

TECHNICAL NOTE

Energy and Load Curtailment Based Indices in Probabilistic Transient Stability Studies

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Abstract. In this paper, stochastic models for both simultaneous and adaptive reclosing are presented and examined using a new set of probabilistic transient stability risk indices. The developed indices are based on load curtailments resulting from bus isolations and/or corrective actions to be taken to restore the system to a normal operating state. The developed stochastic models and the new probabilistic transient stability risk indices are utilized to evaluate the transient performance of a hypothetical test system. The effects of bus load uncertainty were also considered and demonstrated. The obtained results show that reclosing, especially adaptive reclosing, can improve the transient performance of a power system.

Introduction

Reliability evaluation of composite systems is an important area of concern for system designers, planners and scientists. A simple but reasonable subdivision of system reliability is system adequacy and system security [1]. System adequacy relates to the existence of sufficient facilities within the system to satisfy the consumer load demand. These include the necessary facilities to generate sufficient energy and the associated facilities to transmit this energy to the different customer load points. System adequacy, therefore, is associated with static conditions which do not include system disturbances. System security, on the other hand, relates to the ability of a system to respond to disturbances and perturbations arising within that system. System security, therefore, involves the dynamic behavior of the system and may require dynamic studies such as transient stability analysis, which involve detailed power system modeling. Adequacy assessment and security analysis

deal with quite different reliability issues and therefore involve quite different assessment techniques. In general, there are two main published techniques for probabilistic assessment of transient stability: the analytical approach which uses the conditional probability theorem [2-7] and the Monte-Carlo simulation [8] technique. In this paper, stochastic models for both simultaneous and adaptive reclosing are presented and the conditional probability theorem is utilized to calculate a new set of basic probability indices for transient stability studies. The indices are further extended by including the severity of the load curtailed due to corrective actions and/or load isolation. The effect of load uncertainty is also considered in the framework presented in this paper.

References 2-9 propose the inclusion of probabilistic considerations in the evaluation of power system stability. The first and the most difficult step in the probabilistic approach is to collect appropriate statistical data on system faults such as fault types, locations, clearing and reclosing times and fault duration. Each of these factors are mutually exclusive and, therefore, the conditional probability approach [2-7] can be used directly to assess system transient stability. In general, there are several uncertainties that have considerable effect in the probabilistic assessment of transient stability. There are [2-9]:

1. *Type of fault*
2. *Location of fault*
3. *Fault duration*
4. *Fault clearing phenomena*
5. *System parameters and operating conditions*

Figure 1 shows a possible probability density function for the fault clearing time c (t_c). If the critical clearing time (CCT) is the maximum time in which the fault must be cleared, then the shaded area in this figure represents the probability of stability P_{ijkl} for a fault type i at a location j of line k when the load is at level l . Using the conditional probability approach, the probability of stability (P_{ST}) for all fault types (I) at all possible locations (J) of all transmission lines (K) when all load levels (L) are considered is given by the following equation:

$$P_{ST} = \sum_{l=1}^L \sum_{k=1}^K \sum_{j=1}^J \sum_{i=1}^I P_{ijkl} P_i P_j P_k P_l \quad (1)$$

where:

- P_i is the probability of having a fault of type i ,
- P_j is the probability of having a fault at location j ,
- P_k is the probability of having a fault at link k and
- P_l is the probability of operating at the load level l .

The stability index given by Equation (1) is a basic probability index for the overall system. Equation (1) can be adjusted to calculate the probability of stability for each line in the system or to calculate the probability of stability at a specific load level.

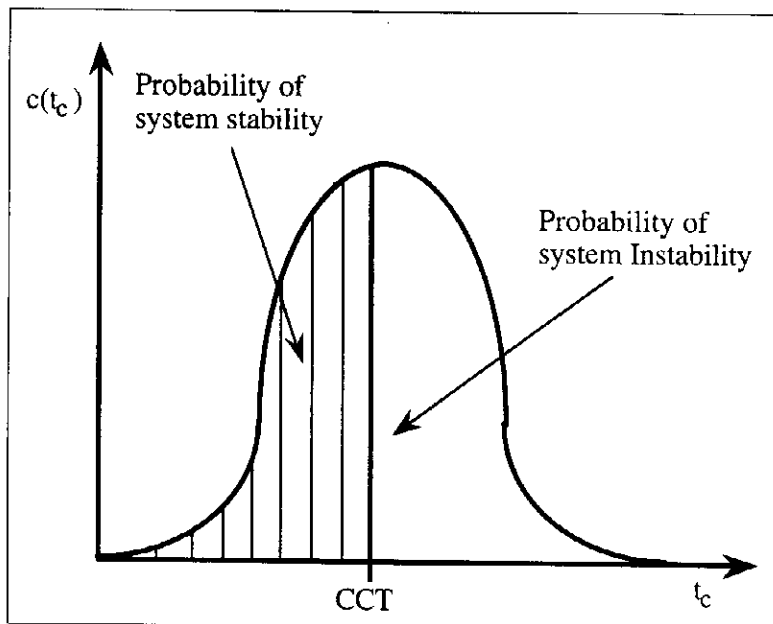


Fig. 1. Probability density function of the fault clearing.

Stochastic Modeling of Reclosing

In order to incorporate the stochastic modeling of line reclosure in probabilistic transient stability studies, stochastic models for both the reclosing equipment and the fault duration must be developed. Both models are then convolved with each other to calculate the probability of successful reclosing. The probability of successful reclosing is utilized together with the probability of stability obtained from Eq. (1) to form two basic sets of probabilistic transient stability indices: probability of stability with successful reclosing and probability of stability with unsuccessful reclosing.

Reclosing modeling

Most of the faults that a power system experience are transient in nature and disappear as soon as the line is de-energized. After deionizing the arc, the line can be restored to service. Operating experience [9,10-12] has shown that 70% to 90% of the reclosing operations were successful. High speed reclosure of circuit breakers was used for the purpose of increasing the transient stability limit by Griscom and Torok [10] in 1933 and was first put into practice in 1936 [12]. The time in which a fault is cleared, the line is

assumed to be deionized and the line is re-energized and put back into service is an important factor in the stochastic modeling of both simultaneous and adaptive reclosing. The operating times associated with the equipment which have to detect the fault, remove the fault by de-energizing the line and put the line back into service are random variables. The probability distribution of reclosing time depends upon the protection system and may, therefore, be different for each line. For a given fault, this distribution is different for close-in faults and mid-line faults. The probability distribution of reclosing time can be obtained by considering the actual protection system involved. This includes consideration of the primary and back-up protection schemes and protection philosophy of the particular system.

Fault duration modeling

Lightning is the most common cause of faults on transmission lines and most of the faults caused by lightning are transitory. In addition, system faults due to other causes, such as swinging conductors and temporary contacts with conducting objects are also transitory in nature. Such faults usually, cause little permanent damage to lines or plants but do require the operation of protective devices. In general, transmission system faults result from many different causes and each will force the protection system to de-energize the faulted part for a certain amount of time. These causes and their associated durations are random variables and hence, many be modeled by a probability distribution function.

Calculating the successful reclosing probability

Figure 2 shows a possible probability density function for the reclosing time $r(t_r)$ and fault duration probability density function $f(t_d)$. The successful reclosing probability P_{SR} can be calculated from both distributions as follows:

$$P_{SR} = \int_{t_r=0}^{t_r=\infty} \int_{t_d=0}^{t_d=t_r} r(t_r) f(t_d) dt_d dt_r \quad (2)$$

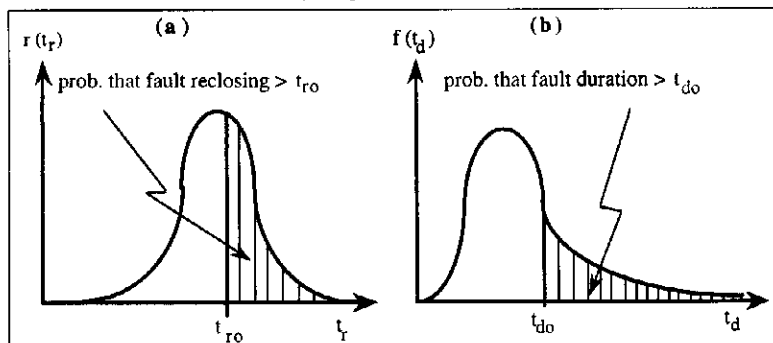


Fig. 2. (a) Probability density function for the reclosing time
(b) Probability density function for the fault duration .

Calculating the probabilistic transient stability indices

The probability of stability with successful reclosing in the case of simultaneous or adaptive reclosing is given by:

$$P_{ST}^{SR} = P_{ST} \times P_{SR} \quad (3)$$

In the case of simultaneous reclosing, the reclosing equipment may reclose into a multi-phase fault depending on the fault type existing at the time of reclosing. In this case, the probability of stability with unsuccessful reclosing when simultaneous reclosing is employed is given by:

$$P_{ST}^{USR} = P_{ST}^1 \times P_{ST}^{2S} \times (1 - P_{SR}) \quad (4)$$

where:

P_{ST}^1 is the probability of stability after the first attempt to clear the fault, and

P_{ST}^{2S} is the probability of stability after the second attempt to clear the fault

Adaptive reclosing of a transmission line involves controlling the circuit breakers reclose sequence and timing based upon specific existing conditions on the transmission line [12-14]. The main advantage of adaptive reclosing is that it can eliminate the possibility of reclosing the line into a multi-phase fault. Figure 3 illustrates a general flow chart for the reclosing logic during the adaptive reclosing of a transmission line tripped with triple-pole switching due to a system fault [13,14]. Figure 3 shows that the worst case, if adaptive reclosing is used, is a reclose into a single line to ground fault which will have a smaller impact on stability compared to that of simultaneous reclosing into a multi-phase fault. The probability of stability with unsuccessful reclosing when adaptive reclosing is employed is given by Eq. (5):

$$P_{ST}^{UAR} = P_{ST}^1 \times P_{ST}^{2A} \times (1 - P_{SR}) \quad (5)$$

where:

P_{ST}^{2A} is the probability of stability after the second attempt to clear a single line to ground fault.

In summary, the probability of stability can be divided into two parts: probability of stability with successful reclosing and probability of stability with unsuccessful reclosing. It is clear from Equation (3) that the probability of stability when the reclosing is successful is equal to the product of the probability of stability and the probability of successful reclosing. In the case in which the reclosing is unsuccessful, the circuit breaker must trip again and the fault must be isolated again. The probability of stability for unsuccessful reclosing if simultaneous reclosing is used is equal to the product of the probability of unsuccessful reclosing, the probability of stability in the first attempt to clear the fault and the probability of stability in the second attempt to clear the fault as given in Eq. (4). The probability of stability for unsuccessful reclosing if an adaptive reclosing technique is

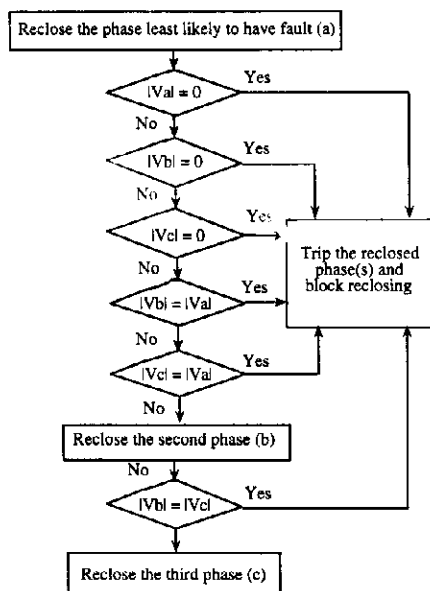


Fig. 3. Reclosing logic for identifying system status during adaptive reclosing of a transmission line (Assume that the reclosing sequence is a-b-c).

used is equal to the product of the probability of unsuccessful reclosing, the probability of stability after the first attempt to clear the fault and the probability of stability after the second attempt to clear a single line to ground fault due to the use of the adaptive reclosing. Equation (3), (4) and (5) can be easily extended to recognize multiple reclosing.

A Basic Procedure for Transient Stability Indices Assessment

Unlike fault type and location, which can be modeled as discrete random variables, fault clearing time, reclosing time and fault duration are modeled as continuous random variables. The basic probability of stability index [2-7] obtained from Fig. 1 does not consider the impact of using simultaneous or adaptive reclosing. In this section, a procedure is described for calculating a new set of transient stability indices based on the energy and load to be curtailed during fault events. The North American Electric Reliability Council (NERC) has applied the terms "adequacy" and "security" to describe functional aspects of bulk system reliability. These terms are used to measure the overall ability of the composite generation and transmission systems to satisfy the total system power and energy

requirements and to withstand system disturbances. The IEEE Task Force on Measuring Bulk System Reliability defined bulk system unreliability events as those events in which the bulk system is unable to supply electricity required by one or more customers [15]. The state enumeration approach [1,16] and the following risk indices are used in this paper. A comprehensive interpretation of these indices can be found in Reference [1].

<i>EDNS</i>	<i>Expected Demand Not Supplied (MW)</i>
<i>EENS</i>	<i>Expected Energy Not Supplied (MWh/Yr)</i>
<i>BPECI</i>	<i>Bulk Power-Energy Curtailment Index (MWh/MW-Yr)</i>
<i>MBECI</i>	<i>Modified Bulk/Energy Curtailment Index</i>
<i>SI</i>	<i>Severity Index (system minutes)</i>

The overall stochastic transient stability evaluation procedure considering load forecast uncertainty, and the employment of simultaneous or adaptive reclosing can be summarized as follows:

1. Collect security data and compute fault statistics
2. Select network topology
3. Select load condition
4. Select disturbance location
5. Select disturbance type
6. Calculate the Probability of Stability (P_{ST}) from the fault clearing time probability density function, Fig. 1
7. Calculate the Probability of Successful Reclosing (P_{SR}) from the probability density functions of the fault clearing time and fault duration, Fig. 2, using Equation 2
8. Calculate the basic probabilistic transient stability using equations (3), (4) and (5)
9. If there is a system problem then take the appropriate remedial action
10. If the problem still exists then calculate the amount of load and energy to be curtailed
11. Calculate the probabilistic transient stability indices for the selected event based on the employed protection scheme and utilizing the following Equations:

$$EDNS^{NR} = DNS^O \times P_{ST}^{NR} + DNS^{IS} \times (1 - P_{ST}^{NR}) \quad (6)$$

$$EDNS^{SR} = DNS^O \times P_{ST}^{USR} + DNS^{IS} \times (1 - P_{ST}^{USR} - P_{ST}^{SR}) \quad (7)$$

$$EDNS^{AR} = DNS^O \times P_{ST}^{UAR} + DNS^{IS} \times (1 - P_{ST}^{UAR} - P_{ST}^{SR}) \quad (8)$$

where:

$EDNS^{NR}$	is the EDNS if no reclosing is used
$EDNS^{SR}$	is the EDNS if simultaneous reclosing is used

- EDNS^{AR} is the EDNS if adaptive reclosing is used
 DNS^O is the demand to be curtailed due to not using reclosing or due to unsuccessful reclosing and
 DNS^{IS} is the demand to be curtailed due to system instability

Equation 6,7 and 8 consider the risk index EDNS. Similar equations can be formed to calculate other indices.

12. After examinaing all the selected cases and by utilizing the conditional probability approach, overall probabilistic transient stability indices can be found for the system, a specific line or a specific location.

Probabilistic Transient Stability Assessment in the RBTS

Figure 4 shows the single line diagram for the reliability test system (RBTS) [17]. The RBTS has a total installed capacity of 240 MW provided by eleven generating units as shown in Fig. 4. The basic line data and bus data are given in Reference 17. The data provided in Reference 17 does not include the information required to conduct basic transient stability studies on the RBTS. These additional deterministic data are given in the Appendix. The required probabilistic data to conduct probabilistic transient stability evaluation and to model fault duration and reclosing are also given in the Appendix.

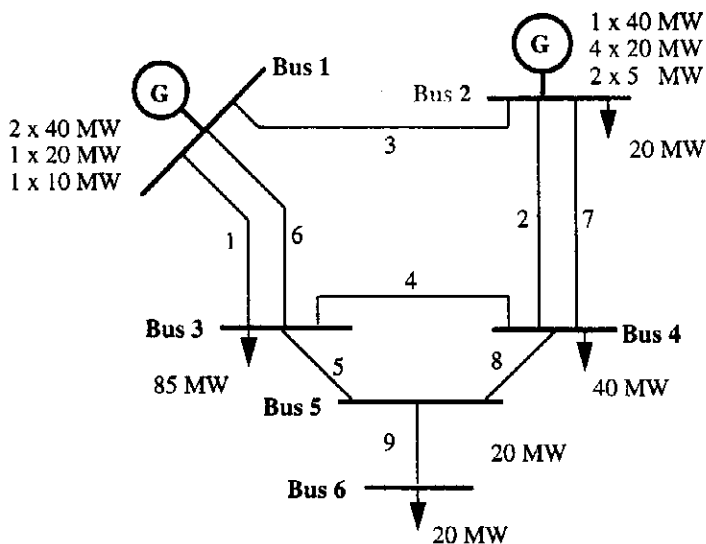


Fig. 4. Single line diagram of the RBTS.

The normal distribution representing load uncertainty can be approximated by a discrete intervals model [17]. In order to illustrate the effect of load uncertainty, a standard deviation (SD) of 4% is utilized. The basic probabilistic transient stability indices (Probability of Stability) for the RBTS are presented in Tables 1 and 2. Tables 3 and 4 lists the energy based and load based transient stability indices for the RBTS. In all tables, the "total" probability of stability can be calculated by adding the probability of stability for successful reclosing to the probability of stability for unsuccessful reclosing.

Table 1 shows the basic probabilistic transient stability indices for different transmission lines in the cases of no reclosing, simultaneous reclosing and adaptive reclosing. The "total" probability of stability is shown for each case. The probability of stability with successful and unsuccessful reclosing is presented for the case of simultaneous and adaptive reclosing. Table 1 shows that line # 3 has the lowest total probability of stability in all cases. This is basically due to the fact that this line links the two generating stations. Table 1 also shows that the "total" probability of stability for Line # 2 and line # 7 is less than unity. This is also due to the fact that these lines are connected to the major generator bus (bus 2). The "total" probability of stability for the other transmission lines is unity for all cases, which means that the protection system can operate successfully if any type of fault at any location occurs.

Table 1. Probabilistic transient stability indices for different transmission lines

Line number	No. reclosing	Probability of Stability					
		Simultaneous reclosing			Adaptive reclosing		
		Successful reclosing	1 Reclosing	Total	Successful reclosing	1 Reclosing	Total
1 & 6	1.000000	0.827407	0.172593	1.000000	0.827407	0.172593	1.000000
2 & 7	0.960300	0.656263	0.295658	0.951920	0.656263	0.304037	0.960300
3	0.950200	0.649360	0.290328	0.939689	0.649360	0.300840	0.950200
4,5,8 & 9	1.000000	0.841215	0.158785	1.000000	0.841215	0.158785	1.000000

It can be seen from Table 1, that for any transmission line, the total probability of stability if reclosing is not employed is greater than or equal to the total probability of stability if simultaneous reclosing is utilized. The reason for that is that the system will experience another instability problem in the case of unsuccessful reclosing. In the case of adaptive reclosing, the total probability of stability is equal to the probability of stability if no reclosing is utilized. This is due to the fact that in the case of unsuccessful reclosing, the system will experience a single line to ground fault problem. The probability of stability for all single line to ground faults in the RBTS is unity and therefore, the total probability of stability for the case of adaptive reclosing is equal to the probability of stability if no reclosing is used.

Table 2 shows the effect of load uncertainty on the basic probabilistic indices for the RBTS. The overall effect of load uncertainty on the RBTS were calculated using the

conditional probability approach as stated in Section III. The total probability of stability for the system in the cases of simultaneous and adaptive reclosing is calculated by adding the probability of stability with successful reclosing to the one with unsuccessful reclosing. In general, Table 2 shows that the total probability of stability decreases as the load increases. Similar observations to the ones obtained from Table 1 can be drawn. The total probability of stability in the case in which simultaneous reclosing is utilized is less than the one if no reclosing is done. The probability of stability if no reclosing is employed is equal to the total probability of stability in which adaptive reclosing is used.

Table 2. Probabilistic transient stability indices for different load steps and for the overall system

Deviation from mean	No. reclosing	Probability of Stability					
		Simultaneous reclosing			Adaptive reclosing		
		Successful reclosing	1 Reclosing	Total	Successful reclosing	1 Reclosing	Total
-3	0.994444	0.781743	0.211529	0.993272	0.781743	0.212702	0.994444
-2	0.990741	0.779212	0.209575	0.988786	0.779212	0.211529	0.990741
-1	0.990741	0.779212	0.209575	0.988786	0.779212	0.211529	0.990741
0	0.983333	0.774150	0.205666	0.979815	0.77415	0.209184	0.983333
1	0.983333	0.774150	0.205666	0.979815	0.77415	0.209184	0.983333
2	0.983333	0.774150	0.205666	0.979815	0.77415	0.209184	0.983333
3	0.983333	0.774150	0.205666	0.979815	0.77415	0.209184	0.983333
Total	0.985644	0.775629	0.206885	0.982614	0.775729	0.209915	0.985644

The most significant indices in composite power system reliability evaluation are those related to load curtailment. Different fault types at different system locations not only have different impacts on the basic probabilistic transient stability indices as seen in Tables 1 and 2, but they also result in different associated load curtailments. As an example, if a fault occurs on line # 9 of the RBTS, the load at bus # 6 will be isolated if reclosing is not used or due to unsuccessful reclosing into a system fault.

Table 3 shows the impact of including the effect of load curtailment on the transient stability risk indices associated with different transmission lines. Annualized energy and load based transient stability indices (risk indices) were calculated for each transmission line assuming no reclosing, simultaneous reclosing and adaptive reclosing is utilized. Table 3 shows that the risk indices for line # 4, # 5 and # 8 are zero since the total probability of stability for these lines is unity and no load is curtailed following any fault. Table 3 shows that the use of simultaneous reclosing increases the risk indices for line # 2, # 3 and # 7. This is due to the fact that the associated load curtailments following a system fault on these lines is small or zero. If adaptive reclosing is used, the transient stability risk indices for line # 2, # 3 and # 7 are equal to the indices obtained if no reclosing is used. This is because the possibility of reclosing into a multi-phase fault is eliminated if an adaptive protection scheme is used. Table 3 also shows that using simultaneous reclosing decreases the risk indices for line # 1, # 6 and # 9. This is due to the large impact of the

associated load and energy curtailments following a system fault on these lines. If adaptive reclosing is utilized, the indices for line # 1, # 6 and # 9 are lower than the indices obtained if no reclosing or simultaneous reclosing is used. This is due to the fact that the system will reclose only into a single line to ground fault if adaptive reclosing is employed. Table 3 shows that the most critical line is line # 3 which connects the generator buses. This line has the highest risk indices.

Table 3. Transient stability risk indices for different transmission lines

Line no.		EDNS	EENS	BPECI	MBECI	SI
	N	3.1494	27589	149.129	0.01702	8948
1 & 6	S	0.5436	4762	25.739	0.00294	1544
	A	0.5436	4762	25.739	0.00294	1544
	N	7.4387	65163	352.234	0.04021	21134
2 & 7	S	9.0088	78917	426.580	0.04870	25595
	A	7.4387	65163	352.234	0.04021	21134
	N	9.2174	80745	436.458	0.04982	26188
3	S	11.163	97788	528.582	0.06034	31715
	A	9.2174	80745	436.458	0.04982	26188
	N	0	0	0	0	0
4,5 & 8	S	0	0	0	0	0
	A	0	0	0	0	0
	N	20.000	175200	947.027	0.10811	56822
9	S	3.1757	27819	150.373	0.01717	9022
	A	3.1757	27819	150.373	0.01717	9022

N: No reclosing; S: Simultaneous reclosing; A: Adaptive reclosing

Table 4 shows the transient stability risk indices for different load points in the RBTS. It can be seen from Table 4 that the risk indices for buses # 2, # 4 and # 5 increase when simultaneous reclosing is used due to the fact that the only associated load curtailments for these buses is when the system is unstable. If adaptive reclosing is used, the transient stability risk indices for buses # 2, # 4 and # 6 are equal to the indices obtained if no reclosing is used. This is because the possibility of reclosing into a multi-phase fault is eliminated if an adaptive protection scheme is used. Table 4 also shows that the use of simultaneous reclosing decreases the risk indices for buses # 3 and # 6, due to the large impact of the associated load and energy curtailments following any system fault on these buses. If adaptive reclosing is utilized, the transient stability risk indices for buses # 3 and # 6 are lower than the indices obtained if no reclosing or simultaneous reclosing is used due to the fact that if adaptive reclosing is employed the system will reclose only into a single line to ground fault. Table 4 shows that the most critical load is at bus # 6 when no reclosing is used and bus # 3 if simultaneous or adaptive reclosing is used.

Table 5 shows the effect of load uncertainty on the overall transient stability risk indices for the RBTS. In Table 5, the transient stability risk indices were calculated for

Table 4. Transient stability risk indices for different load points

Bus no.		EDNS	EENS	BPECI	MBECI	SI
2	N	0.2894	2535	13.705	0.00156	822
	S	0.3505	3071	16.598	0.00189	996
	A	0.2894	2535	13.705	0.00156	822
3	N	1.9299	16906	91.385	0.01043	5483
	S	1.6105	14108	76.259	0.00871	4576
	A	1.3509	11834	63.965	0.00730	3838
4	N	0.5789	5071	27.410	0.00313	1645
	S	0.7010	6141	33.195	0.00379	1992
	A	0.5789	5071	27.410	0.00313	1645
5	N	0.2894	2535	13.705	0.00156	822
	S	0.3505	3071	16.598	0.00189	996
	A	0.2894	2535	13.705	0.00156	822
6	N	2.5117	22002	118.930	0.01358	7136
	S	0.7034	6162	33.306	0.00380	1998
	A	0.6423	5626	30.143	0.00347	1825

N: No reclosing; S: Simultaneous reclosing; A: Adaptive reclosing

Table 5. Overall transient stability risk indices for the RBTS

St. Dev.		EDNS	EENS	BPECI	MBECI	SI
-3	N	2.8600	25054	135.425	0.01546	8125
	S	1.4059	12315	66.569	0.00760	3994
	A	1.2150	10643	57.530	0.00657	3452
-2	N	3.6204	31714	171.429	0.01957	10286
	S	2.2332	19563	105.744	0.01207	6345
	A	1.9006	16649	89.994	0.01027	5400
-1	N	3.7778	33093	178.883	0.02042	10733
	S	2.3303	20413	110.342	0.01260	6621
	A	1.9832	17373	93.906	0.01072	5634
0	N	5.3056	46477	251.225	0.02868	15074
	S	4.0870	35802	193.525	0.02209	11611
	A	3.4362	30101	162.708	0.01857	9762
1	N	7.4511	65272	352.820	0.04028	21169
	S	4.5842	40157	217.066	0.02478	13024
	A	3.9073	34228	185.017	0.02112	11101
2	N	9.0656	79414	429.266	0.04900	25756
	S	4.9896	43709	236.266	0.02697	14176
	A	4.2868	37552	202.985	0.02317	12179
3	N	10.698	93713	506.554	0.05783	30393
	S	5.3982	47288	255.612	0.02918	15337
	A	4.6693	40903	221.098	0.02524	13266
Total	N	5.5993	49050	265.134	0.03027	15908
	S	3.7159	32552	175.955	0.02009	10557
	A	3.1509	27602	149.197	0.01703	8952

N: No reclosing; S: Simultaneous reclosing; A: Adaptive reclosing

each load step and the conditional probability theorem was utilized to calculate the overall transient stability risk indices for the three protection methodologies: no reclosing, simultaneous reclosing and adaptive reclosing. Table 3 shows that using simultaneous and adaptive reclosing may or may not decrease the risk indices. However, the overall system risk indices presented in Table 5 confirms that the overall transient stability risk indices for the RBTS decrease if a simultaneous or adaptive reclosing scheme is utilized. Table 5 shows that the risk indices decrease as the system load increases. Similar observations to the ones obtained from Table 2 can be drawn. The overall risk indices decrease by more than 33% if simultaneous reclosing is employed and by more than 43% if adaptive reclosing is employed. It is very important to appreciate that the overall transient stability risk indices for the RBTS can also be calculated from Table 4 by adding the indices obtained for each load point.

It can be seen from Table 3, 4 and 5 that the inclusion of the associated load curtailments is an important consideration in the overall evaluation of transient stability. The probabilistic framework proposed and illustrated in this paper provides the opportunity to incorporate these considerations in an overall probabilistic transient stability evaluation.

Conclusions

This paper illustrates a basic procedure for modeling simultaneous and adaptive reclosing. A new set of transient stability indices which include the basic probability values and the energy and load to be curtailed following a fault event is introduced. The effect of load forecast uncertainty on the indices was also included in the overall procedure. This procedure and the resulting indices provide the ability to quantitatively assess the overall impact of transmission faults on the system dynamic performance. It permits the recognition of uncertainty in transient stability analysis and provides the ability to perform sensitivity studies which include fault probabilities, locations, clearing times, reclosing times and schemes, and fault durations. Both simultaneous and adaptive modeling and the developed security indices are demonstrated using the RBTS. It can be seen from the results presented that the employment of either simultaneous or adaptive reclosing can decrease the overall system security risk indices. The basic concepts presented in this paper can be extended to include other residual uncertainties which exist in actual practice using the approach described in this paper.

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Appendix: Transient Stability Data for the RBTS

Deterministic data

Transmission lines: The negative sequence impedances for the transmission lines are equal to the positive sequence values given in [19]. The zero sequence impedances are assumed to be three times the positive sequence values.

Generators: The classical model parameters are provided for the RBTS in [19]. Extra data needed to conduct transient stability analysis are given in Table A.I. All values given in tables have a 100 MVA base.

Table A.I. Additional deterministic generator data for the RBTS

Unit No.	X_d (pu)	X_2 (pu)	X_0 (pu)	Rating (MW)	H (s)
1,2 and 7	0.20	0.10	0.08	40.0	5.0
3	0.10	0.05	0.03	10.0	3.0
4,8,9,10 and 11	0.15	0.10	0.05	20.0	4.0
5 and 6	0.10	0.05	0.03	5.0	1.0

Probabilistic data

The probabilities associated with type, location and fault clearing, reclosing and duration times are shown in Tables A.II, A.III and A.IV respectively.

Table A.II. Transmission line fault probabilities

Type of fault	Probability of occurrence
Single line to ground fault	0.70
Double line fault	0.15
Double line to ground fault	0.10
Three phase fault	0.05

Table A.III. Transmission line fault location probabilities

Fault location (pu Line length)	Probability
0.0	1/3
0.5	1/3
1.0	1/3

Table A.IV. Fault clearing time, fault duration and reclosing time probability distribution data

Line No.	Fault clearing (Norm. dist.)		Fault reclosing (Norm. dist.)		Fault duration (Rayleigh dist.)
	μ (s)	σ (s)	μ (s)	σ (s)	κ
1 and 6	0.3	0.03	0.6	0.03	15
2, 3 and 7	0.4	0.04	0.8	0.04	5
4, 5, 8 and 9	0.2	0.02	0.4	0.02	40

دراسات الاحتمالية في الاتزان العابر باستخدام المعاملات المشتقة من فصل الحمل والطاقة

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ملخص البحث . تمّ عرض واختبار النماذج الاحتمالية لإعادة الوصل اللحظي والأمثل وذلك باستخدام مجموعة جديدة من معاملات الخطر المحتملة للاتزان العابر . وتعتمد المعاملات المستحدثة على فصل الأحمال الناتج عن عزل القضبان و / أو التدخلات الإصلاحية لإعادة النظام إلى حالة التشغيل العادية . كما تمّ استخدام معاملات الخطر المحتملة والنماذج الاحتمالية المقترحة في إيجاد أداء السلوك العابر لمنظومة اختبار مع اعتبار تأثير غموض حمل القضبان . وتوضّح النتائج التي تمّ الحصول عليها أنّ إعادة الوصل وبالأخص الوصل الأمثل تعمل على تحسين أداء السلوك العابر في المنظومة الكهربائية .