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Probabilistic Operation of Electric Power Systems Considering Environmental Constraint (Part 11)*

—System Security of DSS Operation—

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Abstract

The estimation method of the state probability of a thermal unit is described when the thermal unit starts up and shuts down. Since the state probability is affected by the past operation history, estimation equations are described separately depending on whether the thermal unit is before shutdown, during scheduled shutdown or after re-startup. Although failure is neglected practically in the period of transition before shutdown, failure is considered in the period of transition before re-start up.

Considering daily operations, some simulations are concretely examined by a model system. An improvement in the power supply probability is checked by a proposed method previously reported.

1. Introduction

A fast scheduling method was reported previously[1] to satisfy every line capacity and NO_x emission constraint.

In this report, an estimation method is described for the state probability of daily start and stop (DSS) thermal units. The state probability is considered separately depending on the kinds of scheduled state. That is, the state probability is estimated by different equations depending on whether it is the operating state before shutdown, the scheduled shutdown state or the operating state after re-startup. A relationship is shown between the shutdown time and the state probability of the thermal unit after re-startup. Power supply is achieved by the previous method and power supply probability is estimated for daily operation in this report.

The proposed method is applied to a model system, and some simulations are examined when a start and stop pattern is specified for the thermal units.

2. Definition of Failure Rate and Repair Rate

Investigation of records of the past operation for elements in the power system should provide a mean time of healthy operation and a mean time of

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outage state. They are denoted by T_{health}, and T_{outage} respectively. T_{health} means the average time from just after operation starts to a forced outage regardless of each cause. T_{outage} means the average time from the forced outage to completion of a repair.

The failure rate p_{fail} and the repair rate p_{repair} are defined as follows[2)] respectively.

$$p_{fail}=\frac{1}{T_{health}} \tag{1}$$

$$p_{repair}=\frac{1}{T_{outage}} \tag{2}$$

Where, p_{fail} means that the forced outage is likely to occur p_{fail} times on average during a unit time of the healthy state. The meaning of p_{repair} is similar.

3. The Healthy State Probability of an Operating Thermal Unit

When an infinitesimal time dt is considered, the healthy state is introduced in two ways at $t+dt$. The first is a continuous healthy state, in which the thermal unit was healthy at t previously and forced outage does not occur during continuous dt. The second way is the repair case, in which the unit was in outage at t previously and is repaired during continuous dt. When $s_{on}(t+dt)$ denotes the healthy state of the operating unit at $t+dt$, it is estimated by eq. (3).

$$s_{on}(t+dt)=s_{on}(t)\cdot(1-p_{fail}\cdot dt)+\left\{1-s_{on}(t)\right\}\cdot p_{repair}\cdot dt \tag{3}$$

When differential equation (3) is solved, eq. (4) is obtained.

$$s_{on}(t)=s_{on}(0)\cdot e^{-(p_{fail}+p_{repair})\cdot t} + \frac{p_{repair}}{p_{fail}+p_{repair}}\cdot\{1-e^{-(p_{fail}+p_{repair})\cdot t}\} \tag{4}$$

Where, $s_{on}(0)$ is the initial condition. For the sake of convenience in this report, the operating time is assumed to be sufficiently long before the thermal unit shuts down at the first. Then the healthy state probability becomes eq. (5) and is dependent on neither the operating time nor the initial condition $s_{on}(0)$.

$$s_{on}(t)=\frac{p_{repair}}{p_{fail}+p_{repair}} \tag{5}$$

Eq. (5) also estimates the healthy state probability of each transmission line because they do not shutdown and originally have a sufficiently long operating time.

4. Healthy State Probability During Shutdown

We may have to consider the fail probability in the period of transition leading shutdown, strictly speaking, but the proposed method assumes that it can be practically neglected[3].

The healthy state probability during shutdown can also be introduced similarly to eq. (4). When the shutdown of the thermal unit is started at t_1 and the healthy state probability is denoted by $s_{\text{off}}(t)$ at $t(>t_1)$, it becomes as follows:

$$s_{\text{off}}(t)=s_{\text{on}}(t_1)\cdot e^{-(p_{\text{fail}}+p_{\text{repair}})\cdot(t-t_1)} + \frac{p_{\text{repair}}}{p_{\text{fail}}+p_{\text{repair}}}\cdot\{1-e^{-(p_{\text{fail}}+p_{\text{repair}})\cdot(t-t_1)}\} \quad (6)$$

Where, a value of $s_{\text{on}}(t_1)$ is obtained by eq. (5) because of the assumption. Values of p_{fail} and p_{repair} must be respectively used values during shutdown in eq. (6), which should be obtained by an investigation of the mean times of healthy state and outage state during shutdown.

Since the power supply probability does not depend on the state of the shutdown units, $s_{\text{off}}(t)$ does not need to be estimated each time.

5. Healthy State Probability After Starting Up

In the period of transition leading to start up, outage may occur in thermal units. The frequency of this occurrence is denoted by p_{up}. When the thermal unit starts up at $t_2(>t_1)$, the healthy state probability becomes $(1-p_{\text{up}})\cdot s_{\text{off}}(t_2)$ just after starting up. At $t(>t_2)$, the healthy state probability becomes as follow.

$$s_{\text{on}}(t)=(1-p_{\text{up}})\cdot s_{\text{off}}(t_2)\cdot e^{-(p_{\text{fail}}+p_{\text{repair}})\cdot(t-t_2)} + \frac{p_{\text{repair}}}{p_{\text{fail}}+p_{\text{repair}}}\cdot\{1-e^{-(p_{\text{fail}}+p_{\text{repair}})\cdot(t-t_2)}\} \quad (7)$$

Where, p_{fail} and p_{repair} are the failure rate and the repair rate respectively during a thermal unit's operation.

6. Power Supply Probability

The power supply probability is estimated by summing up the individual system state probabilities which can supply power. The system states may supply power when every line capacity is satisfied by a previously reported method[1]. The system state probability is estimated by the multiplication by the state probabilities of individual lines and the state probabilities of each thermal unit, excepting units scheduled as shutdown.

In this report, a simultaneous outage is estimated only when one thermal unit and one line fall into outage simultaneously. Every single outage which is only one line outage or only one unit outage is checked. For other cases it is assumed that power supply is impossible without practical estimation, in this proposed method.

7. Simulations by a Model System

The same model system was used for simulations as in a previous paper[4]. Table 1 shows the probabilistic data for thermal units about states of both opera-

Table 1. Failure rate and repair rate of thermal units

Thermal unit	Scheduled operation		Scheduled shutdown		Failure frequency for start up
	failure	repair	failure	repair	
1	0.0006	0.02	0.0005	0.02	0.01
2	0.0005	0.02	0.0004	0.02	0.01
3	0.0004	0.02	0.0003	0.02	0.01
4	0.0004	0.02	0.0003	0.02	0.01
5	0.0003	0.02	0.0002	0.02	0.01

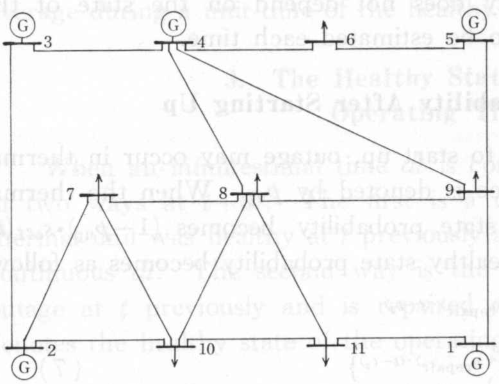

Fig. 1. Model power system.

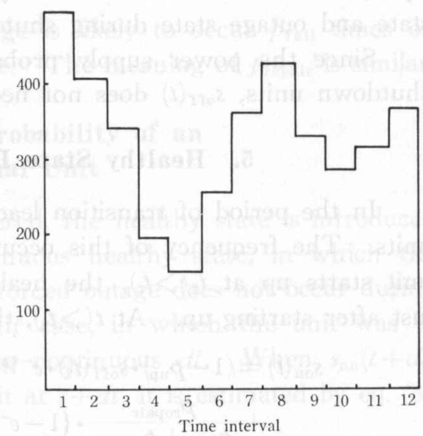

Fig. 2. Load curve.

Table 2. Economic operation by deterministic start and stop pattern

Time interval	thermal unit 1	2	3	4	5	Power supply probability [%]	Expected value Cost	Emission
1						76.28	3262.9	704.38
2						78.03	2774.5	602.38
3						79.91	2413.7	527.18
4	×	×				81.78	1449.1	366.54
5	×	×				84.71	1199.2	303.34
6	×	×				78.85	1753.4	443.48
7						77.92	2480.7	540.70
8						76.18	2804.1	608.10
9						79.81	2345.9	512.92
10	×	×				78.85	1953.4	494.06
11						79.69	2246.2	491.96
12						77.83	2509.5	546.72

Table 3. Optimum operation by probabilistic start and stop pattern

Time interval	thermal unit 1	2	3	4	5	Power supply probability [%]	Expected value Cost	Emission
1						84.32	3607.4	778.90
2						88.85	3159.8	685.66
3				×		80.79	2404.0	504.16
4		×		×		85.00	1508.3	296.36
5	×	×		×		85.80	1160.8	301.54
6	×	×				85.43	1900.1	480.46
7		×				75.79	2380.8	516.16
8						88.65	3264.2	707.40
9		×				84.40	2444.6	522.96
10	×	×				81.05	2007.8	507.86
11	×	×				79.60	2178.3	550.72
12			×			87.29	2789.4	560.18

tion and shutdown. The deterministic constants of each thermal unit were already shown in the previous paper. Fig. 1 shows the model system, and Fig. 2 shows a load curve during a day.

The results of Table 2 were obtained by the following assumptions and conditions. The start and stop pattern of each thermal unit were determined simply economically. That is, that a forced outage never occurred on any power line or any thermal unit, that the capacity of each power line was sufficiently large and that the emission was not constrained. A unit commitment at each time interval was constructed according to this economic pattern. The output power of each thermal unit was always decided by the economic load dispatch at each system state. System states were constructed for each outage of the thermal units and the power lines considered probable to occur according to the data of the model system. In the table, a symbol × means the scheduled shutdown of the thermal unit, and a blank means the scheduled operation.

On the other hand, the start and stop pattern of Table 3 was determined by considering each forced outage and each line's capacity. That is, the unit commitment was selected at each time interval so that the expected value of the operating cost became minimum when every line capacity was satisfied by the proposed method[1] with each kind of system state. From tables 2 and 3, an improvement can be seen for the power supply probability using the proposed method at almost every time interval. Exceptions were the 7th and 11th time intervals.

In future, we shall develop a decision method for the optimum start and stop pattern of a thermal unit considering the system security and the emission constraint.

8. Conclusion

An estimation method was described for the state probability of each thermal unit when the thermal units shut down and start up. It was also shown that the state probability must be separately estimated when the thermal unit is before shutdown, during scheduled shutdown or after restartup. Three kinds of equations were shown to estimate each state probability.

The results of simulations were shown concretely for daily operation of a model power system. The improvement of the power supply probability was shown by using a previously reported proposed method.

Since the state probability depends on the past operation state, we consider that a simple multistage choice process may not be able to determine the optimum start and stop pattern.

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