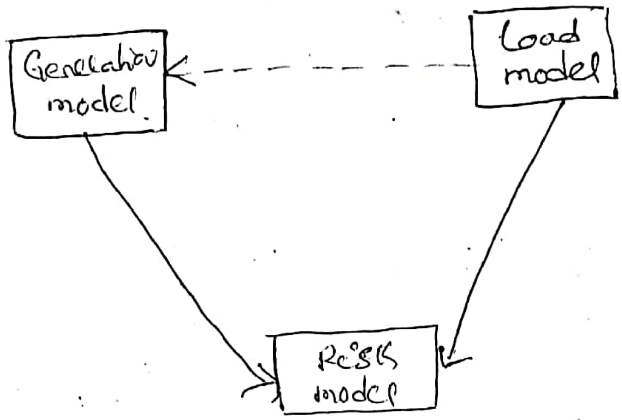
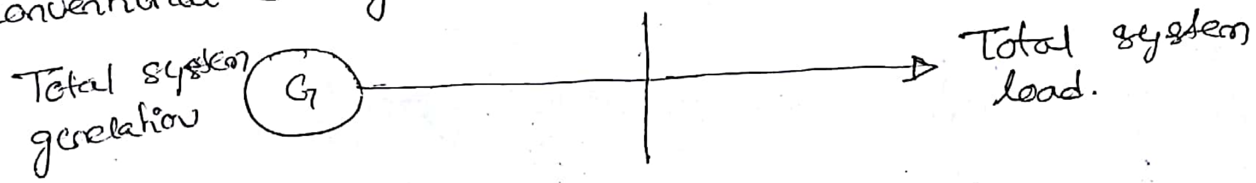
UNIT-VI

Generation System Reliability Analysis :- ①

The basic approach to evaluating the adequacy of a particular generation configuration is fundamentally the same as any technique shown in fig.



The generation and load models shown in fig are combined to form the appropriate risk model. The calculated indices in this case do not reflect generation deficiencies at any particular customer load point but measure the overall adequacy of the generation system. Specific load point can be done in composite system reliability evaluation. The system representation in a conventional study is shown in fig.



Generation system model :-

Generating unit unavailability :

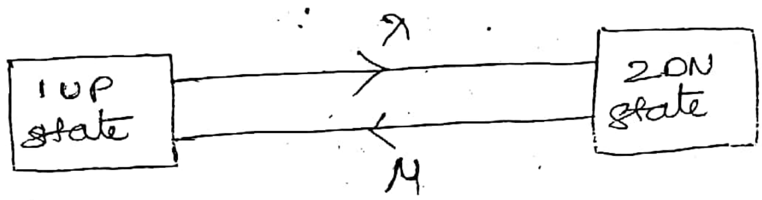
The basic generating unit parameter used in static capacity evaluation is the probability of finding the unit as forced outage rate at some distant time in the future. This probability is unit unavailability and in power system applications called as Forced outage rate.

$$\text{unavailability } U = \frac{\lambda}{\lambda+\mu} = \frac{r}{m+r} = \frac{r}{T} = \frac{f}{\mu}$$

$$= \frac{\sum_f \text{down time}}{\sum_f \text{down time} + \sum_f \text{up time}}$$

$$\text{Availability } A = \frac{\mu}{\lambda+\mu} = \frac{m}{m+r} = \frac{m}{T} = \frac{f}{\lambda}$$

$$= \frac{\sum_f \text{up time}}{\sum_f \text{up time} + \sum_f \text{down time}}$$



where
- λ = expected failure rate
- μ = expected repair rate
- m = mean time to failure = MTTF = $\frac{1}{\lambda}$
- r = mean time to repair = MTTR = $1/\mu$
- $m+r$ = mean time b/w failures = MTBF = $1/f$
- f = cycle frequency = $1/T$
- T = cycle time = $1/f$

System Model :-
In the first and simplest model it is assumed that n identical generating units are installed in a system. It is also assumed that all units are independent i.e they can fail, and be repaired independently of the failures and repairs of the other units. A state space model for a system of four identical, independent units is shown in fig.
In general, if the total number of units n, the probability P_g of state g where g units have failed out of n is given by

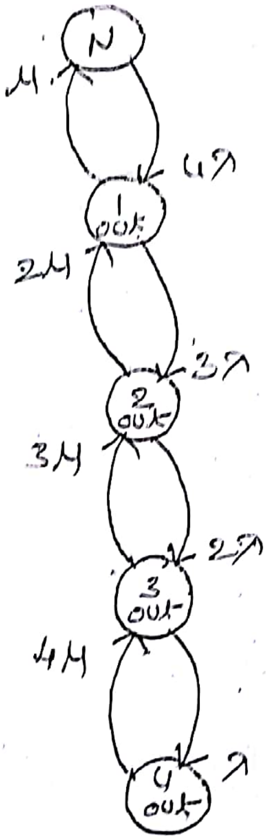
$$P_g = \binom{n}{g} \bar{A}^{g} A^{n-g}$$

where $\bar{A}$ is the unavailability of a unit, and $A = 1 - \bar{A}$ is the availability. The frequency of state g is (2)

$$f_g = P_g(\lambda_{g+} + \lambda_{g-})$$

where λ_{g+} is the transition rate from state g to the states with a lower 'g' index (higher capacity states) and λ_{g-} is the transition rate from state g to the states with a higher 'g' index (lower capacity states). In the given case

$$\lambda_{g+} = g\mu \qquad \lambda_{g-} = (N-g)\lambda$$



A model of four identical, independent generating units.

1. Sequential Addition Method :-

Recursive algorithm for capacity model building :-

Let X MW capacity outage state of a unit

U unavailability (forced outage rate)

C MW capacity of unit added

$P(X)$ = cummulative probability of a particular capacity outage state of x when 'c' unit of MW unit is added

$P'(X)$ = cummulative probability of a particular capacity of x before the unit is added.

<u>Assumption</u> :-

$P'(X) = 1.0$ for $x \leq 0$

$P'(X) = 0$ otherwise

$$P(X) = (1 - U)\, P'(X) + U\, P'(X - C)$$

1. In a generating system there are 3 units of capacities two, 25 MW and one 50 MW respectively, each has a failure rate of 0.01 failures/day and repair rate of 0.49 repairs/day using sequential addition method. determine the capacity outage cummulative probability table.

<u>Sol</u>

$\lambda = 0.01$ F/day

$\mu = 0.49$ R/day

1	2	3
25	25	50

$$A = \frac{\mu}{\lambda+\mu} = \frac{0.49}{0.49+0.01} = 0.98$$

$$U = 1 - A = 0.02$$

<u>Step 1</u> : Add the first unit

$x = 0$

$$P(0) = (1 - 0.02)(1) + 0.02(1) = 1.0$$

$x = 25$

$$P(25) = (1 - 0.02)(0) + 0.02(1) = 0.02$$

Step 2 : Add the second unit of 25 MW $\quad x = 25$, $c = 25$

$p(0) = (1 - 0.02) 1 + 0.02 (1) = 1.0$ ②

$p(25) = (1 - 0.02)(0.02) + 0.02(1)$

$= 0.0396$

$p(50) = (1 - 0.02)(0) + 0.02 \times 0.02$

$= 0.0004$

From COPT

	Cap out in MW	Ind prob	Cum prob
Step 1 :	0	0.98	1.0
	25	0.02	0.02
Step 2 :	0	$(0.98)^2$	1.0
	25	$(2)(0.98)(0.02)$	0.0396
	50	$(0.02)^2$	0.0004

Step 3 : Add 50 MW unit

$= (1 - 0.02)(1) + 0.02(1) = 1.0$

$p(0) = (1 - 0.02)(0.0396) + 0.02(1) = 0.058808$

$p(25) = (1 - 0.02)(0.0004) + 0.02(1) = 0.020392$

$p(50) = (1 - 0.02)(0.0006) + 0.02(1) = 0.020392$

$p(50) = (1 - 0.02)(0) + 0.02 \times 0.0396 = 0.000792$

$p(75) = (1 - 0.02)(0) + 0.02 \times 0.0004 = 0.000008$

$p(100) = (1 - 0.02)(0) + 0.02 \times 0.0004$

From COPT :

Cap in (MW)	Cap out (MW)	Ind prob	Cum prob
100	0	$(0.98)^3 = 0.941192$	1.0
75	25	$2A^2U = 0.038416$	0.058808
50	50	$A^2U + AU^2 = 0.0196$	0.020392
25	75	$2AU^2 = 0.000784$	0.000792
	100	$U^3 = 0.000008$	0.000008

2. For unit Removal :-

$$P(X) = (1-U)\,P'(X) + U\,P'(X-C)$$

$$P'(X) = \frac{P(X) - U\,P'(X-C)}{1-U}$$

$$P'(X-C) = 1.0 \text{ for } x \le C$$
$$= 0 \quad \text{otherwise}$$

continuation of pb (1)

(2) Now consider 50 MW unit is removed from COPT, formulate the capacity outage cumulative probability table.

Sol Consider that 50 MW unit to be removed

$x=0 \quad P'(0) = \dfrac{1 - 0.02(1)}{0.98} = 1.0$

$x=25 \quad P'(25) = \dfrac{0.058808 - 0.02(1)}{0.98} = 0.0396$

$x=50 \quad P'(50) = \dfrac{0.020392 - 0.02(1)}{0.98} = 0.0004$

Sequential Addition Method :-

(for derated states)

For 'n' states called multi state representation

For determining COCPT

$$P(X) = \sum_{i=1}^{n} P_i \; P'(X - C_i) \rightarrow (1)$$

P_i — probability of i^{th} unit

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where n = no of unit states

C_i = capacity outage of state i (a) of unit being added.

P_i = probability of existance of the unit state 'i'

For 2 state model

$$P(X) = (1-U)\,P'(X) + U\,P'(X - C_i) \quad \rightarrow (2)$$

when $n = 2$ eq (1) becomes eq (2).

Ex3. Consider the system having 2 units of 25MW & one 50MW unit having a failure rate of 0.01 f/day and 0.49 repairs/day. consider that 50MW unit has 3 state model with probabilities given as

state	Capacity out (C_i)	state prob (P_i)
1	0	0.96
2	20	0.033
3	50	0.007

Sol step 1 : Add the first unit of 25MW

$= (1-0.02)(1) + 0.02(1) = 1.0$

$p(0) = (1-0.02)(1) + 0.02(1) = 0.02$

$p(25) = (1-0.02)(0) + 0.02(1)$

step 2 : Add the second unit of 25MW

$= (1-0.02)(1) + 0.02(1) = 1.0$

$P(0) = (1-0.02)\,0.02 + 0.02(1) = 0.0396$

$p(25) = (1-0.02)\,0.02 + 0.02(1) = 0.0396$

$p(50) = (1-0.02)(0) + 0.02(0.02) = 0.0004$

step 3 : Add 50 MW unit

$= 0.96 \times 1.0 + 0.033 \times 1.0 + 0.007 \times 1.0 = 1.0$

$P(0) = 0.96 \times 1 + 0.033 \times 1 + 0.007(1) = 0.048016$

$P(20) = 0.96 \times 0.0396 + 0.033 \times 1 + 0.007 \times 1$

$P(25) = 0.96 \times 0.0396 + 0.033 \times 0.0396 + 0.007 \times 1$

$= 0.0463228$

$P(45) = 0.96 \times 0.0004 + 0.033 \times 0.0396 + 0.007 \times 1$
$= 0.0086908$

$P(50) = 0.96 \times 0.0004 + 0.033 \times 0.0004 + 0.007 \times 1$
$= 0.0073972$

$P(70) = 0.96 \times 0 + 0.033 \times 0.0004 + 0.007 \times 0.0396$
$= 0.000290$

$P(75) = 0.96 \times 0 + 0.033(0) + 0.007 \times 0.0396$
$= 0.0002772$

$P(100) = 0.96 \times 0 + 0.033 \times 0 + 0.007 \times 0.0004$
$= 0.0000028$

Loss of Load Indices :-

Evaluation of Loss of load expectation (LOLE) :-

The simplest load model and one that is used quite extensively is one in which each day is represented by its daily peak load. The individual daily peak loads can be arranged in descending order to form a cumulative load model which is known as the daily peak load variation curve. The resultant model is known as the load duration curve when the individual hourly load values are used, and in this case the area under the curve represents the energy required in the given period. This is not the case with the daily peak load variation curve.

The individual daily peak loads can be used in conjunction with the capacity outage probability table to obtain the expected number of days in the specified period in which the daily peak load will exceed the available capacity. The index in this case is designated as the loss of load expectation (LOLE).

(i) Depending on type of load Condition :- (5)

peak load in (MW)

expected No of occurrances in a year

$$LOLE = \sum_{i=1}^{n} x_i P_i (C_i - L_i).\text{days/period}$$

where x_i is the number of times of occurence of peak load over a particular period

C_i is the available capacity of a generating station

L_i is the load level 'i'

P_i is the cumulative probability

$(C_i - L_i)$

1. Consider there are 2 generating units of 25MW each and a one 50MW unit in a generating station. The failure rate of each unit is 0.01/day and repair rate of 0.49 r/day. The load data is

peak load (MW)	57	52	46	41	34
No of occurences in a year	12	83	107	116	47

Compute loss of load expectation (LOLE).

Sol we know

$$LOLE = \sum_{i=1}^{n} x_i P_i (C_i - L_i)$$

COPT :

Cap out in MW	cap in in MW	Individual probability	Cumulative probability
0	100	$A^3 = 0.941192$	1.0
25	75	$2A^2U = 0.038416$	0.058806
50	50	$AU^2 + A^2U = 0.0196$	0.020392
75	25	$2AU^2 = 0.000784$	0.000792
100	0	$U^3 = 0.000008$	0.000008

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$$A = \frac{\mu}{\lambda+\mu} = \frac{0.49}{0.01+0.49} = 0.98$$

$$U = 1 - A = 0.02$$

$$LOLE = \sum x_i P_i (c_i - L_i)$$

$$= 12\,P(100-57) + 83\,P(100-52) + 107\,P(100-46) + 116\,P(100-41) + 47\,P(100-36)$$

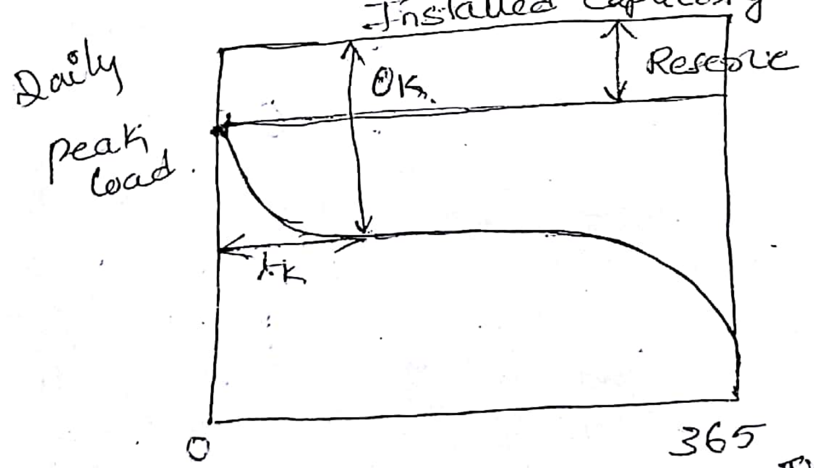
$$= 12(0.020392) + 83(0.020392) + 107(0.000792) + 116(0.000792) + 47(0.000792)$$

$$= 2.15108 \text{ days/year}$$

2. <u>Given daily peak load duration curve</u> :-

1. <u>Linearised</u> :-

Fig shows a typical system load - capacity relationship where the load model is shown as a continuous curve for a period of 365 days.



$$LOLE = \sum_{K=1}^{N} P_K t_K$$

→ Time load exceeds the indicated value.

where ⑥

P_K = Individual probability of capacity outage O_K.

O_K = Magnitude of the K^{th} outage in the system capacity outage probability table.

t_K = % time load exceeding the indicated value. (Number of time units in the study interval that an outage magnitude of O_K would result in a loss of load)

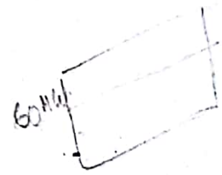
P_K from COPT

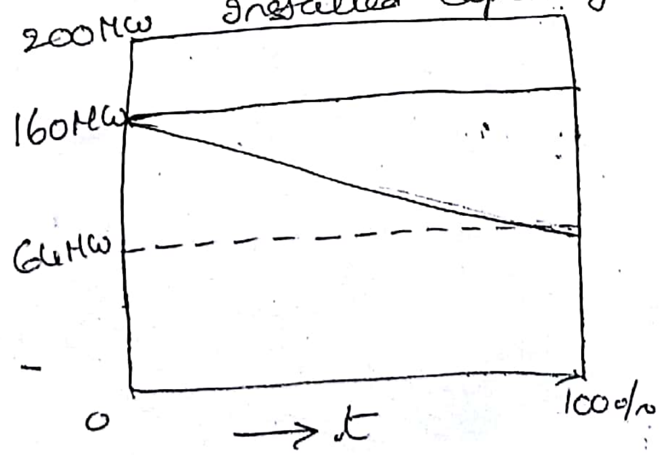
$$LOLE = \sum_{K=1}^{n} P_K T_K$$

P_K = Cumulative ~~capacity~~ outage probability for capacity state O_K

T_K = Individual time

2. Consider the system containing 5, 40 MW units each with a forced outage rate of 0.01, the daily system load model is represented by daily peak load variation curve is shown in fig. Compute LOLE using
(a) Individual probabilities
(b) Cumulative probabilities
Assume peak load is 160 MW.





Sol

$\eta = 5$ $\quad U = 0.01$

$A = 1 - U = 0.90$

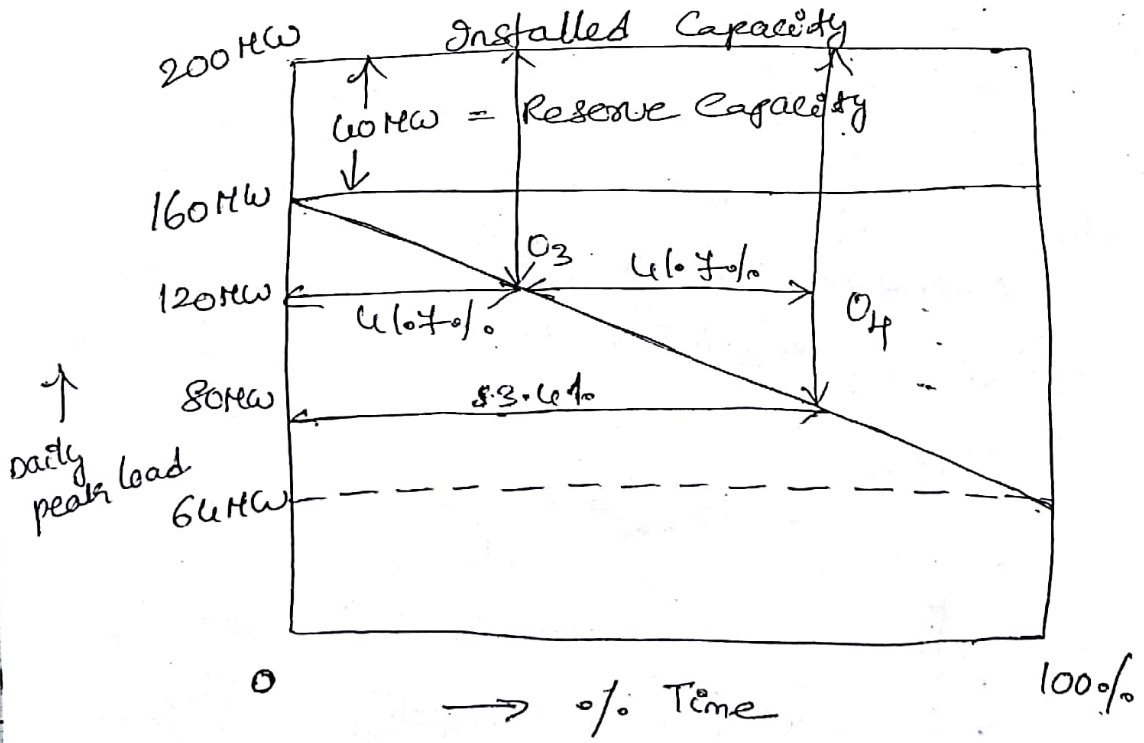
COPT

Cap out MW	Capa. in MW	Individual probability	Total time (%)	LOLE
0	200	0.950991	0	0
40	160	0.048029	0	0
80	120	0.000971	61.7	0.0604907
120	80	0.000009	83.4	0.0007506
160	40	0	–	–
200	0	0	–	–

$$LOLE = \sum P_K t_K = 0.0612613$$

$\therefore$ LOLE $= 0.0612613 \times 365$

$= 15.0761$ days.



COPT :

Cap out (MW)	Cap in (MW)	Cumulative probability	Time interval T_K (%)	LOLE
0	200	1.000000	0	–
40	160	0.049009	0	–
80	120	0.000980	41.7	0.0408660
120	80	0.000009	41.7	0.0003753

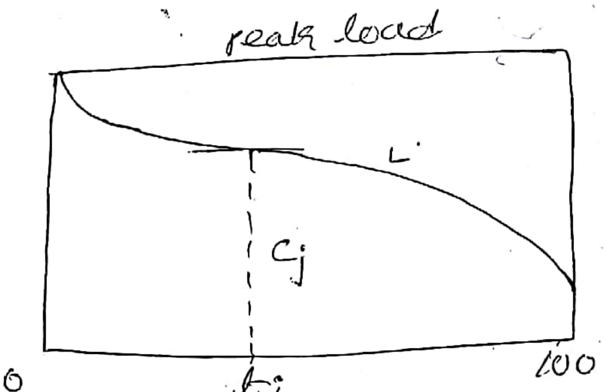
17

$$LOLE = \sum_j P_K T_K = 0.0412413$$

26

3. Load duration Curve :-

The load model used in this method is a simple cumulative load curve as shown in fig.



percentage of time for which Load exceeds (L)

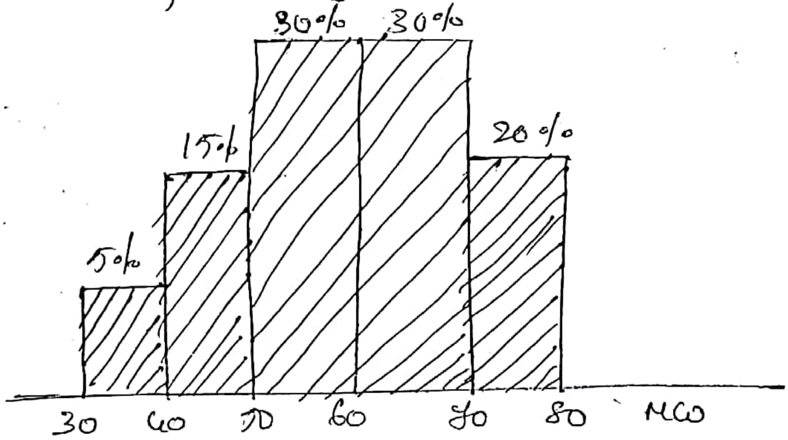
Fig (a) : cumulative load curve (load duration curve)

For a system state where the remaining generating capacity is C_j, the percentage of time t_j, during which the load demand exceeds C_j can be determined from the curve of fig (a). The overall probability that the load demand will not be met is called the loss-of-load probability (LOLP) given by

$$LOLP = LOLE = \sum_{k=1}^{N} \frac{P_K t_K}{100}$$

where P_K is individual probability
t_K; total % of time.

③ The distribution of daily peak is described by relative frequency diagram shown in fig.



Consider that there are 3 generating units of 20MW and one 40MW unit each having a failure rate of 0.4 f/year and repair rate of 9.6 r/year. Combine the load model with generation model. Assuming a 20MW installed reserve capacity is obtained and hence estimate the LOLE.

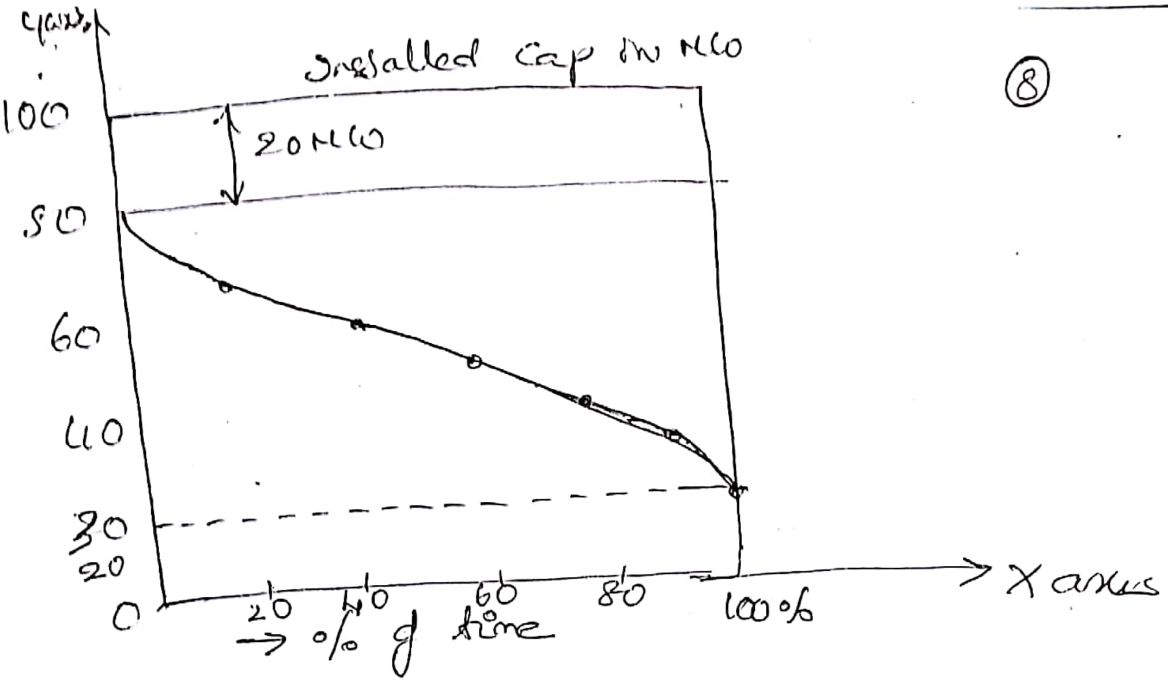
Sol

$$A = \frac{\mu}{\lambda + \mu} = \frac{9.6}{9.6+0.4} = 0.96$$

$$U = 1 - A = 0.04$$

COPT

Cap out in MW	Cap in in MW	Individual probability
0	100	0.849437
20	80	0.106168
40	60	0.039813
60	40	0.004485
80	20	0.000184
100	0	0.000003



(8)

$t_1 = 0$

$t_2 = 0$

$t_3 = 50\%$

$t_4 = 95\%$

$t_5 = t_6 = 100\%$

$$\sum_{K=1}^{n} \frac{P_K \, t_K}{100} = LOLP$$

$$= \frac{1}{100}\left[0.039813 \times 50 + 0.004685 \times 95 + 0.000184 \times 100 + 0.000003 \times 100\right]$$

LOLP $= 0.02446$

LOLP in days $= 0.02446 \times 365$

$= 8.9$ days/year

4. A generating station consists of two 5 MW units with a forced outage rate of 0.1 and one 3 MW units with a forced outage rate of 0.2. Determine

1. The capacity outage probability table and hence determine the cumulative probability of various capacity states
2. Use sequential method to obtain cumulative probability

3. At the end of (ii) above, if one unit of 5MW is deleted, determine the cumulative probabilities.

Sol

For 5 MW.

$U = 0.1$

$A = 1 - U$
$= 0.9$

For 3 MW.

$U = 0.2$

$A = 1 - U$
$= 0.8$

For 3MW

cap out	Indue	Cumulative
0	0.8	1.0
3	0.2	0.2

For 5MW

Capout		Indue	Cumulative
0	0	$A^2 = 0.81$ 0.8×0.9 $= 0.72$	~~1.0~~ 1.0
3	5	$2AU = 0.18$ 0.9×0.2 $= 0.18$	~~0.19~~ 0.28
~~5~~ 8	10	$U^2 = 0.01$ 0.8×0.1 $= 0.08$ 0.1×0.2 $= 0.02$	~~0.01~~ 0.1 0.02

1. Combined COPT

Capout	Individual prob.	Cumulative prob
0	$A_1^2 A_2 = 0.648$	1.0
3	$A^2U = 0.162$	0.352
5	$A^2U + A^2U = 0.144$	0.19
8	$U^2A + U^2A = 0.036$	0.046
10	$U^2 A = 8 \times 10^{-3}$	0.01
13	$U^3 = 2 \times 10^{-3}$	2×10^{-3}

3

2. Sequential addition method :-

9

$$P(X) = (1-U)\,P'(X) + U\,P'(X-C)$$

1. Add 3MW units :-

$P(0) = (1-0.2)\,1 + 0.2(1) = 1.0$

$P(3) = (1-0.2)\,0 + 0.2(1) = 0.2$

2. Add the second unit 5MW unit

$p(0) = (1-0.1)\,1 + 0.1(1) = 1.0$

$p(3) = (1-0.1)\,0.2 + 0.1(1) = 0.28$

$p(5) = (1-0.1)\,0 + 0.1(1) = 0.1$

$p(8) = (1-0.1)\,0 + 0.1(0.2) = 0.02$

3. Add the Next unit of 5MW :

$p(0) = (1-0.1)(1) + 0.1(1) = 1.0$

$p(3) = (1-0.1)\,0.28 + 0.1(1) = 0.352$

$p(5) = (1-0.1)\,0.1 + 0.1(1) = 0.19$

$p(8) = (1-0.1)\,0.02 + 0.1(0.28) = 0.046$

$p(10) = (1-0.1)\,0 + 0.1(0.1) = 0.01$

$p(13) = (1-0.1)\,0 + 0.1(0.02) = 0.002$

3. If one unit of 5MW is removed :

$$p'(X) = \frac{P(X) - U\,p'(X-C)}{1-U}$$

$$p'(0) = \frac{P(0) - 0.1(1)}{1-0.1} = 1.0$$

$$p'(3) = \frac{P(3) - 0.1(1)}{1-0.1} = 0.28$$

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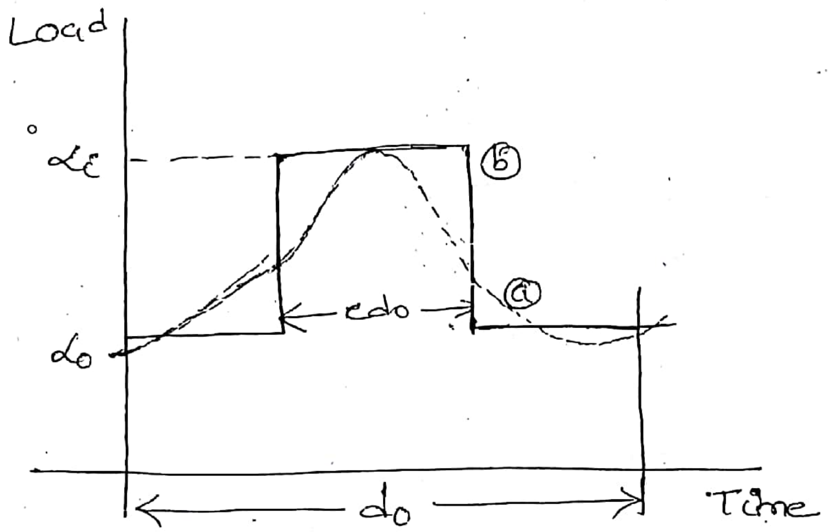
$$p'(5) = \frac{p(5) - 0.1(1)}{1 - 0.1} = \frac{0.19 - 0.1}{0.9} = 0.1$$

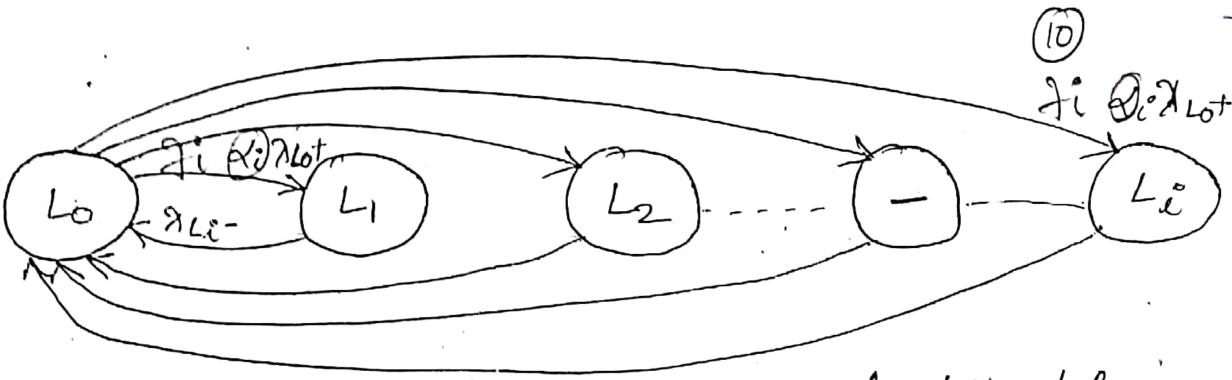
$$p'(8) = \frac{p(8) - 0.1(0.352)}{1 - 0.1} = 0.012$$

Two - level representation of the daily load :-



Fig(a): Two-level representation of the daily load
(a) the true load curve
(b) the model

The first method to approximate a the daily load curve was proposed by Ringlee and wood, and it is basically a two-level load model as shown in fig(a) while the low-load level d_0 is always the same, the peak loads d_i are different for every day, and they can occur in a random sequence. The mean duration t_i of the peaks is described by the exposure factor $e = t_i/d_0$, where d_0 is the length of the load cycle, 1 day in this application. The factor e is considered the same for every day, its magnitude is b/w 0 and 1, otherwise arbitrarily chosen.



Fig(b): state-space diagram for CSC load model

A markov-model for the above load representation is shown in fig(b). The transition rates in the diagram are

$$\lambda_{L0+} = \frac{1}{(1-e)d_0}$$ the rate at which the load is operated

$$\lambda_{Li-} = \frac{1}{e d_0}$$

and $\gamma(\alpha_i)$ are the relative frequencies of the corresponding peak loads L_i so that

$$\sum_i \alpha_i = 1 \quad (i = 1, 2 \ldots)$$

The state probabilities are

$$P_{L0} = 1 - e$$

$$P_{Li} = \alpha_i e$$

$$\simeq e$$

2. Merging the generation and load models :-

The generation and load models can be easily combined on the basis that the events in the two are independent and therefore, the event probabilities in any one of them will remain the same while changes occur in the other. The merges of a load model with four peak load levels and a generation model, where the identical capacity states are combined is shown in fig (c). In the diagram, C_1 is
..

the remaining capacity in a generating outage state and C_0 is the total installed capacity. Each state K in the diagram can be labelled by an index M_K indicating the margin by which the generation in that state exceeds the load demand, thus; $M_K = C_j - L_i$ and this margin can be negative as well as positive.

The transition rate from a given state K to any higher-margin state is

$$\lambda_{K+} = \lambda_{Li-} + \lambda_{Cj+}$$

and to any lower-margin state

$$\lambda_{K-} = \lambda_{Li+} + \lambda_{Cj-}$$

Note that for the given load model,

$$\lambda_{Li+} = 0 \text{ if } i \neq 0 \text{ \& } \lambda_{L0-} = 0$$

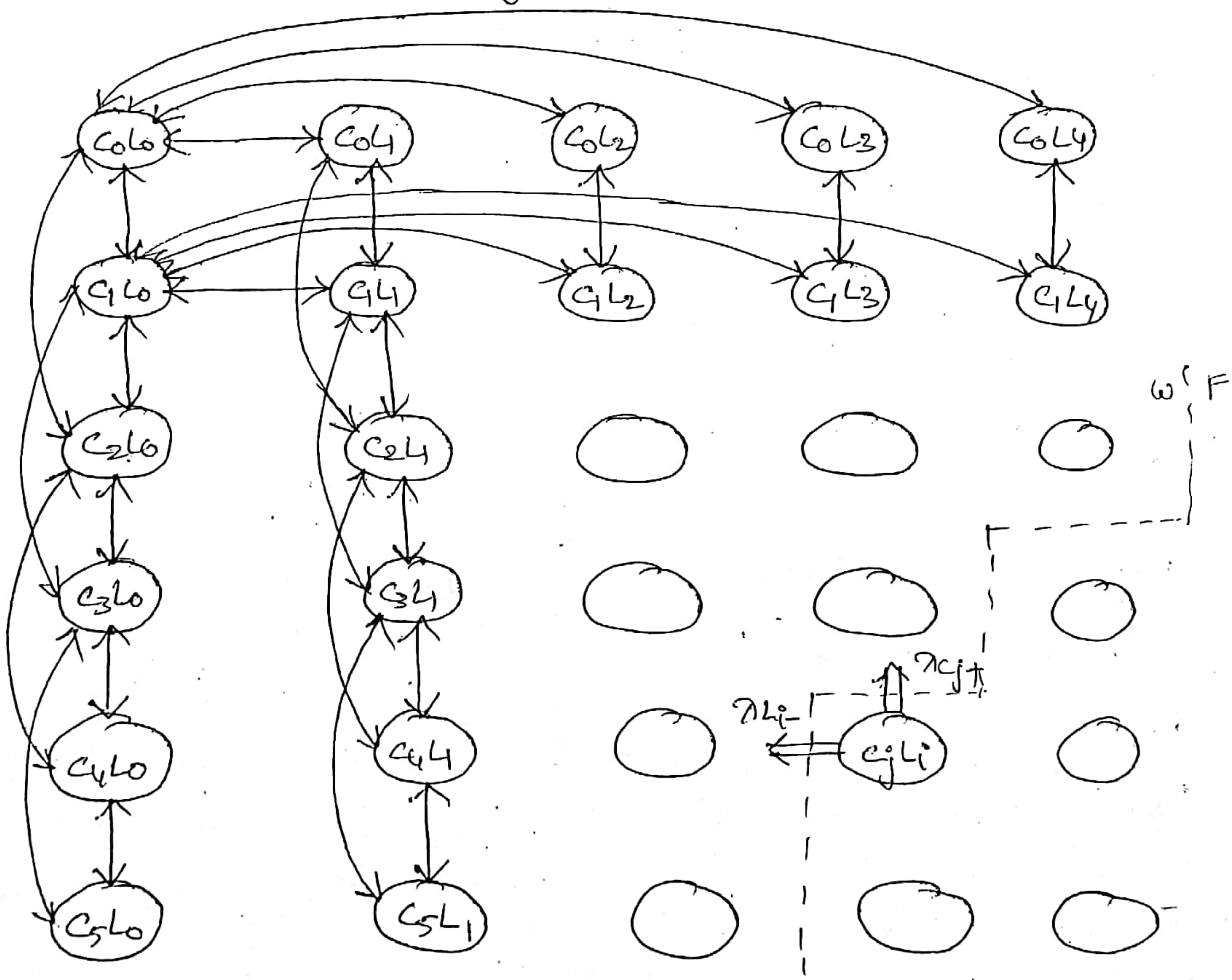


Fig (c) Combined generation-load model

Let NM denote the set of negative-margin states and PM the set of positive or zero-margin states then the system failure probability P_F is given by (11)

(1) $$P_F = \sum_{K \in NM} P_K$$

where the probability of state K, P_K is simply equal to

$$P_K = P_{Li} P_{Cj}$$

(2) The system failure frequency f_F is

$$f_F = \sum_{K \in NM} P_K \sum_{l \in PM} \lambda_{Kl}$$ or

(4) Loss of load probability

$$LOLP = \frac{P_F}{e}.$$

(5) LOLE = Loss of load expectation

$$= LOLP \times 365.$$

(3) $$f_F = \sum_{K \in NM} P_K \sum_{l \in PM} \mu_{Kl}$$

(6) The mean duration of system failure, T_F equals the ratio P_F / f_F.

problem:-

1. A generating station consists of two units of cap 40 and 60 MW with a forced outage rate of 0.08 and 0.05 respectively. The mean time to repair of either unit is 20 days. Calculate LOLP and frequency of the failure of the system if it has deliver a steady load of 50 MW. Assume an exposure factor of 0.5.

Cumulative Probabilities :-

Let there be 'N' Combined states in the Combined state model (lies b/w $(n+1)$ to 2^n) where n is number of Components.

Let $P_A, P_B \ldots P_N$ be the cumulative probabilities of the Combined states A, B to N respectively.

where A is highest available capacity state
N is the lowest available capacity state

P_{N-1} = Cumulative probability upto $(N-1)^{th}$ state starting from N^{th} state

$$\therefore P_{N-1} = P_N + P_K$$

Cumulative Frequency :-

higher order ↓ lower order ↓

$$F_{N-1} = F_N + P_K \mu_{K-H} - P_K \lambda_{K-L}$$

$$= F_N + P_K(\lambda + K) - P_K(\lambda - K).$$

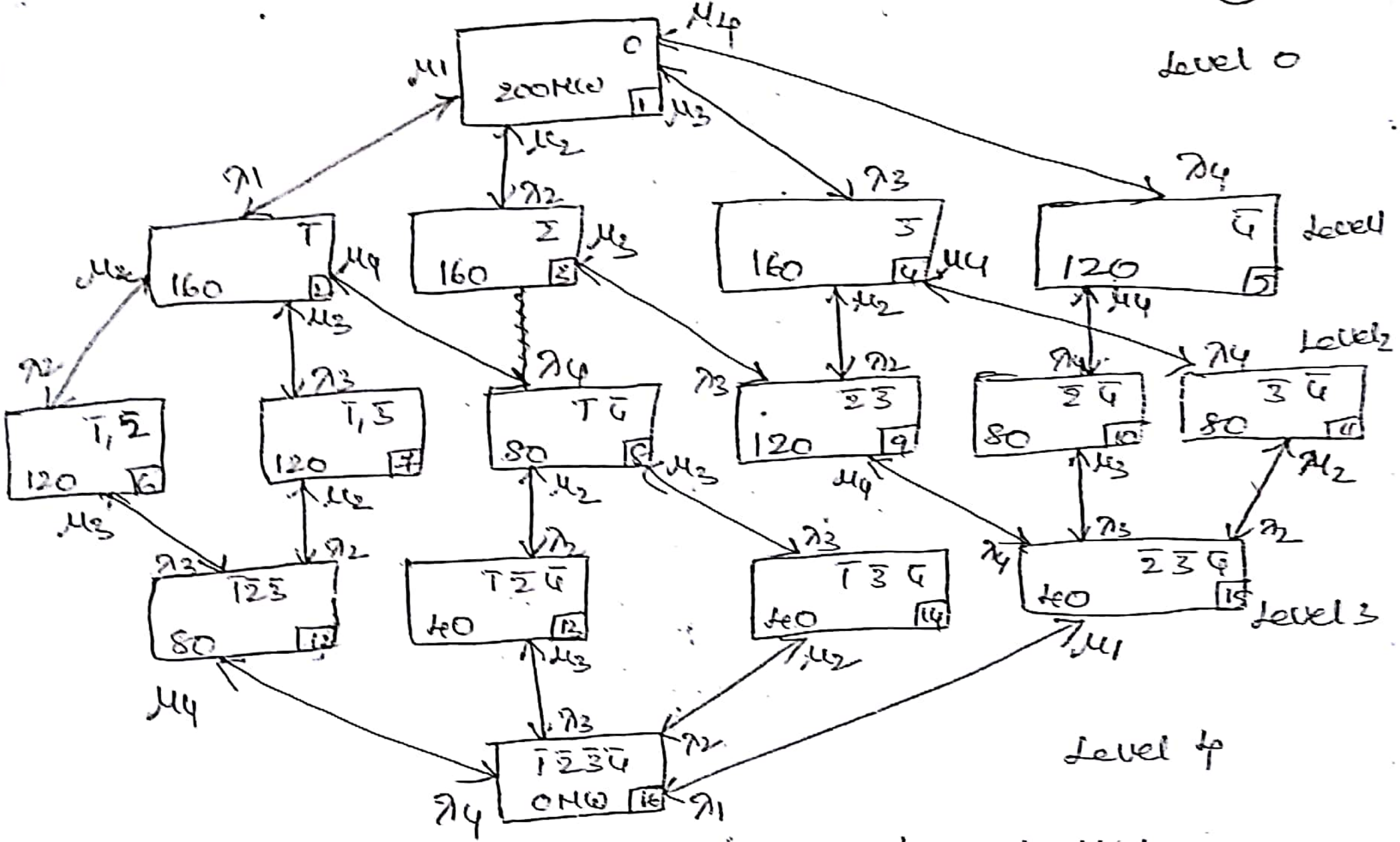
Problems :

1. A system has 04 generating units A, B, C & D units A B and C have a capacity of 80 MW each while D has a capacity of 40 MW each. Failure & repair rates of each unit are 0.4 /year & 9.6 /year respectively. obtain the state space model with identical capacity states enumerated. Determine the equivalent transitional rates of various Capacity states.

Sol Given $\lambda_1 = \lambda_2 = \lambda_3 = \lambda_4 = 0.4$ f/year

$\mu_1 = \mu_2 = \mu_3 = \mu_4 = 9.6$ r/year

$$A = \frac{\mu}{\lambda + \mu} = 0.96 \qquad U = 1 - A = 0.04.$$



Capacities of units 1, 2, 3 had 40MW
4 had 80 MW

$$P_A = P_1$$

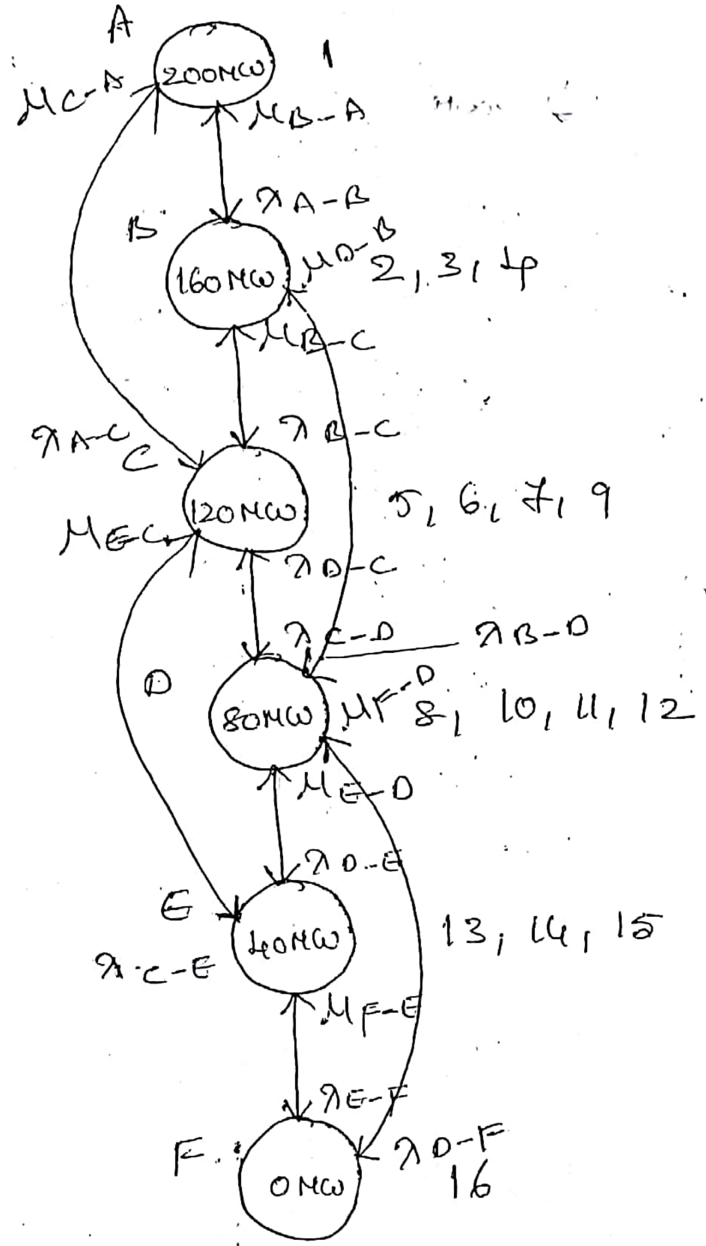
$$P_B = P_2 + P_3 + P_4$$

$$P_C = P_5 + P_6 + P_7 + P_9$$

$$P_D = P_8 + P_{10} + P_{11} + P_{12}$$

$$P_E = P_{13} + P_{14} + P_{15}$$

$$P_F = P_{16}$$



For 3, 40 MW

$P_1 = A^4 = (0.96)^4 = 0.84934656$

$P_2 = P_3 = P_4 = P_5 = A^3 U = (0.96)^3 \times 0.04$

$= 0.03538944$

$P_6 = P_7 = P_8 = P_9 = P_{10} = P_{11} = A^2 U^2$

$= (0.96)^2 (0.04)^2$

$= 0.001474$

$P_{12} = P_{13} = P_{14} = P_{15} = AU^3 = (0.96)(0.04)^3$

$= 0.0000614$

$P_{16} = (0.04)^4 = 0.00000256$

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Equivalent failure rates :

(13)

$\lambda_{K-L} = \sum_{i=1}^{K} P_i \sum_{j \in L} \lambda_{ij} \Big/ \sum_{i=1}^{K} P_i$

$\lambda_{K-L} = \sum_{i=1}^{K} P_i \lambda_{ij} / P_K$

$$\lambda_{A-B} \quad (1 - 2,3,4) = \frac{P_1 [\lambda_2 + \lambda_3 + \lambda_4]}{P_1}$$

$$= 3\lambda = 3 \times 0.4 = 1.2$$

$$\lambda_{A-C} \quad (1 - 5,6,7,9) = \frac{P_1 (\lambda_4)}{P_1} = \lambda_4 = 0.4$$

$$\lambda_{B-C} \quad (2,3,4 - 5,6,7,9) = \frac{P_2 (\lambda_1 + \lambda_3) + P_3 (\lambda_2 + \lambda_4) + P_4 (\lambda_1 + \lambda_2)}{P_2 + P_3 + P_4}$$

$$= 2\lambda = 2 \times 0.4 = 0.8$$

$$\lambda_{B-D} \quad (2,3,4 - 8,10,11,12) = \frac{P_2 (\lambda_4) + P_3 (\lambda_4) + P_4 (\lambda_4)}{P_2 + P_3 + P_4}$$

$$= \lambda_4 = 0.4$$

$$\lambda_{C-D} \quad (5,6,7,9 - 8,10,11,12) = \frac{P_5 (\lambda_1 + \lambda_2 + \lambda_3) + P_6 (\lambda_3) + P_7 (\lambda_2) + P_9 (\lambda_1)}{P_5 + P_6 + P_7 + P_9}$$

$$= 1.11$$

$$\lambda_{C-E} \quad (5,6,7,9 - 13,14,15) = \frac{P_5 (0) + P_6 (\lambda_4) + P_7 (\lambda_4) + P_9 (\lambda_4)}{P_5 + P_6 + P_7 + P_9}$$

$$= 0.044$$

$$\lambda_{D-E} = \frac{P_8(\lambda_2+\lambda_3)+P_{10}(\lambda_1+\lambda_3) + P_{11}(\lambda_1+\lambda_2)+P_{12}(0)}{P_8+P_{10}+P_{11}+P_{12}}$$

8, 10, 11, 12 – 13, 14, 15

$$= 0.789$$

$$\lambda_{D-F} = \frac{P_8(0)+P_{10}(0)+P_{11}(0)+P_{12}(\lambda_4)}{P_8+P_{10}+P_{11}+P_{12}}$$

8, 10, 11, 12 – 16

$$= 0.005$$

$$\lambda_{E-F} = \frac{P_{13}(\lambda_3)+P_{14}(\lambda_2)+P_{15}(\lambda_1)}{P_{13}+P_{14}+P_{15}}$$

13, 14, 15 – 16

$$\lambda = 0.04$$

<u>Equivalent</u> <u>Repair</u> <u>Rates</u> :

$$\mu_{F-E} = \frac{P_{16}(\mu_3+\mu_2+\mu_1)}{P_{16}}$$

16 – 13, 14, 15

$$= 3\mu = 29.8$$

$$\mu_{F-D} = \frac{P_{16}(\mu_4)}{P_{16}} = \mu = 9.6$$

16 – 8, 10, 11, 12

$$\mu_{E-D} = \frac{P_{13}(\mu_2+\mu_1)+P_{14}(\mu_3+\mu_1) + P_{15}(\mu_3+\mu_2)}{P_{13}+P_{14}+P_{15}}$$

13, 14, 15 – 8, 10, 11, 12

$$= 2\mu = 19.6$$

82, 66, 65, 71, 70, 69, 79,
205, 12, 83, 86, 67, 98, 13.
264

$\mu_{E-C} = 9.6$

13, 14, 15 - 5, 6, 7, 9

$$\mu_{K-H} = \frac{\sum_{i=1}^{x} P_i \mu_{ij}}{P_K = \sum_{i=1}^{y} P_i}$$

$\mu_{C-B} = 2.153$

$\mu_{C-A} = 8.553$

$\mu_{B-A} = 9.6$

$\mu_{D-C} = 9.863$

$\mu_{D-B} = 9.468$

Evaluation of Cumulative Probability & Cumulative frequency :-

n - No of units

N - No of merged states or Combined states

Cumulative Probability

$P_{N-1} = P_K + P_N$

Cumulative frequency

Higher order ↓ Lower order ↓

$$F_{N-1} = \underset{\text{cum}}{F_N} + \underset{\text{table}}{P_K \cdot \mu_{K-H}} - P_K \lambda_{K-L}$$

1. Find the cumulative probability & cumulative frequency of 3 unit generating system having capacities of two units of 25MW each and one unit of 50MW with a failure rate of 0.01 f/day and repair rate of 0.49 rep/day.

Sol $2^3 = 8$

1, 2 - 25MW

3 - 50MW

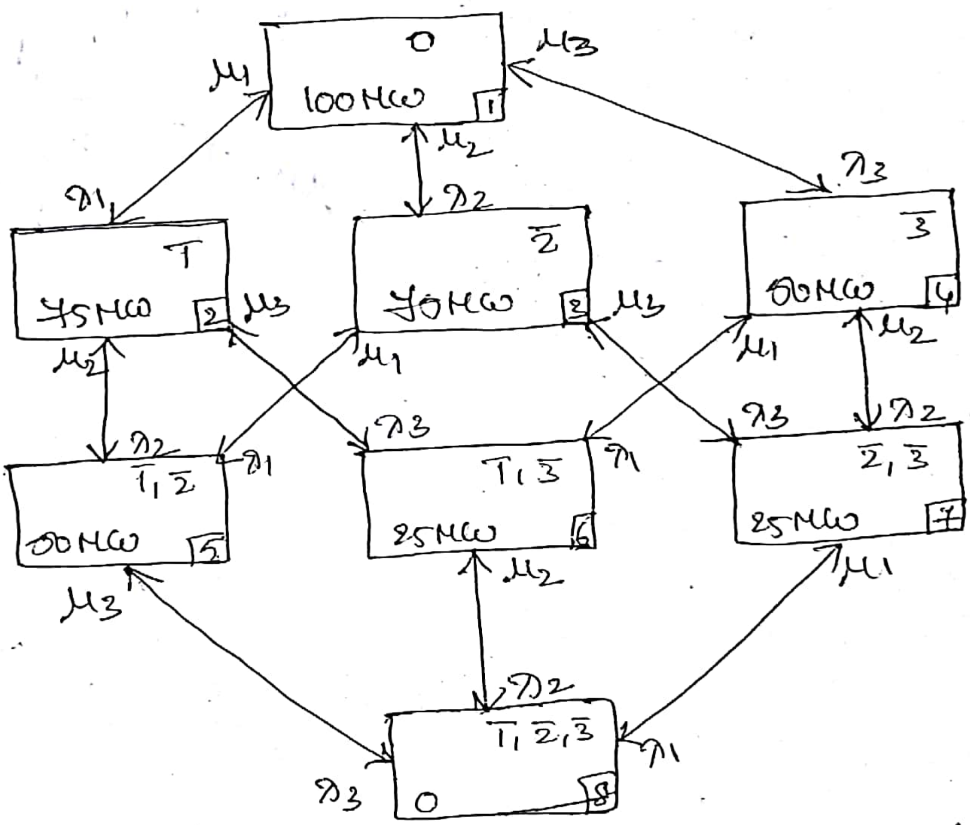
State space diagram:

Level 0

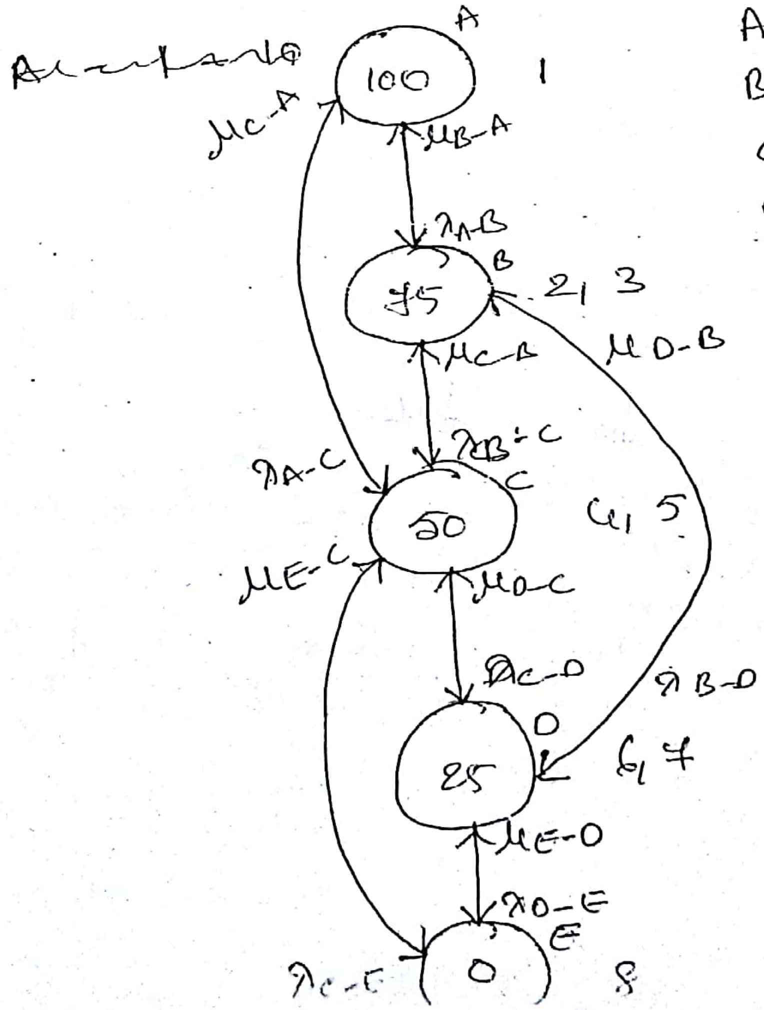
Level 1

Level 2

Level 3



There are 8 possible states, Combined states are



A - 1 - 100 MW

B - 2, 3 - 75 MW

C - 4, 5 - 50 MW

D - 6, 7 - 25 MW

E - 8 - 0

$$A = \frac{\mu}{\lambda+\mu} = \frac{0.49}{0.01+0.49} = 0.98$$

$$U = 1 - A = 0.02$$

$$P_1 = A^3 = (0.98)^3 = 0.941192$$

$$P_2 = P_3 = P_4 = A^2U = (0.98)^2 \times 0.02$$
$$= 0.019208$$

$$P_5 = AU^2 = (0.98)(0.02)^2$$
$$= 0.000392$$

$$P_6 = P_7 = AU^2 = (0.98)(0.02)^2$$
$$= 0.000392$$

$$P_8 = U^3 = (0.02)^3 = 0.000008$$

Frequency of encountering individual states (1 to 8):

$\lambda_1 = \lambda_2 = \lambda_3 = 0.01$

$\mu_1 = \mu_2 = \mu_3 = 0.49$

$$f_1 = P_1 \times \text{rate of transition}$$
$$= P_1(\lambda_1+\lambda_2+\lambda_3)$$
$$= 0.02823576$$

$$f_2 = P_2(\lambda_2+\lambda_3+\cancel{\lambda_4}\,\mu_1)$$
$$= 0.00979608$$

$$f_3 = P_3(\lambda_1+\lambda_3+\mu_2)$$
$$= 0.00979608$$

$$f_4 = P_4(\lambda_1+\lambda_2+\mu_3)$$
$$= 0.00979608$$

$$f_5 = P_5(\lambda_3+\mu_1+\mu_2)$$
$$= 0.00038808$$

$$f_6 = P_6(\lambda_2 + \mu_1 + \mu_3)$$
$$= 0.00038808$$

$$f_7 = P_7(\lambda_1 + \mu_2 + \mu_3)$$
$$= 0.00038808$$

$$f_8 = P_8(\mu_1 + \mu_2 + \mu_3)$$
$$= 0.00001176$$

Cumulative probabilities & Cumulative frequency values :-

1. $P_E = P_E = 0.00008$

$F_E = F_E = 0.00001176$ / day

2. $P_D = P_E + P_D = 0.000792$

$F_D = F_E + P_D[\mu_{D-H} - \lambda_{D-L}]$

$= F_E + P_D[\mu_{D-C} + \mu_{D-B} - (\lambda_{D-E})]$

$= 0.000407224$ / day

3. $P_C = P_D + P_C = 0.020392$

$F_C = F_D + P_C[\mu_{C-A} + \mu_{C-B} - (\lambda_{C-D} + \lambda_{C-E})]$

$= 0.01018024$ / day

4. $P_B = P_B + P_C = 0.058806$

$F_B = F_C + P_B[(\mu_{B-A}) - (\lambda_{B-C} + \lambda_{B-D})]$

$= 0.02823576$ / day

0.49 - (0.01 + 0.00)
0.48

5. $P_A = P_B + P_A = 1.0$

$F_A = F_B + P_A[\mu_{A-H} - \lambda_{A-L}]$

$= F_B + P_A[0 - (\lambda_{A-B} + \lambda_{A-C})]$

$= 0$

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Individual state	Combined state	Capacity out in MW	Capacity in MW	Probability in P_K	Probability in J_K
1	A	0	100	$P_1 = 0.96192$	$J_1 = 0.02823576$
2, 3	B	25	75	$P_2+P_3 = 0.038416$	$J_2+J_3 = 0.01959216$
4, 5	C	50	50	$P_4+P_5 = 0.0196$	$J_4+J_5 = 0.01018416$
6, 7	D	75	25	$P_6+P_7 = 0.000784$	$J_6+J_7 = 0.00077616$
8	E	100	0	$P_8 = 0.000008$	$J_8 = 0.00001176$

Equivalent Transitional Rates:

$\lambda_{A-B} = 0.02$

$\lambda_{A-C} = 0.01$

$\lambda_{B-C} = 0.01$

$\lambda_{B-D} = 0.01$

$\lambda_{C-D} = 0.0196$

$\lambda_{C-E} = 2\times10^{-4}$

$\lambda_{D-E} = 0.01$

Equivalent Repair Rates:

$\mu_{E-D} = 0.98$

$\mu_{E-C} = 0.49$

$\mu_{D-C} = 0.49$

$\mu_{D-B} = 0.49$

$\mu_{C-B} = 0.0196$

$\mu_{C-A} = 0.6802$

$\mu_{B-A} = 0.49$

H.W

1. A generating station has 3 generators, two rated for 30MW and the third for 40MW. The failure and repair rate of each unit are 0.5 f/yr and 9.5 r/yr respectively. obtain the state space diagram and mark various transitional rates. Hence, evaluate the cumulative probability & cumulative frequency of various merged states.

Exam question.

1. Explain the two-level representation of the daily load in a generating system.
2. Write short notes on
   (a) Computation of loss of energy indices in generating units.
   (b) loss of load probability.
3. Explain the two-level representations of the daily load and its merging the generation and load models of a generating system.
4. Write short notes on.
   (a) Two-level representation of the daily load
   (b) sequential addition method
   (c) Combined generation capacity model.
5. How the generation load models are merged and explain the evaluation of transition rates for merged state models.

~~2. A generating station has 3 generators, two rated for 30MW and the third for 40MW. The failure and repair rate of each unit are 0.5 f/yr and 9.5 r/yr respectively. Obtain the state space diagram and mark various transition rates. Hence, evaluate the cumulative probability and cumulative frequency of various merged states.~~

Sol

1 2 3

30

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1. A generating station has 3 generators, two rated for 15MW and third one for 25MW. The failure and repair rates of each unit are 0.35 f/yr and 0.65 r/yr. Obtain the state space diagram and mark various equivalent transitional rates. Hence, evaluate the cumulative probability & frequencies of the various combined states.

2. A generating station consists of two 6MW units with a forced outage rate of 0.05 and one 8MW units with a forced outage rate of 0.08. Determine
   1. The capacity outage prob table.
   2. Use sequential addition method to obtain cumulative probability
   3. If one unit of 8MW is removed, determine the cumulative probabilities.

3. A generating plant containing three identical 40MW generating units, is connected to a constant 82MW load. The unit failure and average repair times are 3 f/yr and 8 days respectively. Develop frequency, duration and probability risk indices for this system.

4. A generating station consists of three identical 40 MW generating units is connected to a constant 82 MW load. Each unit failure and repair rates are 0.3 f/yr and 9.7 r/yr respectively. Calculate LOLP of the system. Assume suitable data for the load.

5. A generating station consists of 3 generators of 10 MW, 20 MW & 30 MW units respectively and a 40 MW unit and each unit having forced outage rate of 0.07. Calculate the LOLE for this system with a single peak load of 60 MW.

21/5 POS

Weight for generation with load model

Given

1 unit – 40 MW

2 unit – 60 MW

$U_1 = 0.08 \quad A_1 = 0.92$

$U_2 = 0.05 \quad A_2 = 0.95$

MTTR = Repair time of each unit = 20 days

$\mu_1 = \mu_2 = 1/MTTR = 1/20 = 0.05$

$A_1 = \dfrac{\mu_1}{\lambda_1 + \mu_1}$

$A_2 = \dfrac{\mu_2}{\lambda_2 + \mu_2}$

on solving

$\lambda_1 = 4.34 \times 10^{-3}$

$\lambda_2 = 2.63 \times 10^{-3}$

Capacity outage probability table :

Cap out in MW	Cap in MW	Individual prob
0	100	$A_1 A_2 = 0.874$
40	60	$A_2 U_1 = 0.076$
60	40	$A_1 U_2 = 0.046$
100	0	$U_1 U_2 = 0.004$
		1.0

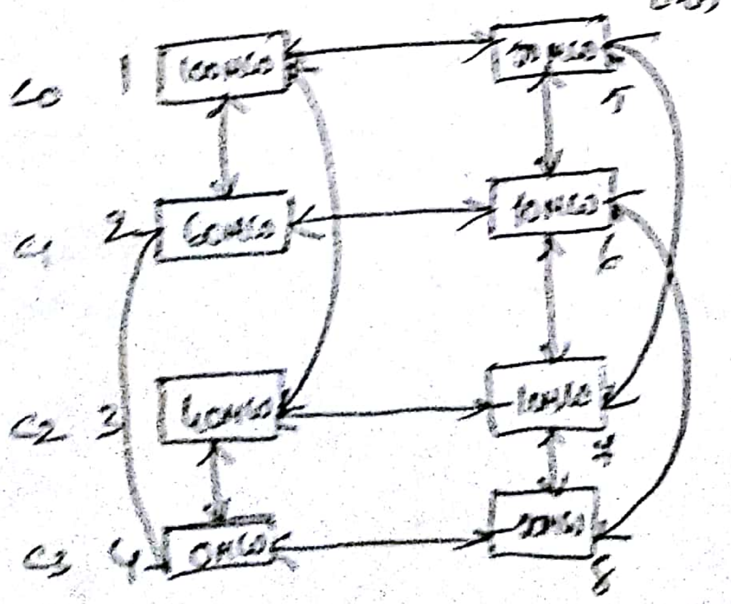
0

40 60

100MW

404

0.05



Assuming

$P_{L_i} = 0.5 \quad d_0 = 1$ day

$P_{L_0} = 0.5$

days

$\lambda_{L_i}^{-} = 2$

$\lambda_{L_0}^{+} = 2$

0^{-3}

10^{-3}

Capacity margin prob table :

Capacity Margin (MW)	Individual prob of the merged state $(P_{L_i} * P_{C_j})$
100	$0.5 \times 0.874 = 0.437$
60	$0.5 \times 0.076 = 0.038$
40	$0.5 \times 0.046 = 0.023$
0	$0.5 \times 0.004 = 0.002$
50	$0.5 \times 0.874 = 0.437$
10	$0.5 \times 0.076 = 0.038$
-10	$0.046 \times 0.5 = 0.023$
-50	$0.004 \times 0.5 = 0.002$

very pasdab

system failure $P_F = \sum P_K$ (sum of negative margin states)

$= P_7 + P_8$

$= 0.023 + 0.002$

$= 0.025$

$LOLP = \frac{P_F}{e} = \frac{0.025}{0.5} = 0.05$

$$\therefore f_P = P_{(-10)}\,\mu_{(-10)\text{ to PM}} + P_{(-00)}\,\mu_{(-00)\text{ to PM}}$$

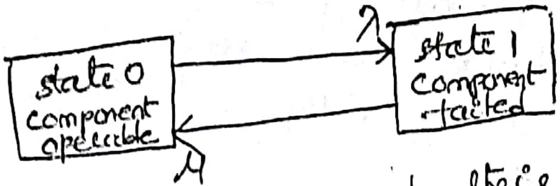
$$= P_7\left[\mu_2 + \lambda_{Li}^{-}\right] + P_8\left[\lambda_{Li}^{-} + \mu_2\right]$$

$$= \{0.023\,[0.05+2] + 0.02\,[2+0.05]\} \times 365$$

$$= 17 \text{ days/year}$$

Frequency and duration Concept :-

The basic concepts associated with the frequency and duration technique are best in terms of the single repairable component used to describe the continuous Markov process. The state space diagram of this system is shown in figure (a).



fig(a)

The two system states and their associated transitions can be shown chronologically on a time graph. The mean values of up and down times can be used to give the average performance of this two state system, shown in fig (b)

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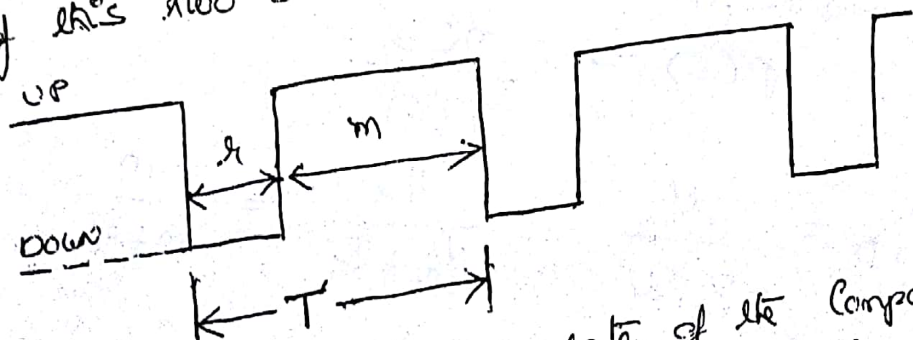
0406856944



fig(b)

where λ = failure rate of the component
μ = repair rate of the component
m = mean operating time of the component
r = mean repair time of the component