

RELIABILITY ANALYSES OF A SELF-HOLDING TYPE RELAY SYSTEM BY A DYNAMICAL EVENT TREE AND THE GO-FLOW METHODOLOGY

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SUMMARY

The authors have developed a system reliability analysis methodology GO-FLOW, which is a success oriented system reliability analysis method. A modeling technique produces a GO-FLOW chart, which represents system configuration, engineering function and system failure phenomena. The GO-FLOW can analyze dynamic systems, and it has been already applied to a hold-up tank problem. In the present paper, a self-holding type relay system is taken up as an example of a dynamic system, and analyses are performed by the GO-FLOW methodology and by a dynamical event tree which has been developed for the analysis of dynamical system behavior and presented at PSAM4.

Self-holding type relay systems are widely used for switching on/off of an engineering system and secures to prevent the unintentional restart of an engineering system after the recovery of electrical power source. If failure occurs for each component, the intended function will not be satisfied with a certain probability. The purpose of the present analysis is to quantify the time series of mission success probability.

It is shown that the dynamical event tree can treat a self-holding type relay system. But, for the modeling of this relay system, we have to make two event trees. The first one is for the actuation by the first switch and following event sequence, and the second one is for self-holding sequence by the second relay.

Analysis by the GO-FLOW is also performed. A self-holding type relay system is easily modeled into a GO-FLOW chart. The GO-FLOW automatically identifies all the possible combinations of component failures, that is, all the possible system states or all the possible sequences with component actions and failures.

Comparison of the analysis procedures shows us the advantages of the GO-FLOW. Modeling of the GO-FLOW is straightforward and well corresponds to the layout of the relay system.

INTRODUCTION

The authors have developed a system reliability analysis methodology GO-FLOW[1], which is a success oriented system reliability analysis method. A modeling technique produces a GO-FLOW chart, which represents system configuration, engineering function and system failure phenomena. The GO-FLOW can analyze dynamic systems, and it has been already applied to the hold-up tank problem [2]. In the present paper, a self-holding type relay system is taken up as an example of a dynamic system, and analyses are performed by the GO-FLOW methodology and by a dynamical event tree [3]. It is shown that the dynamical event tree can also treat this relay system. Comparison of the analysis procedures shows us the advantages of the GO-FLOW. Modeling of the GO-FLOW is straightforward and well corresponds to the layout of the relay system. The GO-FLOW automatically identifies all the possible combinations of component failures, that is, all the possible system states or all the possible sequences with component actions and failures.

SELF-HOLDING TYPE RELAY SYSTEM

Self-holding type relay systems are widely used for switching on/off of an engineering system safely. Figure 1 shows a typical example of self-holding type relay system. At the initial state, electric power is not supplied to the bulb as shown in figure 1. First, push on a button of switch A, then switch A is closed to energize a relay 1 and a contact of relay 1 is closed. Relay 2, which is connected in series with a contact of relay 1, is energized to close a contact of relay 2. The electric power is supplied to a bulb through both the contacts 1 and 2.

Usually the switches A and B are designed as self-return type switches. After releasing the button, switch A becomes open state with the self-return mechanism. Even if, the switch A opens, the power supply to the bulb is maintained by self-holding of the relay 2, that is, through the contact of relay 2. In this state, on/off actions of the switch A do not make any effect to the bulb lighting condition.

If the switch B is opened, the relay 2 is de-energized to open the contact of relay 2. Then, the power supply to the bulb is interrupted.

Usually, the switch A is used as a start button of an operation of some electrical system(bulb), and the switch B is used for the stop button. This self-holding type relay system secures to prevent unintentional restart of an engineering system after the recovery of electrical power source. If failure occurs for each component, the intended function will not be satisfied with a certain probability. The purpose of the present analysis is to quantify the time series of mission success probability.

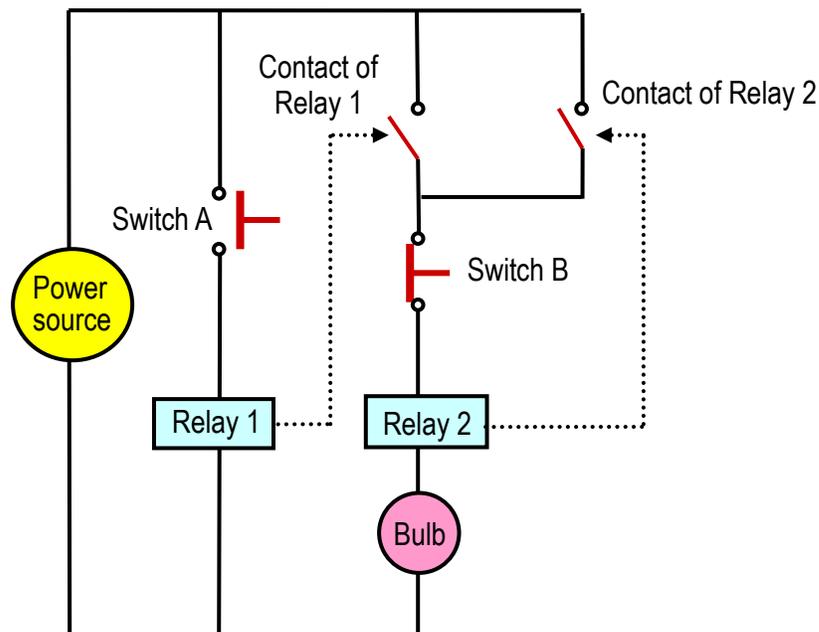


Figure 1. Self-holding type relay system (Initial state)

Failure Data

In the present analysis, failure rates or demand probabilities for components are assigned as shown in table 1.

Table 1. Data assigned in the Present Analysis

Components	Failure modes	Failure rates/probabilities or Demand Probabilities
Battery	Failure of power supply	0.003/h
Switch A	Premature closed	0.05
	fails to close	0.07/D
	fails to return open	0.03/D
Switch B	Premature open	0.05
	fails to open	0.07/D
	fails to return closed	0.03/D
Contact of Relay 1	Stick closed	0.05
	fails to close	0.05/D
Contact of Relay 2	Stick closed	0.05
	fails to close	0.05/D
Bulb	Bulb failure	0.003/h

ANALYSIS BY A DYNAMICAL EVENT TREE

A dynamical event tree[3] has been developed in order to treat dynamic operational phenomena of an engineering system with time progresses, and it has following functions.

- (1) Introduction of the time points in the event tree analysis framework: Occurrence probabilities of event sequences are calculated for all the time points.
- (2) Same event can be placed at multiple places in the event tree.
- (3) Dependency between headings can be given for more than two events by defining conditional occurrence probabilities.
- (4) Automatic rearrangement of heading order
- (5) Combination with the GO-FLOW: Analysis results by the GO-FLOW can be directly used as data for the headings in the event tree.

This dynamical event tree can model the self-holding type relay system. First, we define the time points for the expression of event sequence, as shown in Table 2.

Table 2. Time Points defined in the Analysis

Time points	Actual Time (hours)	Actions
1	0	Initial time
2	0	Switch A close action, Relay 1 & 2 are energized.
3	0	Switch A is re-opened.
4	10	10 hours after time point 3.
5	10	Switch B open action, Relay 2 is de-energized.
6	10	Switch B is re-closed.
7	20	10 hours after time point 6.

For the modeling of this event sequence, we have to make two event trees. The first one is for the actuation by switch A and following event sequence, and the second one is for self-holding sequence by relay 2.

Figure 2 shows the first event tree. Branching probabilities of headings are calculated from tables 1 and 2 for all the time points from 1 to 7. For the heading "Contact of Relay 1 good", the value of 0.05 is given as the failure probability(stick closed) for all the time points. For the headings "Contact of Relay 2 good" and "Contact of Relay 1 close by Demand", the value of 0.05 is given also for all the time points. For the headings "Battery normal" and "Bulb normal", the values of 0.0, 0.0, 0.0, 0.0296, 0.0296, 0.0296, 0.0582 are given for the time points 1,2,3,4,5,6,7, respectively, as both the battery and bulb have same failure rate 0.03/h. For the heading "Switch A close state", the values of 0.95, 0.0285, 0.932, 0.932, 0.932, 0.932, 0.932 are given for the time points 1,2,3,4,5,6,7, respectively.

These values are calculated from "Premature closed" probability (0.05), "fails to close" probability (0.07) and " fails to return open" probability (0.03). For the heading "Switch B close state", the values of 0.05, 0.05, 0.05, 0.05, 0.9715, 0.068, 0.068 are given for the time points 1,2,3,4,5,6,7, respectively.

In this event tree, the sequences A, C and D are the state "Bulb is lighting". By this dynamical event tree, the occurrence probabilities of each sequence are obtained for all time points, in this case from time points 1 to 7.

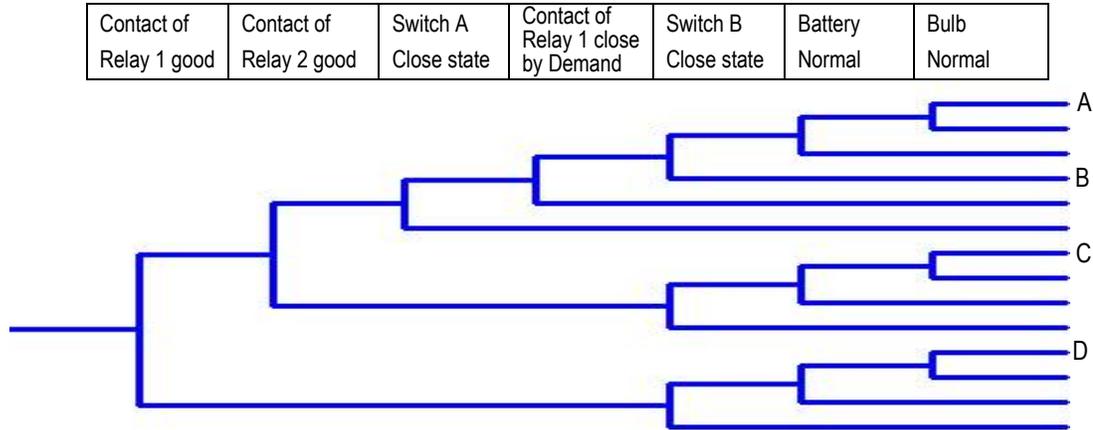


Figure 2. Event Tree for Switch A Close Action and Following Sequence

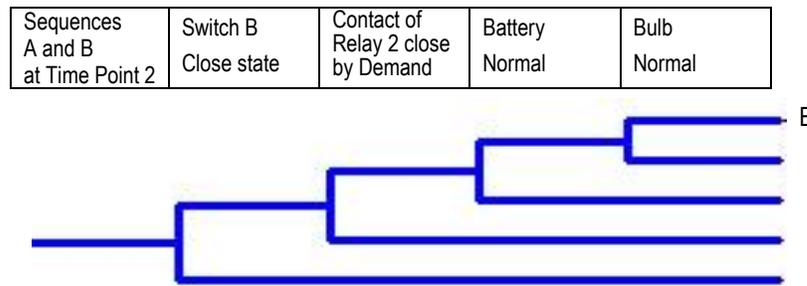


Figure 3. Event Tree for Self-Holding State by Relay 2

Figure 3 shows the second event tree, which expresses the self-holding state by the relay 2. At time point 2, sequences A and B in the first event tree establish the condition of self-holding by the relay 2. Second event tree has the time points from 3 to 7, because self-holding starts after time point 3.

Occurrence probability of "Sequences A and B at time point 2" is obtained from the first event tree as 0.8339 (A:0.7913, B:0.04165). For the heading "Switch B close state", the values of 0.05, 0.05, 0.9715, 0.068, 0.068 are given for the time points 3,4,5,6,7, respectively. For the headings "Contact of Relay 2 close by Demand", the value of 0.05 is given as the failure probability(fails to closed) for all the time points. For the headings "Battery normal" and "Bulb normal", the values of 0.0, 0.0296, 0.0296, 0.0296, 0.0582 are given for the time points from 3 to 7.

In this event tree, the sequence E is the state "Bulb is lighting" by self-holding of relay 2.

Analysis Results

This dynamical event tree gives the occurrence probabilities of every sequences for all the defined time points as shown in Table 3. Total probabilities of "Bulb is lighting" in this relay system are obtained by summing up the results of sequences A, C, D and E in the two event trees. In this process, an analyst has to judge inclusion-exclusion relations among the sequences A, C, D and E. The values in the blue and yellow shadow cells are summed up for the calculation of the total probabilities. Sequences A and E at time points 6 and 7 (yellow shadow cells) have a possibility to occur at the same time, so the contribution from the cross-linking of A and E are subtracted from the values of simple summation of A,C,D and E.

Table 3. Occurrence Probabilities of Sequences in the Event Tree and GO-FLOW Result

Sequence	Time Points						
	1	2	3	4	5	6	7
A	0.0473	0.7913	0.05539	0.05216	0.001565	0.05117	0.04819
C	0.04513	0.04513	0.04513	0.0425	0.001275	0.04169	0.03926
D	0.0475	0.0475	0.0475	0.04473	0.001342	0.04389	0.04133
E			0.7517	0.7079	0.02124	0.02124	0.02
Total	0.1334	0.8839	0.8443	0.7951	0.02386	0.1569	0.1479
GO-FLOW	0.1332	0.8839	0.8471	0.7978	0.02398	0.1565	0.1480

ANALYSIS BY THE GO-FLOW

The GO-FLOW methodology is applied to the evaluation of the mission success probability of this relay system. The system can be easily modeled into a GO-FLOW chart as shown in the figure 4. Failure data and time points given in tables 1 and 2 are also used in the GO-FLOW analysis.

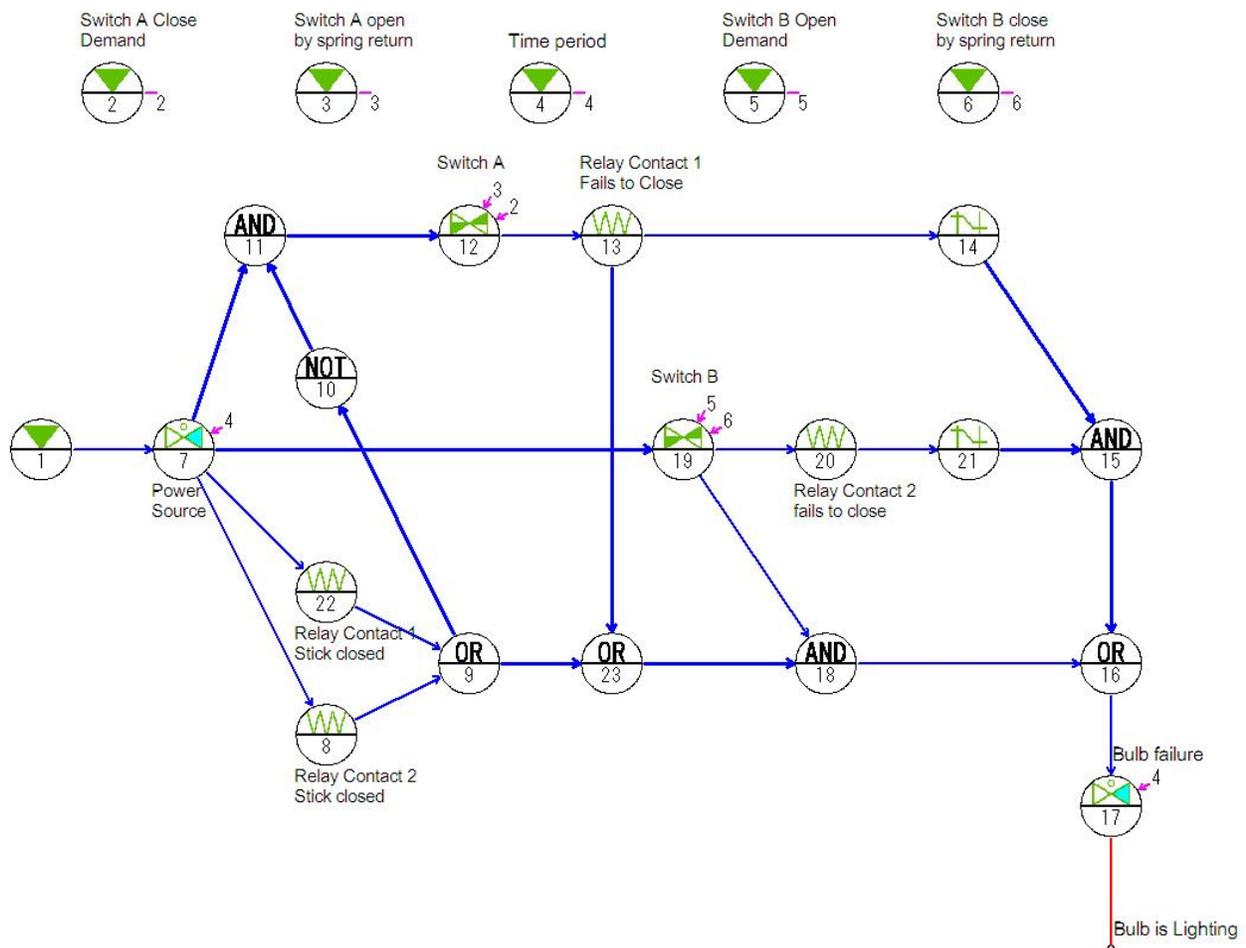


Figure 4. GO-FLOW Chart for Self-Holding Type Relay System

Meanings and functions of operators used in this GO-FLOW chart is explained in reference [1] or the paper "The use of the GO-FLOW Methodology to Investigate the Aging Effects in Nuclear Power Plants" presented at this conference, PSAM8.

Here, we briefly explain the meanings of operators and signal lines in figure 4. Signal line 7 represents the electric power supply. Signal line 9 represents that both or one of the relay contacts are stick closed, and signal line 10 represents that both the relay contact are normal condition. Signal line 13 represents that electric power is supplied to switch B through the contact of relay 1. Signal line 23 represents that electric power is supplied to switch B through the contacts of relay 1 or relay 2. Signal line 19 represents that switch B is in closed state, and then Signal line 18 represents that the electric power is supplied to bulb. But, this signal line does not contain the contribution from the close action of the contact of relay 2, which makes the self-holding condition.

Number 14 operator is a “Phased mission operator”, and it freezes up the intensity of signal 13 at time point 2 (probability that the electric power is supplied to switch B through contact of relay 1 with normal close action) to the intensities from time points 3 to 7. At time point 2, self-holding state is established by closing of contact of relay 2. Signal line 15 represents the electric power supply through self-holding pass(through the contact of relay 2, switch B and relay 2). At time point 3, Switch A is returned to open, but the electric power is continued to supply to bulb through the established self-holding pass. This situation is represented by the signal line 15, because signal line 14 is converted by the phased mission operator No.14.

At time point 5, the switch B is opened and the contact of relay 2 becomes open. Then, self-holding pass disappears. Once, self-holding pass disappears, electric power is not supplied to bulb through the contact of relay 2 even if the switch B is again closed. This situation is represented by the signal line 21 that is converted from signal 20 by a phased mission operator, which freezes up the intensity of signal 20 at time point 5 to the intensities from time points 6 to 7.

After the preparation of GO-FLOW chart with failure data and analysis conditions, the GO-FLOW analysis support system automatically produces input data for GO-FLOW analysis program written in FORTRAN. The GO-FLOW automatically identifies all the possible combinations of component failures, that is, all the possible system states or all the possible sequences with component actions and failures. The function of the GO-FLOW program can judge inclusion-exclusion relations between signal lines.

The analysis results are shown in table 3. They are well in agreement with the values obtained by the dynamical event trees. The figure 5 shows how the probability of "bulb on state" changes with time. The figure 5 shows the analysis results by the GO-FLOW. The results by the dynamical event tree is exactly the same line to that of GO-FLOW on this figure.

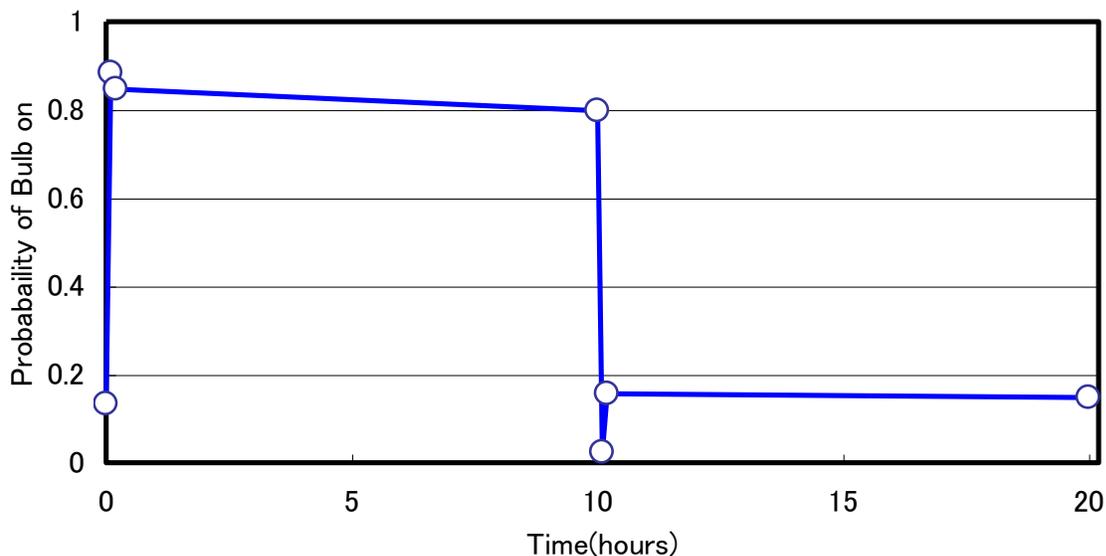


Figure 5. Probability of Bulb On State (by GO-FLOW)

CONCLUSIONS

A self-holding type relay system has been taken up as an example of dynamic system. Analysis procedure by the dynamical event tree has been explained in detail. It has been shown that the dynamical event tree could analyze

this self-holding type relay system. Analysis by the GO-FLOW has been also performed. This self-holding type relay system was easily modeled in a GO-FLOW chart. Brief explanations are given for the signal lines and operators appeared in the GO-FLOW chart.

Comparison of the analysis procedures shows us the advantages of the GO-FLOW, of which modeling technique is straightforward and well corresponds to the layout of the relay system. The GO-FLOW automatically identifies all the possible combinations of component failures, that is, all the possible system states or all the possible sequences with component actions and failures. Furthermore, the GO-FLOW program judges the inclusion-exclusion relation between system states.

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