIB}(t)$ in the event of pre-fault, during fault and post-fault conditions. The calculation of $\delta_{OMIB}(t)$ begins with the initial formulation of OMIB motion or swing given by equation (3) (Pizano-Martianez *et al.,* 2010).

$$\frac{d^2\delta_{OMIB}}{dt^2} = \pi f_{rated} M^{-1}\left(P_{m_{OMIB}} - P_{e_{OMIB}}\right) \quad (3)$$

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where,

$$\text{OMIB mechanical input power, } P_{m_{OMIB}} = \left(\frac{M_{cm}M_{ncm}}{M_{cm}+M_{ncm}}\right)\left[\left(\frac{1}{M_{cm}}\right)\left(\sum_{n\in cm} P_{m_n}\right) - \left(\frac{1}{M_{ncm}}\right)\left(\sum_{n\in ncm} P_{m_n}\right)\right] \quad (3a)$$

$$\text{OMIB generator real output power, } P_{e_{OMIB}} = \left(\frac{M_{cm}M_{ncm}}{M_{cm}+M_{ncm}}\right)\left[\left(\frac{1}{M_{cm}}\right)\left(\sum_{n\in cm} P_{e_n}\right) - \left(\frac{1}{M_{ncm}}\right)\left(\sum_{n\in ncm} P_{e_n}\right)\right] \quad (3b)$$

Further derivation of equation (3) will unravel to a simplified formulation of OMIB motion or swing equation that is,

$$\frac{d^2\delta_{OMIB}}{dt^2} = \pi f_{rated} M^{-1}[P_{m_{OMIB}} \cdots$$
$$\cdots - [(P_{c_{OMIB}} + P_{max_{OMIB}} \sin(\delta_{OMIB} - v))] \quad (4)$$

where,

$$P_{m_{OMIB}} = \frac{M_{ncm}\sum_{n\in cm} P_{m_{cm}} - M_{cm}\sum_{n\in ncm} P_{m_{ncm}}}{M_{cm}+M_{ncm}} \quad (4a)$$

$$P_{c_{OMIB}} = \frac{[M_{ncm}E'^{2}_{cm}G_{cm,cm} - M_{cm}(\sum_{n\in ncm}E'^{2}_{ncm}G_{ncm,ncm}}{M_{cm}+M_{ncm}} \quad (4b)$$

$$P_{max_{OMIB}} = \sqrt{(C^2+D^2)} \quad (4c)$$

$$v = -tan^{-1}\left(\frac{C}{D}\right) \quad (4d)$$

$$C = \frac{(M_{cm}-M_{ncm})\sum_{n\in ncm}(E'_{cm})(E'_{ncm})G_{cm,ncm}}{M_{cm}+M_{ncm}} \quad (4e)$$

$$D = \sum_{n\in ncm} E'_{cm}E'_{ncm}G_{cm,ncm} \quad (4f)$$

Equations (4b), (4e) and (4f) entailed with the value of E' and G which is the shunt conductance of Y_{nk}^{new}. Equation (4a) requires the value of P_m. These has been explained in detailed in (Layden, 2005). δ_{OMIB} is calculated at every time interval of the three fault conditions and this will be discussed in the following explanation.

Generally, equation (4) is only a portion of swing equation used to determine the rotor angle of OMIB at every time interval, $\delta_{OMIBs+1}$, of pre-fault, during fault and post-fault conditions. In equation (4), $P_{c_{OMIB}}$, $P_{max_{OMIB}}$ and v are varied according to the changes in G at pre-fault, during fault and post-fault conditions. Subsequently, the value of E' is constant throughout all the three fault conditions. Equation (4) is using a constant value of $P_{m_{OMIB}}$ based on the P_m determined at the three conditions of fault.

A complete swing equation of $\delta_{OMIB,s+1}$ could be obtained which begins with a derivation of equation (4) yielding to equations (5) and (6).

$$\frac{d\delta_{OMIB}}{dt} = \Delta\omega_{OMIB} \quad (5)$$

$$\frac{d\Delta\omega_{OMIB}}{dt} = \pi f_{rated} M^{-1}[P_{m_{OMIB}} \cdots$$
$$\cdots - [(P_{c_{OMIB}} + P_{max_{OMIB}} \sin(\delta_{OMIB} - v))] \quad (6)$$

By considering the event of during fault and post-fault conditions, equation (6) is then represented by equations (7) and (8), respectively.

$$\left.\frac{d\Delta\omega_{OMIB}}{dt}\right|_{\delta_{OMIB,s}} = \pi f_{rated} M^{-1}[P_{m_{OMIB}} \cdots$$
$$\cdots - \left(P^{df}_{c_{OMIB}} + P^{df}_{max_{OMIB}} \sin\left(\delta_{OMIB,s} - v^{df}\right)\right)] \quad (7)$$

$$\left.\frac{d\Delta\omega_{OMIB}}{dt}\right|_{\delta_{OMIB,s}} = \pi f_{rated} M^{-1}[P_{m_{OMIB}} \cdots$$
$$\cdots - \left(P^{pf}_{c_{OMIB}} + P^{pf}_{max_{OMIB}} \sin\left(\delta_{OMIB,s} - v^{pf}\right)\right)] \quad (8)$$

During the pre-fault condition, δ_OMIB^0 determined by (9) and Δω_(OMIB,s)^0=0 are used in equations (6), (10), (11) and (12) to obtain the value of Δω_(OMIB,s+1)and〖 δ〗_(OMIB,s+1). In equation (6), P_(c_OMIB), P_(〖max〗_OMIB) and v are calculated by considering the G extracted from given in (Layden, 2005) at pre-fault condition. Therefore, the faulted bus and faulted line will not be removed from the construction of

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matrix. Equation (6) also requires the value of E^'. The calculation of δ_OMIB^0 and P_(m_OMIB) require the values of Pm, δ_n^0 and at pre-fault condition. The obtained E^' and P_(m_OMIB) value will be used correspondingly for computing the δ_(OMIB,s+1) at every interval during fault and post-fault conditions.

$$\delta_{OMIB}^{0} = \sin^{-1}\frac{P_{m_{OMIB}}}{P_{max_{OMIB}}} \tag{9}$$

The $\Delta\omega_{OMIB,s+1}$ and $\delta_{OMIB,s+1}$ at pre-fault condition are then used as the initial parameters in equations (7), (10), (11) and (12) to compute the value of $\Delta\omega_{OMIB,s+1}$ and $\delta_{OMIB,s+1}$ for the consecutive time intervals during fault condition. During the event of fault, equation (7) comprising of $P_{c_{OMIB}}^{df}$, $P_{max_{OMIB}}^{df}$ and v^{df} are calculated by considering the G extracted from Y^{new}. Similarly, the above-mentioned process is repeated to determine the $\Delta\omega_{OMIB,s+1}$ and $\delta_{OMIB,s+1}$ at every time interval of post-fault condition using equations (8), (10), (11) and (12) which need the $\Delta\omega_{OMIB,s+1}$ and $\delta_{OMIB,s+1}$calculated at the last interval during fault condition. With regards to the post-fault condition, equation (8) is calculated based on the G originated from the transient stability assessment that takes into account the removal of faulted line.

$$\Delta\omega_{OMIB,s+1} = \Delta\omega_{OMIB,s} + \left.\frac{d\Delta\omega_{OMIB}}{dt}\right|_{\delta_{OMIB,s}} \Delta t \tag{10}$$

$$\left.\frac{d\delta_{OMIB}}{dt}\right|_{\Delta\omega_{OMIB,s+1}} = \Delta\omega_{OMIB,s+1} \tag{11}$$

$$\delta_{OMIB,s+1} = \delta_{OMIB,s} + \left.\frac{d\delta_{OMIB}}{dt}\right|_{\Delta\omega_{OMIB,s+1}} \Delta t \tag{12}$$

By using the modified Euler's method, equations (10) and (12) are replaced with equations (13) and (14), respectively so that the respective results of $\Delta\omega_{OMIB,s+1}$ and $\delta_{OMIB,s+1}$with less error could be attained. Similarly, the above-mentioned process can be applied to determine the $\Delta\omega_{OMIB,s+1}$ and $\delta_{OMIB,s+1}$ at the pre-fault, during fault and post-fault conditions.

$$\Delta\omega_{\text{OMIB,s+1}} = \Delta\omega_{\text{OMIB,s}} + \left(\frac{\left.\frac{d\Delta\omega_{\text{OMIB}}}{dt}\right|_{\delta_{OMIB,s}} + \left.\frac{d\Delta\omega_{\text{OMIB}}}{dt}\right|_{\delta_{OMIB,s+1}}}{2}\right)\Delta t \tag{13}$$

$$\delta_{\text{OMIB,s+1}} = \delta_{\text{OMIB,s}} + \left(\frac{\left.\frac{d\delta_{\text{OMIB}}}{dt}\right|_{\Delta\omega_{OMIB,s}} + \left.\frac{d\delta_{\text{OMIB}}}{dt}\right|_{\Delta\omega_{OMIB,s+1}}}{2}\right)\Delta t \tag{14}$$

By replacing s+1 with t, therefore $\delta_{OMIB,s+1}$ is eventually defined as $\delta_{OMIB}(t)$. Hence, the dynamic response of $\delta_{OMIB}(t)$ can be drawn between the duration of t = 0 and $t = t_c$ followed by $t = t_c$ and $t = t_f$. Whereby t_c is the CCT interval and t_f is the final simulation time. Within this critical time interval, the network protection system should be operated so that the faulty line or generator can be removed without causing any loss of generator synchronism. The OMIB rotor angle obtained in equation (9) will be used in the following section in the determination of CCT for one machine system.

The transformation from multi-machine system provide several advantages on the model of OMIB which only utilizes a small matrix size with single column for several components used in equation (4). This is contrary with the multi-machine model which is basically based on large matrix size relatively n×k for several components used in (Layden, 2005). The computation burden will be intensified at every interval of computation time. In addition, OMIB has the advantage in providing a value of $\delta_{OMIB}(t)$ which is straightforward hence contributing to a fast computation compared to the $\delta_n(t)$ determined for all the n^{th} generating units using the multi-machine model.

Determination of CCT for one machine connected to an infinite bus

Upon the occurrence of unexpected events in the power system, severance of the transmission lines will be carried out in order to isolate the fault from a healthy system. Consequently from an improper time for disengaging the transmission line, it will cause loss of synchronism to a generator which consequently may originate the transient instability to a power system. Therefore, transient stability analysis is performed in order to obtain an opposite value of the CCT for line tripping in order that the system remains transiently stable. As a consequence, the operation of a protection relay should be set according to the CCT so that the fault is cleared without jeopardizing the stability of the generator. The system reaction upon line tripping subjected to the specified CCT can be obtained by solving the swing equation.

Practically, the CCT, t_c can be obtained based on the two approaches. Firstly, it is determined prior to the trial and error analysis of a system during post-fault condition. Second, OMIB equivalent system is used to determine the CCT based on the EAC (Zarate-Minano *et al.*, 2010) of the machine given in equation (15). Scientifically, the computation of CCT involves an intrinsic mathematical formulation derived from the pre-fault, during fault and post-fault conditions (Boussahoua & Boudour, 2009).

$$t_c = \sqrt{\frac{2H(\delta_c - \delta^0)}{\pi f_{rated} P_m}} \tag{15}$$

where,

δ_c : Critical clearing angle

The value of CCT becomes significantly less when transient instability is induced by a three phase fault occurred at the bus bar closest to the substation connected with a sensitive generator. By setting the protection relay with the obtained value of CCT, it is adequate to sustain the transient stability even though fault happened at the other locations. During the occurrence of fault, a circuit breaker which is operating earlier than the smallest CCT will not agitate to a transient instability.

Assuming that P_m is a constant and it is running steadily while sending power to the system with OMIB rotor angle, δ^0_{OMIB}. During a fault occurred at the sending end of a transmission line, the faulted line will be isolated by the circuit breakers. Termination of the faulted line will cause double the amount of power flowing through the adjacent transmission line. Therefore, tripping of the overloaded and faulted transmission lines will hinder transfer of power from the generator to the infinite bus. Since the resistance of the system is neglected, P_e is equal to zero. During the period of fault, the swing equation given in equation (3) becomes equation (16).

$$\frac{d^2\delta_{OMIB}}{dt^2} = \frac{\pi f_{rated}}{M}\left(P_{m_{OMIB}}\right) \tag{16}$$

By performing the double integration at both sides of (16), it will become

$$\delta_{OMIB} = \frac{\pi f_{rated}}{2M} P_{m_{OMIB}} t_{c_{OMIB}}^2 + \delta^0_{OMIB} \tag{17}$$

Therefore the OMIB critical clearing time, $t_{c_{OMIB}}$ can be obtained from equation (18).

$$t_{c_{OMIB}} = \sqrt{\frac{2M(\delta_{Crit_{OMIB}} - \delta^0{}_{OMIB})}{\pi f_{rated} P_{m_{OMIB}}}} \tag{18}$$

where, δ_{OMIB} currently defined as the critical clearing angle, $\delta_{Crit_{OMIB}}$, is given in equation (19). The M, $P_{m_{OMIB}}$, $P_{max_{OMIB}}$ and δ^0_{OMIB} are obtained by using equations (2), (4a), (4c) and (9), respectively.

$$\delta_{Crit_{OMIB}} = \frac{P_{m_{OMIB}}}{P_{max_{OMIB}}}\left(\delta_{max_{OMIB}} - \delta^0_{OMIB}\right) + \cos\delta_{max_{OMIB}} \tag{19}$$

$$\delta_{max_{OMIB}} = 180^o - \delta^0_{OMIB} \tag{20}$$

The algorithm used to determine the OMIB critical clearing time is described in the following procedure

- Select a faulted bus as an event of contingency causing to the termination of affected faulty transmission line. It is assumed that the fault happens in close proximity to the sending bus of the faulty transmission line. For that reason, the faulted bus is selected to be the sending bus of the faulty transmission line (Saadat, 2004).
- Perform the transient stability assessment discussed in (Layden, 2005) to determine the V_n, P_{e_n}, Q_{e_n} and I_n. Hence, determine $Y^{reduced}_{bus}$ or Y^{new} for pre-fault and during fault condition. During pre-fault event, the Y^{new} is calculated without removal of faulted line. On the other hand, in the event of during fault, the Y^{new} is determined by engaging the eliminated faulted bus. By taking into consideration the three phase fault in a system, the faulted bus is resulting to a zero bus voltage magnitude. Therefore, the Y^{new} is reduced in its matrix size due to the removal of faulted bus.
- Calculate the E', and P_m. The P_m is obtained by taking into account the Y^{new} for pre-fault condition as discussed in step (b).
- Calculate M, $P_{m_{OMIB}}$, $P_{max_{OMIB}}$, δ^0_{OMIB} and $\delta_{Crit_{OMIB}}$ using equations (2), (4a), (4c), (9) and (18), respectively. These require the information of E', G

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of Y^{new} during fault condition and P_m as discussed in steps (b) and (c).

- Calculate the OMIB critical clearing time, $t_{c_{OMIB}}$, using equation (18) for the selected faulty transmission line.
- Repeat steps (a)-(e) to determine $t_{c_{OMIB}}$ for the next selected faulty transmission line. This process is repeated until all of the lines have been selected as faulted condition or contingency.
- Select the smallest value of $t_{c_{OMIB}}$ which becomes as a standard specification of critical clearing time applied to all of the protection relays.

RESULTS AND DISCUSSION

Table-1 represent the results of OMIB critical clearing time, $t_{c_{OMIB}}$, obtained for the tripping event of each faulted line afflicted to the IEEE RTS-96 system. This system consist of 33 generator buses and 40 load buses with 120 interconnected transmission lines (Grigg *et al.*, 1999). The results have shown that the maximum and minimum $t_{c_{OMIB}}$ of 0.20 second and 0.01 second, respectively are obtained in conjunction to the tripping of faulted lines. Similar to the above case study, the $t_{c_{OMIB}}$ of 0.01 second is specified as maximum time for the tripping event of violated line contributing to the dynamic system cascading collapse of IEEE RTS-96.

Table-1. OMIB critical clearing time, $t_{c_{OMIB}}$, for IEEE RTS-96.

Faulted Line		Faulted Bus	$t_{c_{OMIB}}$ (s)	Faulted Line		Faulted Bus	$t_{c_{OMIB}}$ (s)	Faulted Line		Faulted Bus	$t_{c_{OMIB}}$ (s)
From Line	To Line			From Line	To Line			From Line	To Line		
101	102	101	0.10	123	217	123	0.10	301	303	301	0.10
101	103	101	0.01	201	202	201	0.01	301	305	301	0.01
101	105	101	0.01	201	203	201	0.01	302	304	302	0.01
102	104	102	0.02	201	205	201	0.02	302	306	302	0.02
102	106	102	0.02	202	204	202	0.02	303	309	303	0.02
103	109	103	0.20	202	206	202	0.20	303	324	303	0.20
103	124	103	0.08	203	209	203	0.08	304	309	304	0.08
104	109	104	0.20	203	224	203	0.20	305	310	305	0.20
105	110	105	0.20	204	209	204	0.20	306	310	306	0.20
106	110	106	0.15	205	210	205	0.15	307	308	307	0.15
107	108	107	0.10	206	210	206	0.10	308	309	308	0.10
107	203	107	0.15	207	208	207	0.15	308	310	308	0.15
108	109	108	0.15	208	209	208	0.15	309	311	309	0.15
108	110	108	0.20	208	210	208	0.20	309	312	309	0.20
109	111	109	0.15	209	211	209	0.15	310	311	310	0.15
109	112	109	0.15	209	212	209	0.15	310	312	310	0.15
110	111	110	0.15	210	211	210	0.15	311	313	311	0.15
110	112	110	0.15	210	212	210	0.15	311	314	311	0.15
111	113	111	0.12	211	213	211	0.12	312	313	312	0.12
111	114	111	0.12	211	214	211	0.12	312	323	312	0.12
112	113	112	0.15	212	213	212	0.15	313	323	313	0.15
112	123	112	0.15	212	223	212	0.15	314	316	314	0.15
113	123	113	0.11	213	223	213	0.11	315	316	315	0.11
113	215	113	0.12	214	216	214	0.12	315	321	315	0.12
114	116	114	0.12	215	216	215	0.12	315	321	315	0.12
115	116	115	0.06	215	221	215	0.06	315	324	315	0.06
115	121	115	0.08	215	221	215	0.08	316	317	316	0.08
115	121	115	0.08	215	224	215	0.08	316	319	316	0.08
115	124	115	0.08	216	217	216	0.08	317	318	317	0.08
116	117	116	0.08	216	219	216	0.08	317	322	317	0.08
116	119	116	0.06	217	218	217	0.06	318	321	318	0.06
117	118	117	0.10	217	222	217	0.10	318	321	318	0.10
117	122	117	0.10	218	221	218	0.10	319	320	319	0.10
118	121	118	0.11	218	221	218	0.11	319	320	319	0.11
118	121	118	0.11	219	220	219	0.11	320	323	320	0.11
119	120	119	0.10	219	220	219	0.10	320	323	320	0.10
119	120	119	0.10	220	223	220	0.10	321	322	321	0.10
120	123	120	0.11	220	223	220	0.11	325	121	325	0.11
120	123	120	0.11	221	222	221	0.11	318	223	318	0.11
121	122	121	0.10	301	302	301	0.10	323	325	323	0.10

CONCLUSIONS

During the incidence of contingency event in a power system, disengagement of a transmission line is performed to isolate the fault from a healthy system. Therefore from an inappropriate time for disconnecting the transmission line, it will cause a generator to experience the loss of synchronism which may instigate the transient instability to a system. Therefore, transient stability analysis is performed to determine the appropriate CCT for line tripping so that the system remains transiently stable. Therefore the operation of a protection relay should be set according to the CCT so that the fault is cleared without exposing the generator synchronism. The system response upon line tripping subjected to the specified CCT can be obtained by solving the swing equation. The proposed technique of one machine infinite bus equivalent has proven that the CCT for each transmission line can be obtained accurately. The evaluation of CCT should be carried out precisely in the power system transient stability analysis in order to avert the power system from any kind of catastrophic events.

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