RELIABILITY ASSESSMENT OF MEDIUM VOLTAGE SUBSTATION

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Abstract: *The differential protection of medium voltage substation is assessed with respect to reliability basis using an efficient technique. The proposed technique, is based on state space analysis. The model is built according to the probabilistic operation modes of the real time system under study and the reliability interactions between both power and protection components. The system reliability indices are computed accordingly at different operating conditions and failure criteria. The results proved that the technique is a powerful tool for protection assessment. and technique is applicable in both planning and operational phases.*

Key words: Differential protection, reliability indices, meduim voltage substation.

1- INTRODUCTION :

The charachteristics of power transformers introduce unique operating conditions that may initiate an inadvertent protection operation [1]. This inadvertent protection operation results in the outage of healthy power system elements. The analysis of the protection system response towards these 2].

The protection system of a substation is usually abstracted to the final operation of circuit breaker(s) during the reliability evaluation [3]. The tripping function of a protective scheme is performed through the integrated performance of its individual elements. A certain element may be expected to perform different tasks according to its location in the scheme and its planned goal with respect to the protected component or subsystem.

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In this work, the failure rates of differential protection are computed with respect to the initiating substation operating mode via fault tree analysis. This analysis yields both qualitative and quantitative information about the concerned system. Quantitative analysis deals with calculating the probability and frequency of system failure. The top event probability could be assessed via bottom-up, top-down and binary decision diagrams [4, 5 and 6].

A new Markov state space model is constucted to simulate the transition between the different probable substation operating modes.

1-1- List of symbols:

Ui	Unnecessary protection operation rate as result of over reaching main differential protection, initiated from operating state "i".
UiT	Unnecessary protection operation rate as result of over reaching backup differential protection, initiated from operating state "i".
r_j	Repair time of component j.
λ_T	Transformer failure rate.
μ_T	Transformer repair rate.
μ_d	Distributor function restoration rate.
μ_f	Feeder function restoration rate.
PO	Transformers parallel operation.
SO	Transformers single operation.
NO	Both transformers out of service.
δ	Main relay percentage of successfull operations.
Ψ_{rs}	Reset switching rate.
Ψ_{cb}	Circuit breaker switching rate.
λ_d	Distributor functional failure rate.
λ_f	Feeder functional failure rate.
T_1	Main transformer number 1

1-2- Assumptions:

- Manual operation of bus ties is 100% reliable.
- Circuit breakers do not operate inadvertently.
- Inadvertent operation of relays is due to either out of zone false operation or due to unnecessary operation.
- Simultaneous failure of both transformers is neglected.

2- ASSESSMENT TECHNIQUE :

The proposed technique is based on using the reliability data of the individual protective elements and the protected elements within the combined power and protection system to assess the protection performance at the system level. This task would be extremely tedious if the effect of every element is investigated separately. Further more the results will not combine forming an indicative means. Instead, this technique makes it possible for the power and protection systems to be viewed as integrated stand-alone entities, the rates of which are applied to the proposed substation Markov model.

The combined system states are established through the construction of fault trees in which the top events are the expected system failure modes. The resulting indices are thus capable of assessing the effect of protection system individual reliability data on its performance. To obtain the state probabilities $p_i(t)$ as function of time, the matrix differential equation [8],

$$[\dot{p}\,(t)] = [p\,(t)\,][A]$$

must be solved where $\dot{p}(t)$ is a row-vector consisting of the elements, (dp_1/dt), (dp_2/dt) , ... $p(t)$ is a row-vector consisting of elemints $p_1(t)$, $p_2(t)$,....., and A is a transilion intensity matrix. If only the tong-term values of probability $p_i(t)$ are of interest, they can be obtained by the much simpler task of solving the set of equations

$$[P\,][A] = [\,0]$$

where

P = are the long-term state probabilityes $p_1(t)$, $p_2(t)$,.....,
0 = row-vector, consists of zeros.

The solution for p requires an additional equation, which is

$$\sum p_i = 1$$

The state frequency of state i is :-

$$f_i = p_i \sum_{j \neq i} \lambda_{ij}$$

and the state duration is

$$T_i = \frac{1}{\sum\limits_{j \neq i} \lambda_{ij}}$$

i.e. the mean duration of stays in any given state equals the reciprocal of the total rate of departures from that state. The states of the system under investigation are defined according to the operating conditions, along with the rates of all the transitions between them. From the state transition matrix and probable states data, the reliability indices are calculted.

The general steps of assessment technique are :

- Definition the criteria for system failure
- Based on the failure cirteria, perform an analysis of failure effects for every system state.
- Solve the state-space model for the long-run state probabilities.
- Combine all the failed states (F) and also succeeded states (S).

The system failure probability , frequency are :

$$p_F = \sum_{i\varepsilon F} p_i$$

$$f_F = \sum_{i\varepsilon F} p_i \sum_{j\varepsilon S} \lambda_{ij}$$

where λ_{ij} is the failure transition rate from failed subset to succeded subset.

3- CASE STUDY:

The system under study is shown in figure (1).

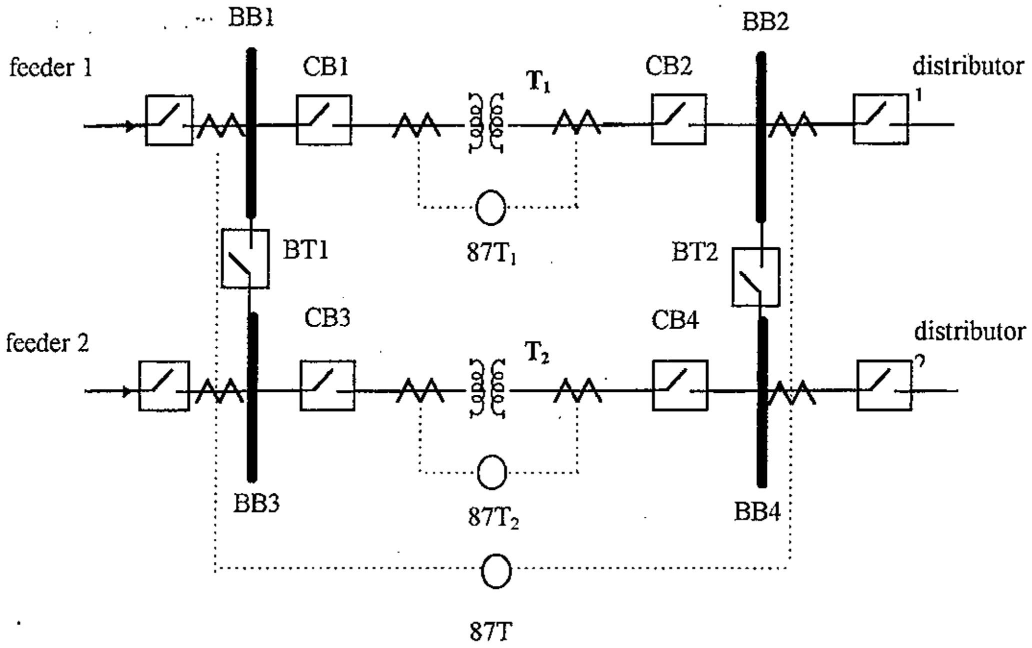

Figure (1) Substation configuration.

The system is composed of two main step down transformers, T_1 and T_2 protected by differential relays ($87T_1$ and $87T_2$). The combined set including the busbars, is protected by a backup differential relay (87T). Field reliability data of the individual elements are used in the analysis [7].

4- THE PROCESS OF STATE-SPACE TECHNIQUE

- The test system is prepared to use state-space techique according to the operating conditions, transition rates and failure criteria.The test system is analysed and all probable states are shown in Fig. (2)

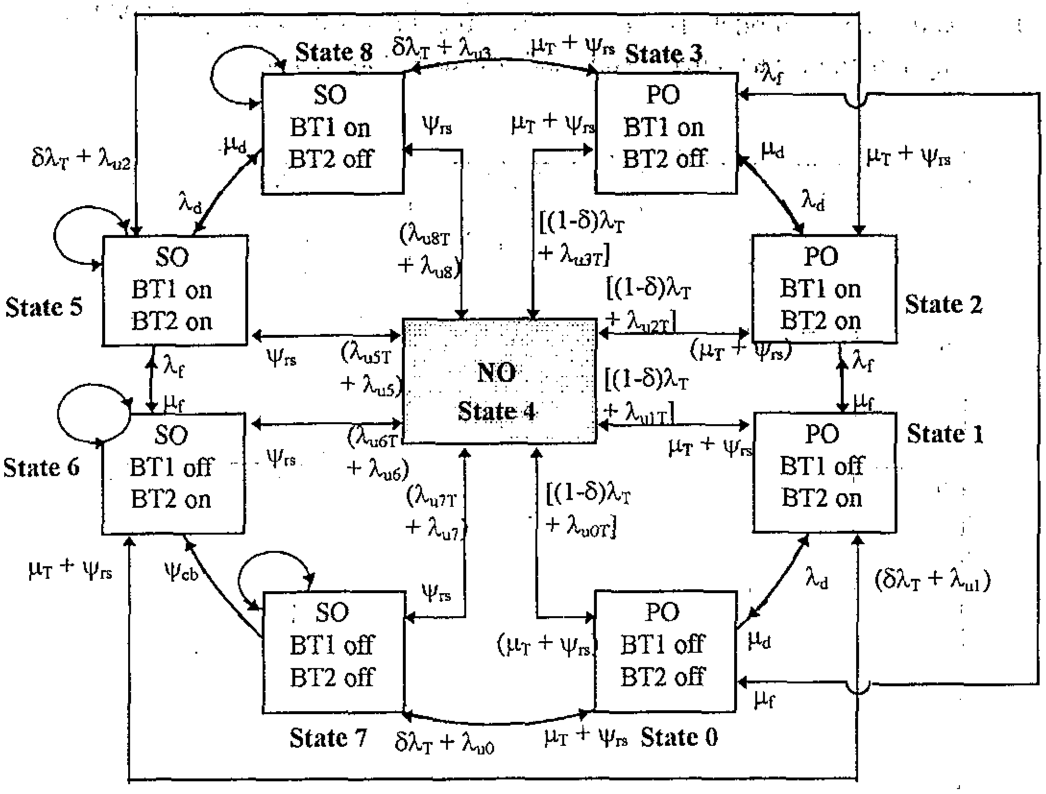

Fig. (2) Substation state-space model.

To explain the state-space model, choose the conditions for transition from state (5) to state (4) due to backup protection inadvertent operation as shown in Fig 3 . Firstly state(5) has both bus/sections BT1 and BT2 which are on, and single transformer operation. By the use of Figs (1and 2), the process of transition can be illustrated.in Fig 4 .

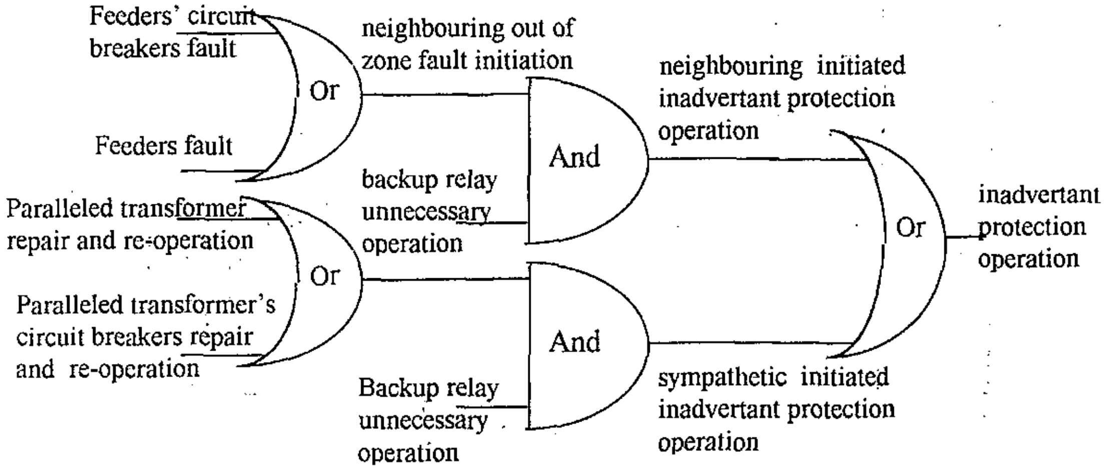

Figure (3) Conditions leading transition from state "5" to "4"

- Based on state-space model seen in Fig. (2), the state space transition materix [A] is constructed as seen in Fig. (4).

- The state-space model is solved for the long run state probabilities, considering No and So as failed states, and PO as succeeded states.

[A]=

$-\lambda_d -\lambda_f -\lambda_{u0T} -\lambda_T -\lambda_{u0}$	λ_d	0	λ_f	$\lambda_{u0T} + (1-\delta)\lambda_T$	0	0	$\lambda_{u0} + \delta\lambda_T$	0
0	$-\lambda_{u1T} -\lambda_f -\lambda_T -\lambda_{u1}$	λ_f	0	$\lambda_{u1T} + (1-\delta)\lambda_T$	0	$\lambda_{u1} + \delta\lambda_T$	0	0
0	μ_f	$-\mu_f -\mu_d -\lambda_{u2T} -\lambda_{u2} -\lambda_T$	μ_d	$\lambda_{u2T} + (1-\delta)\lambda_T$	$\lambda_{u2} + \delta\lambda_T$	0	0	0
μ_f	0	λ_d	$-\lambda_{u3T} -\lambda_{u3} -\lambda_T -\lambda_d -\mu_f$	$\lambda_{u3T} + (1-\delta)\lambda_T$	0	0	0	$\lambda_{u3} + \delta\lambda_T$
$\mu_T+\psi_{rs}$	$\mu_T+\psi_{rs}$	$\mu_T+\psi_{rs}$	$\mu_T+\psi_{rs}$	$-8\mu_T -8\psi_{rs}$	$\mu_T+\psi_{rs}$	$T+ \psi_{rs}$	$T+ \psi_{rs}$	$T+ \psi_{rs}$
0	0	$\mu_T+\psi_{rs}$	0	$\lambda_{u5T} +\lambda_{u5}$	$-\mu_T -\psi_{rs} -\mu_f -\mu_d -\lambda_{u5T} -\lambda_{u5}$	μ_f	0	μ_d
0	$\mu_T+\psi_{rs}$	0	0	$\lambda_{u6T} +\lambda_{u6}$	λ_f	$-\mu_T -\psi_{rs} -\lambda_f -\lambda_{u6T} -\lambda_{u6}$	0	0
$\mu_T+\psi_{rs}$	0	0	0	$\lambda_{u7T} +\lambda_{u7}$	0	ψ_{cb}	$-\mu_T -\psi_{rs} -\psi_{cb} -\lambda_{u7T} -\lambda_{u7}$	0
0	0	0	$\mu_T+\psi_{rs}$	$\lambda_{u7T} +\lambda_{u7}$	λ_d	0	0	$-\mu_T -\psi_{rs} -\lambda_d -\lambda_{u8T} -\lambda_{u8}$

Fig. (4) Transition matrix [A]

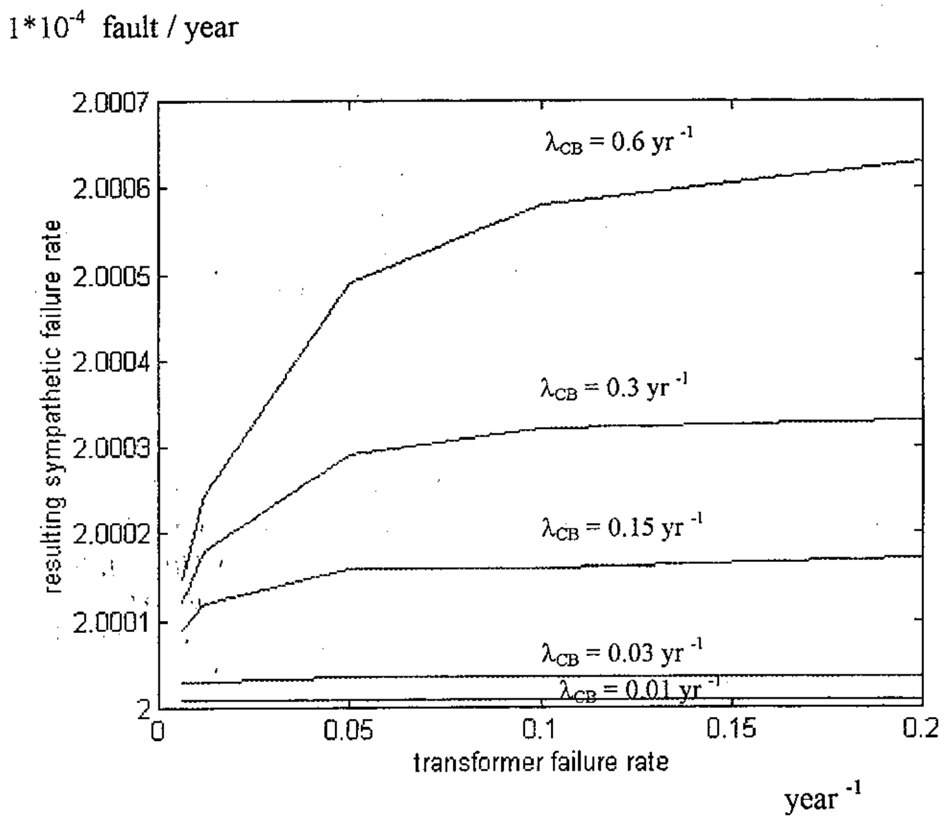

Fig. (5) Transformer failure rate and sympathetic failure rate

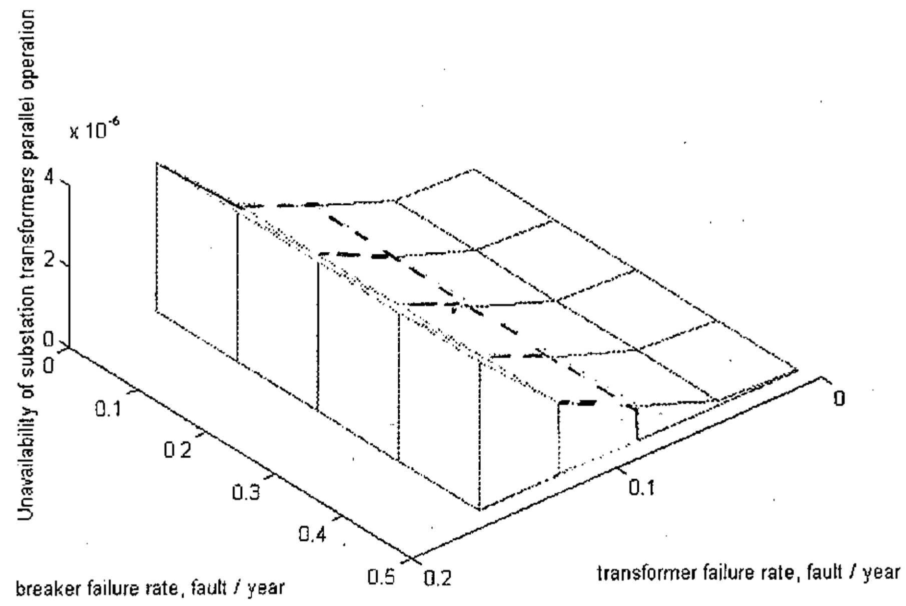

Fig. (6) Relation between Transformer , breaker failure rate and unavailability of substation transformers in parallel operation

5- RESULTS

Fig. (5) illustrates the resulting sympathetic failure rate via transformer failure rate at different values of circuit breaker failure rates . It is shown that at specified value of transformer failure rate the sympathetic failure rate increases when circuit breaker failure rate increases. For the period between λ_T=0.1 to 0.2 f/year, the resulting sympathetic failure rate of certain circuit beraker failure rate,is approximately that is not like the period when (λ_T) between 0.01 to 0.10 failure/year. This means that both transformer and circuit breaker failure rates played an active part in resulting sympathetic failure rate..

Fig. (6) shows the relation between the transformer failure, circuit breaker failure rate and unavailability of substation which contains two main transformers in parallel operation. The unavailability of substation decreases rapidly by the decrease of transformer failure rate, while the circuit breaker failure affects also the unaviability but without the same rate. The paper presents a new approach for calculating substation protection reliability. The process of calculation takes into consideration the probabilistic operation modes of the real time system under study and the reliability interactions between both power and protection components.

6- CONCLUSIONS

The analysis of proposed method shows that circuit breaker, transformer and sympathetic failure rates affect the reliabilitiy assessment of medium voltage substation. The operating conditions and failure criteria are very important factors when constructing transition matrix, and reliability indices. The low values of transformer failure rates provides to low values of sympathetic failure rates. But in large values of transformer failure rates corresponding to constatnt values of sympathetic failure rates.This indicates that the sympathetic failure rate is independent on the high value transformer failure rate. The technique is applicable in both planning and operational phases.

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حساب مؤشرات الإعتمادية لمحطة فرعية جهد متوسط

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يقدم البحث طريقة دقيقة لحساب مؤشرات الإعتمادية لمحطة فرعية جهد متوسط مزودة بنظام وقاية تفاضلى. المحطة التى جرى عليها البحث مكونة من محولين لهما قدرة أكبر من ١٠ ميجا فولت أمبير وبها نظام حماية تفاضلى لكل محول على حدة ثم نظام حماية تفاضلى للمحطة كلها يشتمل على محولين وقضبان الجهد العالى والمتوسط والقواطع وهذه المحطة تناسب المحطات محولات الفرعية للمدن والمصانع الكبرى.

الطريقة المقترحة تعتمد على التحليل الرياضى بإستخدام طريقة الحيز الفراغى (State-space method) والنموذج الرياضى مبنى على أساس حالات التشغيل المحتملة لكل من نظام القوة ونظام الحماية التفاضلى الخاص به ويعتمد أيضا على معدلات الأعطال لعناصر نظام القوة الذى يشمل المحولات وقضبان التوزيع والقواطع وغيرها وكذلك معدلات الأعطال لعناصر نظام الحماية التفاضلى المركب على المحطة. وتم حساب دليل ألإعتمادية (Reliability-index) عند حالات تشغيل مختلفة وأوضحت النتائج أن معدلات الأعطال للقواطع لها تأثير واضح وسريع عند قيم معينة (من صفر إلى ٠,١ عطل/ سنة) ولها تأثير بسيط عند قيم (من ٠,١ إلى ٠,٢ عطل/سنة) . كما بينت النتائج أيضا مدى أرتباط دليل الإعتمادية للمحطة على معدلات ألأعطال لكلا من المحولات والقواطع وحالات التشغيل المختلفة للنظام ونظام الحماية التفاضلى الخاص به.

والطريقة المقترحة تصلح للتطبيق فى حالات التشغيل والتخطيط لنظم الحماية فى محطات الفرعية جهد المتوسط.