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ECONOMICAL RELIABILITY LEVEL FOR ELECTRICAL POWER SYSTEMS

BY

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ABSTRACT:

This paper introduces a mathematical model for having the optimum operation of electrical power system with different values of reliability levels. The start-up costs of the units, minimum-up times and minimum-down times of the units are of the factors considered Based on the reserve requirements and reliability analysis, a suggested method is presented for economical reliability computation of electrical power systems.

1. INTRODUCTION:

To maintain reasonable reliability level for any power system, an amount of power reserve must be included. Its value depends on different factors such as forced outage rates of generating units, continued load growth,..... etc.

Increasing the spinning reserve causes an increase in the system reliability level. To have an adequate reliability level, it is perhaps too easy to say that it is a management decision but actually reliability level is directly related to the investment in the system.

In order to have the increase in reliability per pounds invested and to achieve the maximum reliability benefit, quantitative reliability indices for all points within the system must be developed.

So, it is clear that economics and reliability are not independent variables in daily generation scheduling and in general, once the degree of reliability is determined, short-term economic scheduling is reliatively straight forward can be done.

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2. DEFINITIONS:

2.1. Long-term reserve "cold reserve":

It is the total power of a number of generating units, operated only when required, these units are mainly thermal generating unit.

2.2. Short-term reserve "Spinning reserve":

It is the total power of a number of generating units, operated at minimum-or no-load conditions these mainly are gas-turbines and pumped storage.

2.3. Momentary system reserve:

The momentary system reserve is the result capacity of primary governor action of all interconnected units of all partern systems.

3. OPTIMAL CONDITIONS FOR POWER SYSTEM OPERATION:

3.1 Reserve behaviour:

In power systems, the power reserve must be suficient to cover the failure of generating units and deficits at any part of bulk power and distribution systems.

Fig. (1) shows the reserve application procedure after generation outage.

The power deficit in the system is compensated in the time range up to five minutes by the momentary-reserve of all interconnected units- (primary governor action). Then, after this period at the latest it is requested that the subsystem which caused the power deficit covers the loss through its own reserve- (secondary governor action) and reliefs the supporting partner systems from their reserve shares.

As the mean access-time $E(T_{Z,H})$ to the hour reserve (cold thermal units) is about 0.5 to 8 hour, minute reserves (spinning reserves, gasturabines, short-term and long-term storage plants) with a mean access-time $E(T_{Z,M})$ of 1:5 minutes have to be used.

Because of economical ressons (higher operation costs), technical reasons (limited energy capacity), and reliability reasons (availability of spare fast-response reserve for further failure events), the minute reserve has to be replaced as fast as possible by the hour-reserve.

So, the new reserve model which based on reliability analysis and considers the total reserve as minute-, hour-reserve, must satisfy unforeseen changes in the system load without impairing the system frequency and tie-line regulation and to protect against probable loss of operating capacity.

3.2. Economical operation:

From the economical point of view the cost of the power system operation, can be divided into:-
1) Costs caused by stationary operation.
2) Transitional costs due to operation transitions.

The costs of stationary operation are the fuel costs which are necessary to cover the load. For a generating unit these costs depends on the actual power output at any instance, the heat rate and the specific primary energy price.

The costs associated with operational transitions are mainly fuel costs aristing from the start-up of a generating unit following a shut-down condition. It includes also a cost share which assesses the diminuation of the unit life-time due to wear and tear.

3.3. Constraints on system operation:

The minimum and maximum power output capacity of generating unit as will as the shut-down condition of a unit describe the feasible region, within which a unit can be operated are the basic type of technical component constraints for operation planning.

For operation and planning additional types of constraints for components must be considered as:

1) Must out units: to which belong units, not available for operation due to maintenance or repair.
2) Must run units: this includes units which must be on-line due to operating reliability, technical or economical reasons.
3) Units on fixed power-output: to this type belong units which have been pre-scheduled and have for certain reasons their generation specified for a certain period of time.
4) Changes in capacity limits of units: partial out-ages or maintenance of components can reduce the generating limits and capacity of units. Similarly the restoration of components and the completation of maintenance increase the capacity limit.
5) Load pick-up ability of units: during changes of the power output of units certain permissible rates of change must not be exceeded.
6) Minimum operating and minimum shut-down times for units: during the operation of units it is necessary to consider it for technical or economical reasons. In general that once a unit is brought on-line it is operated for a certain time. Similary, once a unit is shut-down it must not be restarted before a certain period of time.

7) Personal limitations on plants: in certain plants it is not possible due to personal limitations to start-up several units at the same time.

8) Energy constraints on plants: this type includes storage plants (hydro compressed air) and plants or power system interconnections for which certain values for the delivered energy within a certain period of time must be reached for technical (storage volume) or economical reasons (energy constraints).

The operation planning procedure has to include all constraints imposed by the system. This reflects the requirements that even in view of not exactly forecasted load curves and component outages. The demand must be met with a certain probability of supply which means that at any instance such, a power system has to be commited to cover the load and has the required amount of minute-and hour-reserve available.

4. Optimal Cost of Reserve Computations:

To compute the optimal cost of reserve required for a certain power, the following data are required:

1) The forecasted daily load curve.
2) The amount of reserve required.
3) The operation regions of the units.
4) Cost curves of the thermal units.
5) Load pick-up rates of the units.
6) Minimum-up times and minimum-down times of the units.
7) Start-up costs of the units.
8) Energy constraints for energy limited plants.
9) Interconnection characteristics and constraints.
10) Probability distributions of the operation and repair times of power units.
11) Mean access-times to the reserves.

4.1. Reserve modeling formulation:

4.1.1. Constraints:

The different constraints of power system operation can be expressed mathematically as:

. Load constraint:

$$\sum_{i=1}^{NTh} P_{i,t} + \sum_{i=1}^{NS} P_{s,i,t} = P_{s,L,t} \qquad t = 1,\ldots\ldots T \qquad \ldots\ldots\ldots\ldots(1)$$

where,

$$P_{i,t} = P_{min,i} \cdot a_{i,t} + \sum_{i=1}^{NB} P_{j,i,t}$$

$$P_{s,i,t} = P_{T,min,i} \cdot a_{T,i,t} + \sum_{i=1}^{NT} P_{T,j,i,t} - \sum_{j=1}^{NP} P_{p,i,t}$$

$$\cdot\ a_{p,j,i,t} = P_{T,i,t} - P_{p,i,t}$$

2. Reserve requirements:

$$\sum_{i=1}^{NTh} P_{max,i} + \sum_{i=1}^{NS} P_{T,j,i,t} \geqslant P_{s,L,t} + S_{s,HR,t} \qquad \text{......(2)}$$

3. Capacity limitations:

$$\sum_{i=1}^{NB} P_{j,i,t} \leqslant a_{i,t}\,(P_{max,i} - P_{min,i}) \qquad \text{......(3)}$$

$$i=1,\ \ldots\ldots,\ NTh$$

$$\sum_{i=1}^{NT} P_{T,j,i,t} \leqslant a_{T,i,t}(P_{T,max,i} - P_{T,min,i}) \qquad \text{......(4)}$$

$$i=1,\ \ldots\ldots,\ NS$$

4. Load pick-up limitations:

$$\left|P_{i,t} - P_{i,t-1}\right| \leqslant \Delta P_{max,i,t} \qquad \text{......(5)}$$

$$i=1,\ \ldots\ldots,\ NTh$$

5. Start-up restrictions:

$$a_{i,t} - a_{i,t-1} \leqslant S_{i,t} \qquad i=1,\ \ldots\ldots,\ NTh \qquad \text{......(6)}$$

6. Energy restrictions:

$$\sum_{i=1}^{T} P_{i,t} \cdot \tau_t \geqslant E_i \qquad i=1,\ \ldots\ldots,\ NTh \qquad \text{......(7)}$$

7. Storage restrictions:

$$\sum_{j=1}^{t} (C_T \cdot P_{T,i,t} - C_p \cdot P_{p,i,t})\,\tau_j \leqslant V_{o,i} - V_{min,i}$$

$$i=1,\ \ldots\ldots,\ NS$$

$$\sum_{j=1}^{t} (c_p \cdot P_{o,i,t} - C_T \cdot P_{T,i,t})\,\tau_j \leqslant V_{max,i} - V_{o,i} \qquad \text{......(8)}$$

. Commintment variables:

$a_{i,t} = 0$ or 1 $\qquad$ $i=1, \ldots\ldots NTh$

$a_{T,i,t} = 0$ or 1 $\qquad$ $i=1, \ldots\ldots NS$

$a_{p,j,i,t} = 0$ or 1 $\qquad$ $i=1, \ldots\ldots NP$

. Start-up Variables:

$S_{i,t} = 0$ or 1 $\qquad$ $i=1, \ldots\ldots NTh$

where,

$P_{i,t}$ power output of unit i at time step t.

$P_{j,i,t}$ power of unit i in power region j and time step t.

$P_{min,i}$ minimum power output of unit i.

$P_{max,i}$ maximum power output of unit i.

$P_{s,i,t}$ power output of storage plant i at time step t.

$P_{p,i,t}$ pump power of plant i at time stop t.

$P_{T,i,t}$ turbine power of plant i at time step t.

$P_{T,j,i,t}$ turbine power of plant i in power region j and time step t.

$P_{T,min,i}$ minimum turbine power of plant i.

$P_{T,max,i}$ maximum turbine power of plant i.

$\Delta P_{max,i,t}$ maximum permitted power change of unit i at between time steps (t) to and (t-1)

$S_{i,t}$ start-up variable of unit i at time step t.

ζ_t duration of time step t.

T number of time steps of the operation planning period.

$V_{o,i}$ used storage capacity at the beginning of the operation planning period.

$V_{min,i}$ minimum unstable storage capacity.

$V_{max,i}$ maximum unstable storage capacity.

$a_{i,t}$ commitment variable for unit i at time step t.

$a_{p,j,i,t}$ commitment variable for pump operation of unit i at power step j and time step t.

$a_{T,i,t}$ commitment variable for turbine operation of unit i at time step t.

C_p constant for pump operation.

C_T constant for turbine operation.

E_i energy produced by unit i.

NB number of power regions of a unit.

NP number of pump power steps.

NS number of storage plants.

NTh number of thermal plants.

For problem, formulation the objective function is given by the operational costs over the operation planning period which are to be minimized, and contains the restrictions derived from the operational constraints.

4.1.2. Objective functions:

$$\text{Total costs} = \sum_{t=1}^{T} \sum_{i=1}^{NTh} K_{B,i,t}(P_{i,t}) \cdot \tau_t + K_{A,i,t} = \text{Min} \qquad \ldots\ldots\ldots(9)$$

where,

$$K_{B,i,t} = K_{min,i} \cdot A_{i,t} + \sum_{i=1}^{NB} K_j - P_{j,i,t}$$

$$K_{A,i,t} = K_{A,i} \cdot S_{i,t}$$

where,

$K_{B,i,t}$ production cost of unit i at time step t.

$K_{A,i,t}$ start-up cost of unit i at time step t.

$K_{A,i}$ start-up cost of unit i.

K_j specific cost in power region j.

$K_{min,i}$ minimum production costs of unit i.

4.2. The Model:

The probabilistic failure behaviour of generating units determines the required power reserve.

For the computation of reserve one has to distinjuish between minute-reserve and hour-reserve. The probabilistic failure behaviour of unit is thereby described by failure rates γ_k (T_v) depending on the past operation time T_v.

4.2.1. The minute reserve:

Assuming that the minute reserve is replaced by hour reserve after the mean access-time E $(T_{Z,H})$, the operation of the minute reserve can be calculated as a two-state renewal process Fig. (2).

The probability for a power deficit $S_{K,M}$ which has to be covered by minute reserve is,

$$P_r(S_{K,M}) = \frac{\lambda_k (T_v)\ E\ (T_{Z,H})}{1 + \lambda_k (T_v) E\ (T_{Z,H})}$$

4.2.2. The total reserve:

The operational behaviour of each unit on-line is described by a two-stage renewal process with the two states operation and repair Fig. (3).

The probability for a power deficit $S_{K,A}$ which has to be covered by minute-and hour-reserve is,

$$P_r\ (S_{K,A}) = \frac{\lambda_k\ (T_v)\ E\ \ (T_{K,B})}{1 + \lambda_k\ (T_v)\ E\ (T_{k,B})}$$

4.2.3. Required reserve for the system operation:

Assuming independent failure events the number of the stochastical power deficits of similar type in a power system is,

$$N_s = 2^{M_s} - 1$$

where,

$M_s = M_B + M_A$ = total number of units.

M_A = number of lost unit.

M_B = number of units in operation.

Probability of power deficits $S_{sj,A}$, $S_{sj,M}$, $S_{sj,H}$ in power system,

$$P_r(S_{sj,.}\ ,\ S_{sj,.}) = \prod_{K\ M_A} P_r(S_{k,.}) \prod_{L\ M_B} P_r(S_{L,.})$$

Magnitude of the power deficits

$$S_{sj,.} = \sum_{K \in M_A} S_{k,.}$$

Mean duration of the power deficits.

$$T_{sj,.} = \frac{1}{\sum\limits_{K \in M_A} \frac{1}{E\ (T_{k,.})}}$$

Probability of non-supply

$$P_r(S_{s,.} \geqslant S, T_{s,.} \geqslant T) = \sum_{j \in N_s} P_r\ (S_{sj,.}\ ,\ T_{sj,.})$$

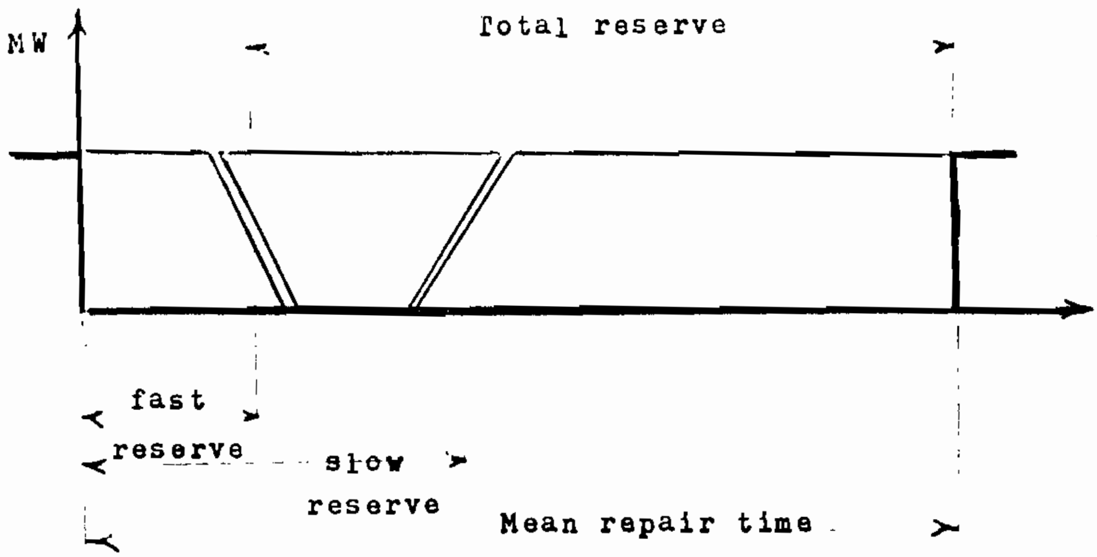
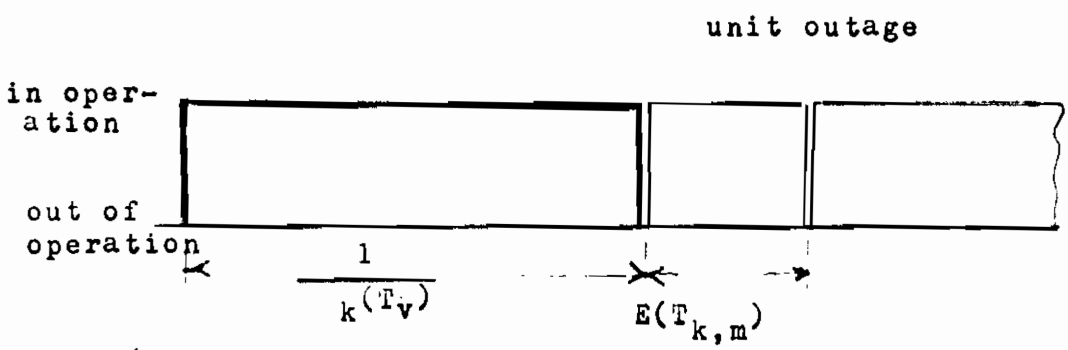


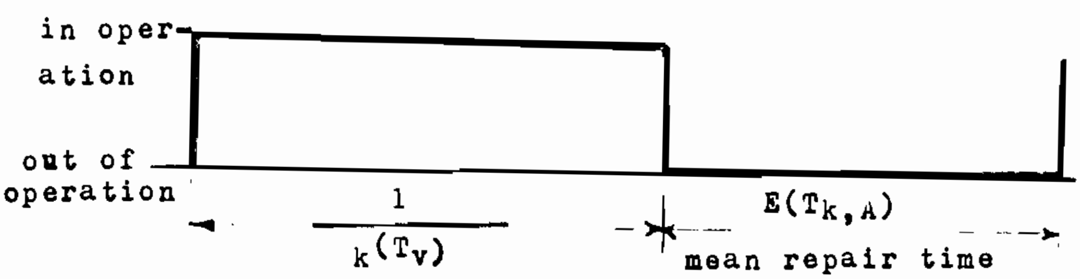
Fig. (1)



$k(T_v)$ = time dependant failure rate

$E(T_k) = E(T_{Z,H})$ =fast reserve.

Fig. (2)



$k(T_v)$ = time dependant failure rate.

Fig. (3)

$$S_{sj,.} \geqslant S \quad , \quad T_{sj,.} \geqslant T$$

Hence for the minute reserve with unrestricted operation which can be used as hour-reserve follows:

$$P_r(S_{S,H} \geqslant S, T_{S,H} \geqslant T) = P_r(S_{S,A} \geqslant S, T_{S,A} \geqslant T) - P_r(S_{S,M})$$

where,

$E(-)$ mean duration.

$E(T_{z,M})$ mean access-time to the fast reserve.

$E(T_{z,H})$ mean access-time to the long-term reserve.

$\lambda_k(T_v)$ forced outage rate as a function of the past operation time.

$P_r(-)$ probability.

Pr def probability of capacity deficiency (give reliability level).

$S_{K,A}, S_{K,M}, S_{K,H}$ random variables: forced outage capacity to be componsated by total reserave (A), fastreserve (M), and long-term (H).

$S_{S,A}, S_{S,M}, S_{S,H}$ Randon variables: forced outage capacity of the power system (S) to be componsated by the total reserve (A), fast reserve (M), and long-term reserve (H).

$S_{S,AR}, S_{S,MR}, S_{S,HR}$ Necessary total reserve (AR), fast reserve (MR), and long-term reserve (HR) for the power system (S).

T_{Ber} Time period considered for the operation planning calculation (e.g. one day).

$T_{K,A}, T_{K,Mi}, T_{K,H}$ Random variables: outage duration of the unit (k) which determine the operation time of the total reserve (A), fast reserve (M), and long-term reserve (H).

T_v past operation time.

Fig. (4) shows the flow chart for the computational procedure.

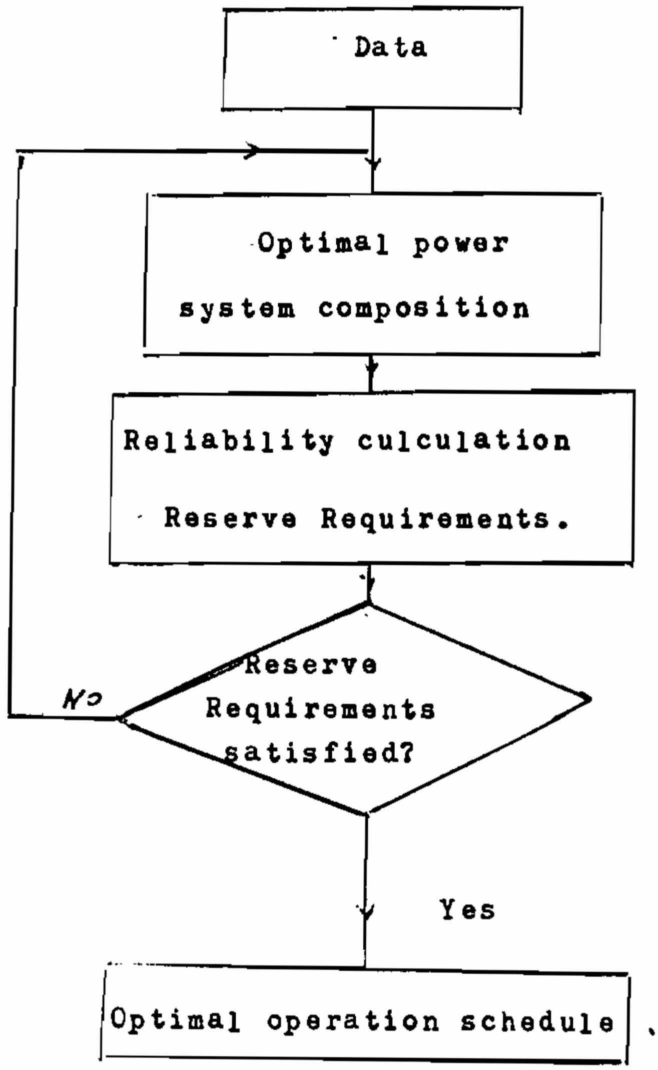

Data
Optimal power
system composition
Reliability culculation
Reserve Requirements.
Reserve
Requirements
satisfied?
No
Yes
Optimal operation schedule

Fig. (4)

5. CONCLUSION

It could be concluded that the economical reliability level for electrical power systems is affected mainly by the total cost of fast and slow reserve.

The required reliability of power system determines the requested fast-response and slow-response reserve.

The method presented discribes the evaluation of optimum power system operation with different values of reliability levels. The start up costs of the units and minimum-up times and minimum-down times of the units are of the factors considered.

The proposed linear equations represents the objective function and different restractions of power system operation as a function of reliability calculations appears to be a simple and sufficient accurate equation of this purpose.

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