ASSESSMENT OF TRANSIENT STATE PROBABILITIES OF THE COMPOSITE POWER COMPONENT

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ABSTRACT

In this paper the state probability transition equations of the composite power component are solved step by step to investigate the variation of these probabilities with time. It has been shown that the probabilities undergo a transient period after restoring the component to service of such length as to necessitate much cautiousness in applying steady state probability values in power system reliability analysis. The effect of various transition rates on the transient period is also investigated.

INTRODUCTION

The effect of the reliability of the protection system on the reliability of power system has been previously investigated[1-4]. While in reference [1] to [3], the dependence of the reliability of power systems on the reliability of their protection systems is pointed out, they did not propose any method for measuring the reliability of the protection system. In reference [4], however, a stochastic model of a composite power component, i.e. the power component and its protection, is developed for that purpose. The steady state solution of the probilities of the composite component being in the different model states is obtained

Due to the unavoidable imperfect reliability, the protection system is shown to produce appreciable reduction in the availability of supply at load points which is dependent on the probability of composite components being in the normal operating state.

In this paper the transient solution of the probilities of the composite component being in the different model states is investigated. The purpose is to show whether or not the steady state solution can be used once the composite component is restored to service after an outage, and how long the transient period extends. The effect of different model transition rates on that period is also investigated.

The work reported here is important to power system analysts to properly assess the different reliability indices at all times, particularly the availability of supply at load points.

SYSTEM MODEL

Figure (1) depicts the model developed in [1] for the composite component. A brief description of the different states follows.

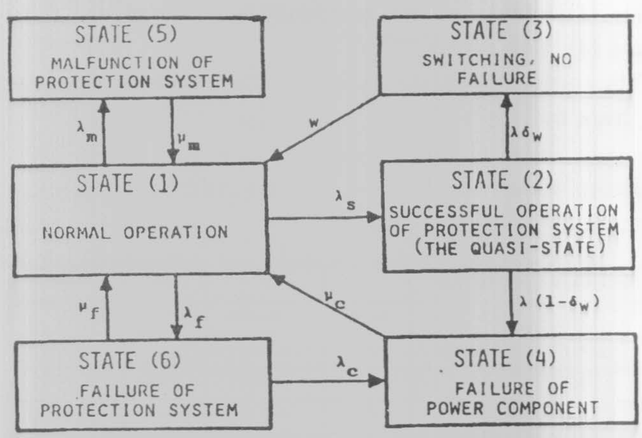

Figure 1. State space model of composite power component.

In state (1), the power component is operating normally in service while the protection system is idle. State (2) represents the composite component when the protection system operates successfully under call. The rate of transition from state (1) to state (2) is λ_s. If the operation of the protection system is effected as back up of nother component, the composite component travels to state (3), with rate λ_w, where it will eventually be switched back to normal service after the failed component is isolated. The rate of transition from state (3) to state (1) is w. If, on the other hand, the operation of the protection system is due to a failure in the protected power component, the composite component travels to state (4), with rate λ_r, where the power component is repaired and returned to normal state (1) with rate μ_c. The sum $\lambda_w + \lambda_r$ is the total transition rate $\lambda$from state (2), which is the inverse of the total expected time stayed in that state. If δ_w is the probability of the protection system operating as aback up system, then $\lambda_w = \lambda$ and $\lambda_r = \lambda\ (1-\delta_w)$.

If the protection system operates falsely, indicating a malfunction, the composite component travels from state (1) to state (5), with rate $\lambda_{,m}$, where the protection system is repaired and then the composite component is returned to state (1), with rate μ_m.

State (6) represents the composite component when the protection system does not respond to a call indicating its failure. The power component will eventually be disconnected by another protection. Transition rate from state (1) to this state is λ_f. The protection system will be repaired and, if the power component is found healthy, the composite component is switched back, with rate μ_f, to state (1); otherwise, the composite component travels to state (4), with rate λ_c.

The corresponding stochastic transition probability matrix is given by:

P =

$1-(\lambda_f+\lambda_m+\lambda_s)\Delta t$	$\lambda_s \Delta t$			$\lambda_m \Delta t$	$\lambda_f \Delta t$
	$1-\lambda\Delta t$	$\delta_w \lambda \Delta t$	$(1-\delta_w)\lambda\Delta t$		
$w\ \Delta t$		$1-w\Delta t$			
$\mu_c \Delta t$			$1-\mu_c \Delta t$		
$\mu_m \Delta t$				$1-\mu_m \Delta t$	
$\mu_f \Delta t$			$\lambda_c \Delta t$		$1-(\mu_f+\lambda_c)\Delta t$

The matrix **p** relates the row vector [p(t)] of the six probabilities of the composite component being in the six model states at time (t) to the same vector at time $(t+\Delta t)$ as per the relationship:

$$[p(t+\Delta t)] = [p(t)]\ \mathbf{P} \tag{2}$$

From (2) the differential equations governing the six probabilities can be obtained as:

$$\dot{p}_1(t) = -(\lambda_s+\lambda_m+\lambda_f)\ p_1(t) + wp_3(t) + \mu_c p_4(t) + \mu_m p_5(t) + \mu_f p_6(t) \tag{3}$$

$$\dot{p}_2(t) = \lambda_s\ p_1(t) - \lambda p_2(t) \tag{4}$$

$$\dot{p}_3(t) = \lambda\delta_w\ p_2(t) - \lambda p_3(t) \tag{5}$$

$$\dot{p}_4(t) = (1-\delta_w)\ \lambda p_2(t) - \mu_c p_4(t) + \lambda_c p_6(t) \tag{6}$$

$$\dot{p}_5(t) = \lambda_m\ p_1(t) - \mu_m\ p_5(t) \tag{7}$$

$$\dot{p}_6(t) = \lambda_f\ p_1(t) - (\lambda_c+\mu_f)p_6(t) \tag{8}$$

Furthermore, the following condition must be satisfied at all times;

$$p_1(t) + p_2(t) + p_3(t) + p_4(t) + p_5(t) + p_6(t) = 1 \tag{9}$$

Setting all the derivatives to zero and using (9), the steady state solution is obtained as [1]:

$$p_{1(ss)} = w\mu_m\ \mu_c\ (\lambda_c + \mu_f)/A \tag{10}$$

$$p_{2(ss)} = w\lambda_s\ \mu_m\ \mu_c(\lambda_c + \mu_f)/(\lambda A) \tag{11}$$

$$p_{3(ss)} = \lambda_s\ \delta_w\ \mu_c\ \mu_m(\lambda_c + \mu_f)/A \tag{12}$$

$$p_{4(ss)} = [w\mu_m\ \lambda_s(1-\delta_w)(\lambda_c+\mu_f) + w\lambda_c\lambda_f\mu_m]/A \tag{13}$$

$$p_{5(ss)} = w\ \lambda_m\ \mu_c\ (\lambda_c+\mu_f)/A \tag{14}$$

$$p_{6(ss)} = w\ \lambda_f\ \mu_m\ \mu_c/A \tag{15}$$

where,

$$A = (\lambda_c+\mu_f)[w\mu_m\mu_c\ (1+\lambda_s/\lambda) + \mu_m\ \mu_c\ \lambda_s\delta_w + w\lambda_s\ (1-\delta_w)\mu_m + w\lambda_m\mu_c) + w\mu_m(\lambda_c+\mu_c)\lambda_f \tag{16}$$

All rates can be estimated from system statistical date, therefore, the exact steady state probabilities (10)-(15) are readily obtained.

THE TRANSIENT SOLUTION

Probability differential equations (3)-(8) can be solved step by step giving the time variation of the six probabilities. If time is extended long enough, one always arrive at the steady state solution. Although accuracy is always controlled by the proper choice of method and the size of the time interval, step by step solutions are only approximate; therefore, one does not expect to obtain the true steady state values using this alternative. However, they give a good estimate of the length of the transient period during which the change in the probabilities with time is appreciable.

In solving equations (3)-(8), the Rung-Kutta method with fourth approximation [5] is used. This method needs no repeated approximations or successive integrations. The error produced is of the order of the fifth power of the size of the time interval used.

Furthermore, it is always assumed that the composite component is initially in state (1). This means that:

$$p_1(0) = 1; \; p_2(0) = p_3(0) = p_4(0) = p_5(0) = p_6(0) = 0$$

AN APPLICATION

A 66 KV overhead transmission line which forms a part of the Alexandria area subtransmission grid is considered as a representative component. The different model transition rates of this composite component from line statistical date is given in Table (1).

Table (1). Transition rates of sample transmission line.

λ_s	λ_m	λ_f	λ_c	μ_m	μ_f	μ_c	w	δ_w	λ
1.2	0.15	0.15	0.2	2000	2000	280	8800	0.2	$1.3X10^{8}$

The transient behavior of the six probabilities is shown in Figures (2) and (3). It is evident that it took up to 72 hours for the probabilities to arrive at a steady state. The values of the six probabilities at hour 72 is given in Table (2). Also given are the exact steady state as computed from equations (10)-(15) and the corresponding percentage errors.

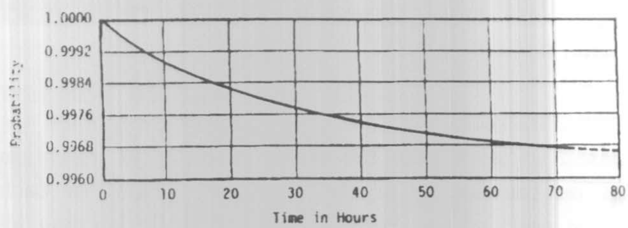

Figure 2. Variation of probability p_1 with time.

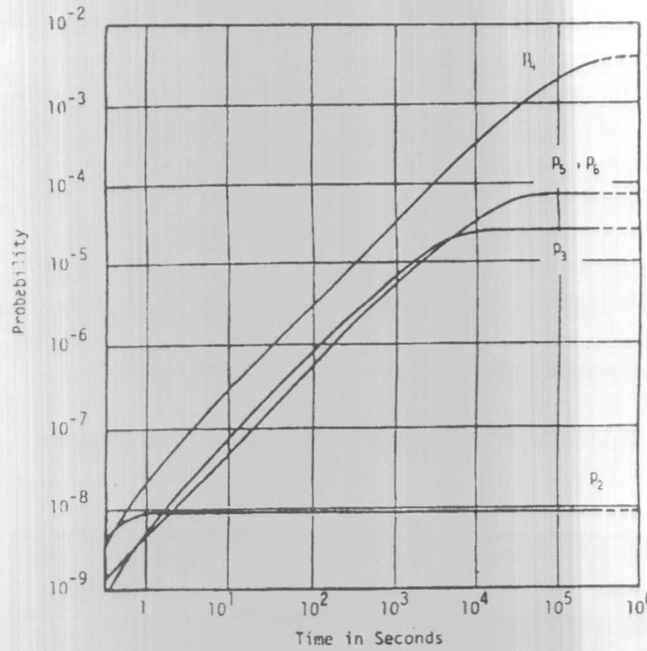

Figure 3. Variation of probabilities p_2 to p_6 with time.

72 hours is quite a long period of time in power system operation, therefore during such period, power system analyst should be prepared to use probability transient values when assessing reliability indices.

	Steady State From Transient solution	Exact Steady State	Percentage Error
p_1	0.99675	0.99641	0.034
p_2	0.9201×10^{-8}	0.9198×10^{-8}	0.034
p_3	0.2718×10^{-4}	0.2717×10^{-4}	0.035
p_4	0.3077×10^{-2}	0.3416×10^{-2}	-9.928
p_5	0.7476×10^{-4}	0.7473×10^{-4}	0.040
p_6	0.7475×10^{-4}	0.7472×10^{-4}	0.040

EFFECT OF TRANSITION RATES ON TRANSIENT PERIOD

Several transient solutions of the sample component are obtained to investigate the effect of different transition rates on the length of the transient period. In each solution one of the rates is changed while keeping all other rates fixed at their values of the base case given in Table (1). Although in each case the steady state probability values have changed, it is found that none of the rates, except the repair rate of the power component μ_c, has an appreciable effect on the length of the transient period. As for the effect of μ_c on that length, the results obtained for seven different values of μ_c, as given in Table (3), clearly show that as the repair of the power component following a failure is accelerated, as indicated by increasing μ_c, the transient period becomes shorter. This justifies, from reliability analysis point of view, the efforts made to accelerate the repair of failed power components and their quick restoration to service.

Table (3). Effect of μ_c on the length of the transient period.

μ_c	70	140	280	450	600	1000	1300
Time to steady state in hours	456.29	186.65	72	35.66	22.59	9.52	6.02

CONCLUSIONS

A previously developed model of the composite power component is used to investigate the behavior of the probability values of the component with time. These values are shown to change with time before arriving to a steady state. This transient period is found to be of such length that power system analysts may need to use probability values different from the steady state in their reliability calculations.

The length of the transient period shown to be affected only by the rate of repair of the failed power component in a way that it becomes shorter, hence less important in analysis, as the rate of repair of the power component becomes larger, emphasizing the importance of accelerated repair of failed power components, at least from the point of view of reliability analysis.

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