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COMPONENT AND PROTECTION FAILURE EFFECTS ON RELIABILITY ANALYSIS

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Abstract: **In standard reliability theory, this probabilistic perspective has been generally used to model and analyse the reliability of a product/service. Reliability related measures such as availability, mean time to failure, importance measures, etc. are also based on such probabilistic perspective. When considering electric power system reliability, researchers and analysts are interested in how component outages and repair rates affect the associated overall system rates. Primary interest is devoted to the quantification of system failures; this quantification is then translated to expected system outage rates, mean outage duration and overall downtime. Protective relaying suffers from two types of failures: failure to operate, and unwanted operation. Protection system failures can have significant effect on the continuity of electricity supply to customers, making its reliability evaluation a priceless task. When protection system does not perform its intended operation, catastrophic failures can occur which leads to significant amount of customer interruptions and in some cases isolation of the power system. A well-designed protection system responds to the predefined abnormal conditions in an expected time delay without causing other backup systems to react and probably disconnect healthy neighbour components from the circuit. In the work presented, nine state Markov Model is used for the analysis unavailability probability.**

Keywords: **Reliability, Catastrophic Failure, Repaired rates, Mean time to failure, Markov model.**

1. INTRODUCTION

The function of protective relaying is to cause the prompt removal from service of any element of a power system when it suffers a short circuit, or when it starts to operate in any abnormal manner that might cause damage or otherwise interfere with the effective operation of the rest of the system. The relaying equipment is aided in this task by circuit breakers that are capable of disconnecting the faulty element when they are called upon to do so by the relaying equipment. Circuit breakers are generally located so that each generator, transformer, bus, transmission line, etc., can be completely disconnected from the rest of the system.

SELF TESTING:

As a minimum, digital relay self-tests include tests of memory chips, a/d converter, power supply, and storage of relay settings. These periodic self-tests monitor the status of the digital relay and close an alarm contact when a failure is detected. Additionally, the digital relay may disable trip and control functions upon detection of certain self-test failures. Since the relay self-tests are executed often in the digital relay, component failures are usually discovered when the failure occurs.

The model shown in makes the following assumptions regarding the relays modelled:

1) An inspection or fault must occur in order to detect a relay failure.

2) A relay must be taken out of service to be inspected.

3) The time required to test a relay is equal to the time required to repair or replace a failed relay.

4) Inspection of the protection always detects failures and does not cause failures.

5) Repair always restores the protection to good as new.

The eight-state model proposed does not account for relay self-testing. Figure shows a nine-state model that accounts for self-testing. The model is divided into four quadrants representing the condition of the relay (Protection) and the line (Component). State 1 represents the normal operating condition where the line is energized (Component UP) and the relay is operating properly (protection UP). When a line fault occurs, the Component makes the transition to a down state represented by State 2. In State 2, the line is faulted, but the relay is operating properly and signals the circuit breaker to trip. The normal switching transition takes the model system to State 6 where the line is isolated. The line is then repaired and reenergized, taking the model system back to State 1. States 5, 3, and 9 represent conditions where the relay is out of service and unavailable to trip should a fault occur. In State 5, the relay is out of service being inspected. In States 3 and 9 the relay is out of service due to a relay failure. State 9 represents the relay under repair .The model system enters State 9 from State 1 when a relay failure is detected by the relay self-test function. The model system enters State 9 from State 3 when a relay failure is detected by a routine maintenance test. The model system enters State 3 from State 1 when a relay failure occurs that is not detected by the relay self-test function. The effectiveness of self-testing can be varied in the model. The overall relay failure rate, Fp, is multiplied by a per unit factor, ST, to indicate the portion of all relay failures that are detected by self-test operation. The remainder of failures can only be detected by routine test or by observing a misoperation. Digital relays with varying degrees of self-test effectiveness can be represented in the model by adjusting the value of ST . The model system enters State 4 if a fault occurs while the relay is out of service, or if a common-cause failure of the relay and system occurs. The model assumes that if a fault occurs while the relay is out of service, remote backup protection must operate to isolate the fault. When the remote protection operates, a larger portion of the power system is taken out of service than would have been removed had the failed relay operated properly. This is represented in State 4 and State 8 by the isolation of C and X, where X is the additional equipment that was removed from service by the backup operation.

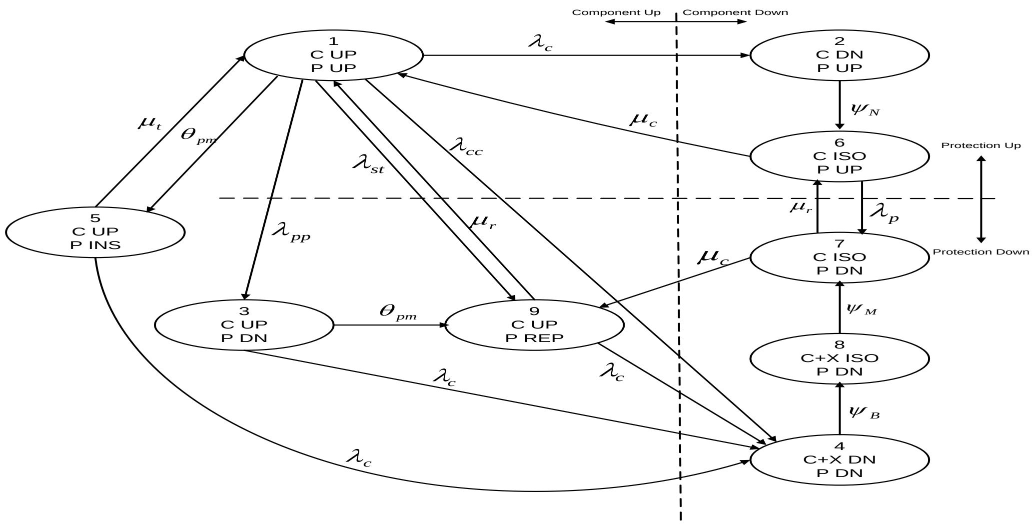


Figure.1: Markov Model of a Protection/Component System that accounts for relay Self-Testing

Notations:

λ_p =Relay Failures (reciprocal of relay Mean Time Between Failures, MTBF)

ST =Self-test Effectiveness Index (per unit)

λ_{st} =Relay Failures detected by self-test (λ_p.ST), failures per year

λ_{pp} = Relay Failures not detected by self-test (λ_p.[l-ST]), failures per year

λ_c = Component Failures, faults per year

λ_{cc} =Common-cause failures of the relay and component, failures per year

μ_c = Protected Component repairs per hour

μ_t = Relay inspections per hour

μr = Relay repairs per hour

Ψ_N = Normal tripping operations per hour (reciprocal of normal fault clearing time)

Ψ_B = Backup tripping operations per hour (reciprocal of backup fault clearing time)

Ψ_M =Manual isolation operations per hour

Θpm =Protection Inspection rate

The probability of the system residing in a given state is calculated using the Markov Transition Matrix. The Markov Transition Matrix is assembled from the transition rates and calculated as shown below.

Transition Matrix T=

$$\begin{bmatrix} -(\lambda_c+\theta_{cp}+\theta_p+\lambda_p+\lambda_{cc}) & \lambda_c & \lambda_p & \lambda_{cc} & \theta_p & 0 & 0 & 0 & \theta_{cp} \\ 0 & -\psi_N & 0 & 0 & 0 & \psi_N & 0 & 0 & 0 \\ 0 & 0 & -(\theta_p+\lambda_c) & \lambda_c & \theta_p & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & -\psi_B & 0 & 0 & 0 & \psi_B & 0 \\ \mu_p & 0 & 0 & \lambda_c & -(\mu_p+\lambda_c) & 0 & 0 & 0 & 0 \\ \mu_c & 0 & 0 & 0 & 0 & -(\mu_c+\lambda_p) & \lambda_p & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & \mu_p & -\mu_p & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & \psi_M & -\psi_M & 0 \\ \mu_{cp} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -\mu_{cp} \end{bmatrix}$$

Let P be the probability vector of the nine state Markov Model,

$$P^T = [P_1 \quad P_2 \quad P_3 \quad P_4 \quad P_5 \quad P_6 \quad P_7 \quad P_8 \quad P_9]$$

Then we have:

$P^T.T = P^T$ or $P^T \cdot [T - I] = 0$ the singularity of $[T - I]$=0

Where I is a nine by nine identity matrix. Finally we need the following equation to overcome the singularity of $[T - I]$

$$\Sigma P_i = 1$$

$$P_1 + P_2 + P_3 + P_4 + P_5 + P_6 + P_7 + P_8 + P_9 = 1$$

The following probabilities are defined. Up & down are for Component & Protection.

Abnormal Unavailability (AbUn) - Probability that both P & C are down:

$$AbUn = P_4 + P_8$$

This unavailability is abnormal because it results from the outage of UP components in addition to the DN C. Therefore, it represents the effect of the readiness of P.

Normal Unavailability (NorUn) - Probability that C is down and P is up:

$$NorUn = P_2 + P_6$$

Protective System Unavailability (ProtUn) - Probability that C is up and P is down:

$$\mathrm{Pr}otUn = P_3 + P_5$$

uredines Probability - Probability that P is not available for use when it should be operable:

readiness Probability = ProtUn/ $(P_1 + P_3 + P_5)$

$$= (P_3 + P_5)/(P_1 + P_3 + P_5)$$

Readiness Probability is a conditional probability that P does not operate when it is called upon to do so. The state probabilities are computed by writing the closed form expressions for each state**.** State 9 is ignored in computing the state probabilities as it does not appreciably affect the other state probabilities.

The following probabilities are defined based on the Markov Model.

$$P_1(N) = \mu_c \mu_p \psi_M \psi_B \psi_N (\lambda_c + \mu_p)(\lambda_c + \theta_p)$$

$$P_2(N) = \lambda_c \mu_c \mu_p \psi_M \psi_B (\lambda_c + \mu_p)(\lambda_c + \theta_p)$$

$$P_3(N) = \mu_c \lambda_p \mu_p \psi_M \psi_B \psi_N (\lambda_c + \mu_p)$$

$$P_4(N) = \lambda_c \lambda_p \mu_c \mu_p \psi_M \psi_N (\lambda_c + \mu_p) + \lambda_{cc} \mu_c \mu_p \psi_M \psi_N (\lambda_c + \theta_p)(\lambda_c + \mu_p) + \lambda_c \theta_p \mu_c \mu_p \psi_M \psi_N (\lambda_c + \theta_p) + \lambda_c \lambda_p \theta_p \mu_c \mu_p \psi_M \psi_N$$

$$P_5(N) = \theta_p \mu_c \mu_p \psi_M \psi_N \psi_B (\lambda_c + \theta_p) + \theta_p \lambda_p \mu_c \mu_p \psi_M \psi_N \psi_B$$

$$P_6(N) = \mu_p \psi_M \psi_B \psi_N \lambda_c (\lambda_c + \theta_p)(\lambda_c + \lambda_p + \lambda_{cc} + \theta_p) + \mu_p^{2} \psi_M \psi_B \lambda_{cc} \psi_N (\lambda_c + \theta_p) + \mu_p^{2} \psi_M \psi_B \psi_N \lambda_c \lambda_p + \mu_p^{2} \psi_M \psi_B \psi_N \lambda_c (\lambda_c + \theta_p)$$

$$P_7(N) = \lambda_c \lambda_p \mu_p \psi_M \psi_N \psi_B (\lambda_c + \theta_p) + \lambda_c \psi_M \psi_N \psi_B (\lambda_c + \theta_p)[(\lambda_p + \mu_c)(\lambda_c + \lambda_p + \lambda_{cc} + \theta_p) - \lambda_c \mu_c] + \lambda_c \lambda_p \mu_p \psi_M \psi_N \psi_B (\lambda_p + \mu_c) + \lambda_{cc} \mu_p \psi_M \psi_N \psi_B (\lambda_c + \theta_p)(\lambda_p + \mu_c)$$

$$P_8(N) = \lambda_{cc} \mu_p \mu_c \psi_N \psi_B (\lambda_c + \mu_p)(\lambda_c + \theta_p) + \psi_N \psi_B \lambda_c \lambda_p \mu_p \mu_c (\lambda_c + \mu_p) + \psi_N \psi_B \lambda_c \theta_p \mu_c \mu_p (\lambda_c + \theta_p) + \psi_N \psi_B \lambda_c \theta_p \mu_c \mu_p \lambda_p$$

A description of the probability calculations through MATLAB programming

From this analysis, any of the defined probabilities can be evaluated for any known system transition rates. Based on the study, we believe that the Abnormal Unavailability is an appropriate measure of the effect of the readiness of P.

To illustrate the nature of the results computed a family of curves representing the Abnormal Unavailability is plotted for various values of the interval between protective system inspections.

STATE1 represents usual operation with both C and P UP. So protective system should have maximum probability in STATE 1.The system having maximum probability and optimum test interval for given values of Fp, Fc, Rp, Rc is shown in figure below.

Fp=0.1/yr, Fc=2/yr, Rp=0.5/yr, Rc=0.5/yr

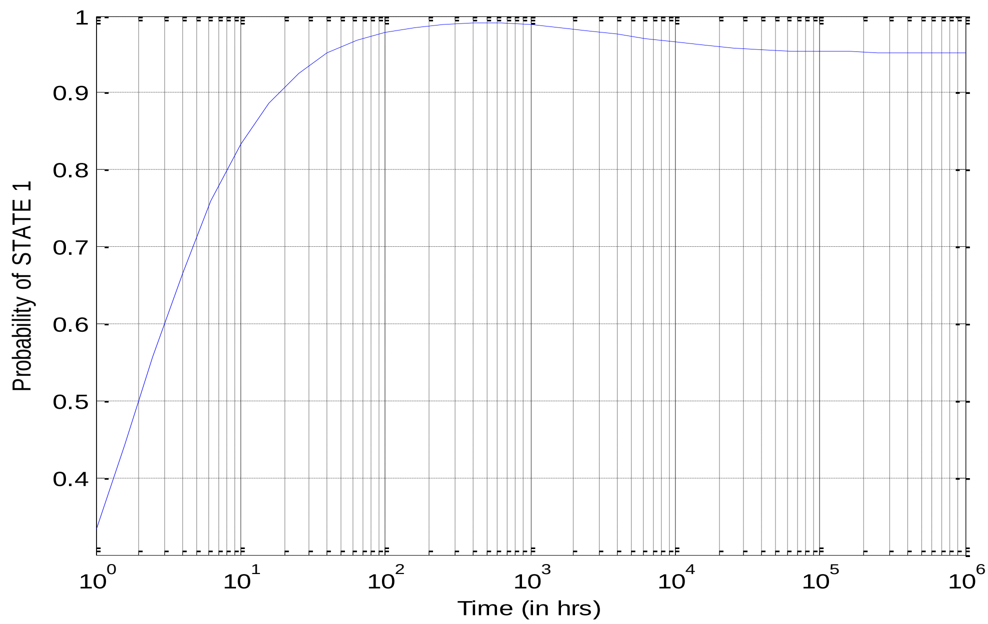


Figure.2: Probability of both C & P in STATE 1

In STATE 2, the relay operates successfully when called upon. In this state, the relay is in healthy condition and responds to any abnormal condition associated with the component under protection.

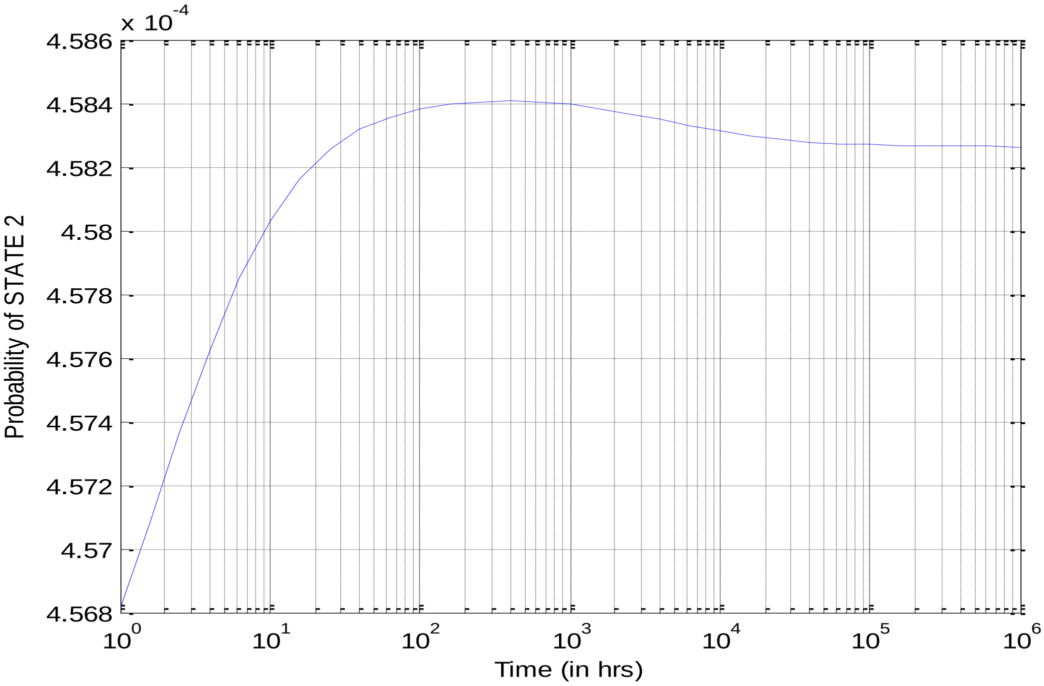


Figure.3: Probability of both C & P in STATE 2

STATE 3 represents operation C is UP and P is in an unannounced failed state. So, protective system should have minimum probability in STATE 3.The system having minimum probability and optimum test interval for given values of Fp, Fc, Rp, Rc is shown below.

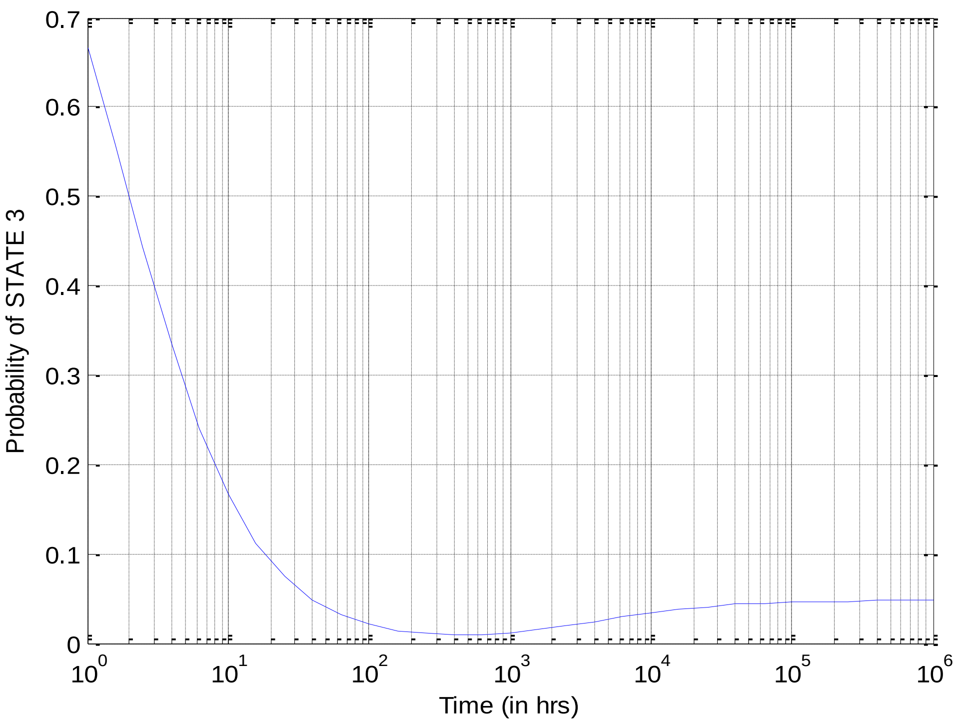


Figure.4: Probability of both C & P in STATE 3

STATE 4 represents unusable operation with both C and P DN. So protective system should have minimum probability in STATE 4.The system having minimum probability and optimum test interval for given values of Fp, Fc, Rp, Rc is shown below.

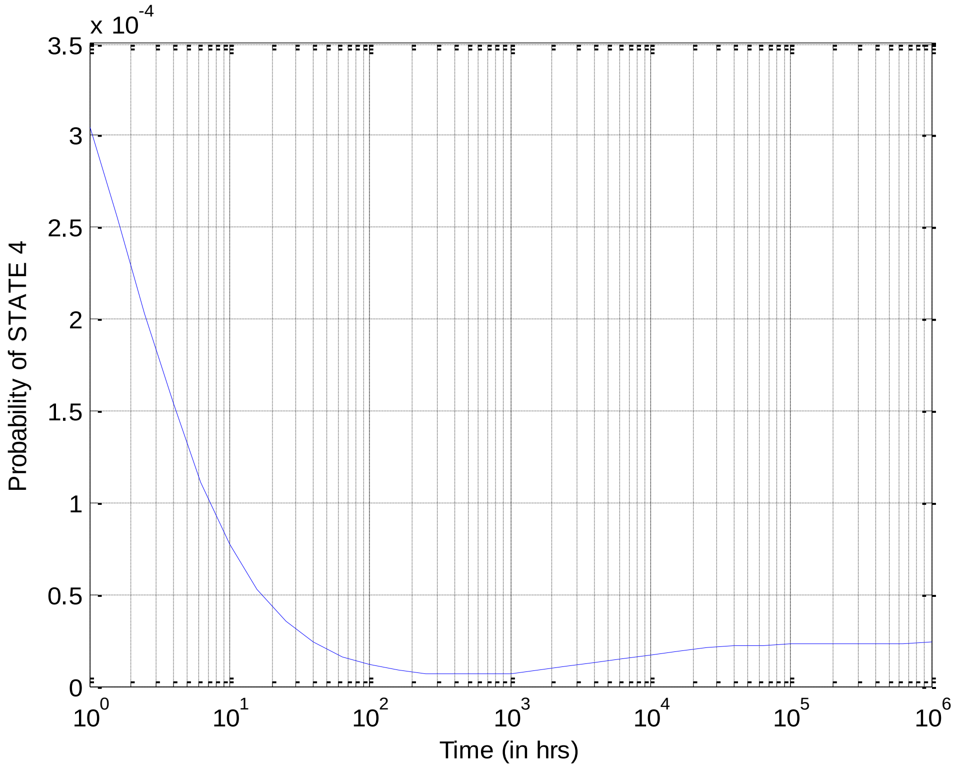
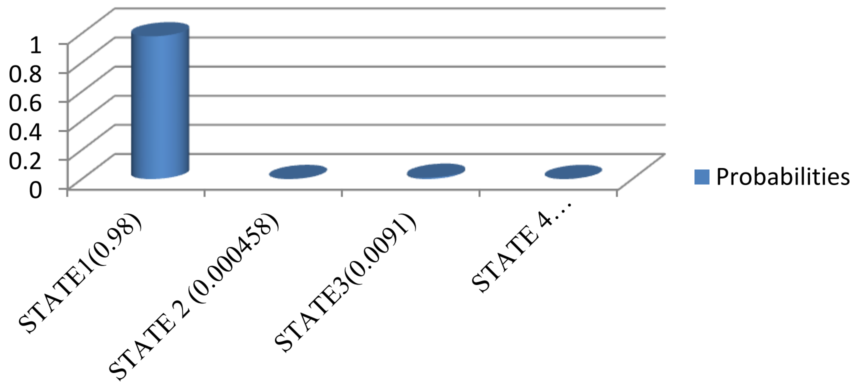


Figure.5: Probability of both C & P in STATE 4



2. CONCLUSION

"COMPONENT AND PROTECTION FAILURE EFFECTS ON RELIABILITY ANALYSIS" explores the common relay failures, reliability concept in protective relay, relay testing of electromechanical relay and Digital relay using the nine state Markov Model. The advantage of the nine state model is that more states are being considered for the analysis. Inclusion of 3 more states (in Digital Relays) makes it more reliable as compared to Electromechanical Relays.

This will be useful for engineers, industrial and commercial electric power plant engineers that are doing reliability and unavailability prediction for industrial electric power distribution systems that employ protective relays

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