Production Costs and Reliability Indices of a Power Generation System

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Abstract :

The expected production cost of a power generating system and associated reliability indices are estimated by proposed Modified Equivalent Energy Function method (MEEF). The proposed approach uses the daily load curves of the considered generation power plant,and the actual outage and fuel consumption rate of generation units. The method calculates the generation production cost function, loss of load probability (LOLP), the expectation of energy not supplied (EENS), and system minutes (SM). The proposed method takes into consideration the state of operation, load curve variation, the actual fuel consumption rate and unit outage rate. An illustrative application is presented using data of ABU-QIR power plant.

Key words: probabilistic production cost, equivalent energy method, power system reliability.

1- Introduction :

Power system production cost simulation was mainly used to simulate on computers the power generation management in power system, to forecast the electricity generation and carry out cost analysis as well as reliability analysis. The probabilistic production cost simulation (PPCS) considers the relevant uncertain factors like the future power load random fluctuation, and/or the random outage of generation units in operation. There are many simulation programs, but these programs differ in structure and algorithms. The main objective of (PPCS) is to be used for planning and also for laying out annual or monthly operation plans for existing power systems. The period for simulation could be a week or a day or even an hour, depending upon the specific demands.

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PPCS are usually carried out many times in order to formulate a reasonable power production plan or reasonable generation planning scheme. There are two proposed algorithms, cumulate method and the equivalent energy junction method.[1]

The Gram-Charalier series or Edgeworth series needs to be used for the cumulate method to compute function values and trapezoidal integration when checking is carried out. The amount of computation is much higher than that of the equivalent energy function method. Under some conditions, a generating unit may develop some partial faults or faults in some auxiliary equipment. Then, the output power can not reach the rated capacity and the unit is in de rated operation, so a multi-state power generating unit model has to be adopted for these situations. Reference [2] stated that the major features that may vary from the application of PPCS program than any other program, along the horizontal axis are long-range planning, fuel budgeting, operation planning, weekly schedules, and allocations of pool savings.

Reference [3] presented a realistic simulation model for the evaluation of generating units variable cost and cost of undelivered energy taking into account existing limitations. The model is applied to the IEEE RTS, for demonstration. The expected production cost of a multi area power system is estimated by constructing a sequence of upper and lower bounds [4]. The approach uses a state space characterization of equipment availability and loads, combined with network optimization methods and standard load duration curve based production costing techniques.

Reference [5], treated the problem of computing the expected value of generating system production costs through a Probabilistic production costing modes to forecast the cost of producing electricity. The most frequently used model of production costing is the one due to Baleriaux and Booth [6]. It provides an analytical formula for the expected production costs by using the load duration curve "LDC" and the forced outage rates of the generating units. This calculation can be quite time-consuming, and therefore many approximate methods have been developed to speed up the computations.

Reference [7], the authors proposed a method to perform probabilistic production simulation involving combined heat and fuel consumption (CHP). This is done by extending the probabilistic approach for power generation simulation to include heat as well. The probabilistic approach is based on two-dimensional probability load density functions.

By convolution of the combined heat and power units, the equivalent load functions are obtained and then determined the expected energy generation of the units, the expected un-served energy, and the expected overflow. It is shown that in (CHP) system a trade of between un-served energy and overflow energy is inherent and therefore the analysis is quantitatively different from analysis of systems with only power units. Reference [8] the authors proposed a technique where the frequency and duration are coupled with the equivalent load duration curve (ELDC) method. The paper deals to assess the complete load-leveling benefits of pumped storage units.

In this paper, the expected cost of power generating units and associated reliability indices are estimated by constructing a modified equivalent energy method. The proposed approach takes into account the units outage rate operation state, load curve variation, and the actual unit consumption rate. Also, the data used are representing real time power generation plant of Abu Qir Power plant, in Egypt.

2-1- Modified Equivalent Energy Function Methods, (MEEF)

Suppose the power generation load duration curve's probability distribution is [1].

$$P = f(x) = F(x)/T \qquad (1)$$

where T= investigated period

Divide the x (power) axis into sections of Δx lengths

A discrete energy function can be defined as

$$E(J) = \int_{x}^{x+\Delta x} F(x)dx = T\int_{x}^{x+\Delta x} f(x)dx \qquad (2)$$

in which

$$J = <x/\Delta x> +1$$

Here the bracket < > means an integer not greater then $x/\Delta x$.

$E(J)$ corresponds to the area under a section of load curve. If the system max. load is x_{max}, then the corresponding discrete variable is

$$N_E =< x_{max.}/D_x > +1$$

The power system total energy is

$$E_D = \int_{0}^{x_{max}} F(x)dx = \sum_{j=1}^{NE} E(J) \qquad (3)$$

where

$$N_E = < x_{max.}/\Delta x > +1$$

The equivalent energy function is an energy function that takes into account the influence of the generating unit random outage. Let the generating unit "i" is assumed to have a capacity of C_i and a forced outage rate of q^i, the equivalent load duration curve $f^{(i)}(x)$ can be expressed as

$$f^{(i)}(x) = p_i\, f^{(i-1)}(x) + q_i f^{(i-1)}(x-c_i) \qquad (4)$$

in which

$$p_i = 1-q_i$$

The above equation can be transformed into the corresponding equivalent energy function according to equation (2)

$$E^{(i)}(J) = T\int_{x}^{x+\Delta x} f^{(i)}(x)dx$$

substituting in equation (4),

$$E^{(i)}(J) = T\int_{x}^{x+\Delta x}\left[p_i f^{(i-1)}(x) + q_i f^{(i-1)}(x-c_i)\right]dx$$

$$= p_i E^{(i-1)}(J) + q_i E^{(i-1)}(J-K_i) \qquad (5)$$

in which

$$K_i = \frac{c_i}{\Delta x}$$

K_i is an integer because x is chosen to be the greatest common factor of all the generating unit capacities.

Assuming that there are "n" generating units in the power system, then the expected energy not served (*EENS*) is,

$$EENS = \sum_{J>J_n} E^{(n)}(J) \qquad (6)$$

and the loss of load probability *LOLP* is,

$$LOLP = \frac{E^{(n)}(J_n) + E^{(n)}(J_n+1)}{2T\,\Delta x} \qquad (7)$$

SM index is the ratio of energy loss due to power interruption as a result of insufficient system generation capacity over daily max. load.

$$SM = EENS / L_p \quad \text{minutes} \qquad (8)$$

in which

L_p = the daily max. load.

2-2- The Process of "MEEF"

The Processes of MEEF are as follows :

1. The primary data needed for the MEEF include load data, power generating units, rating, outage rate, fuel consumption rate and fuel price.
2. Define the state of operation according to the average fuel consumption rate and the priority to share load.
3. Calculate the actual energy output of each unit according to load-sharing order and then the total generated energy (TGE).

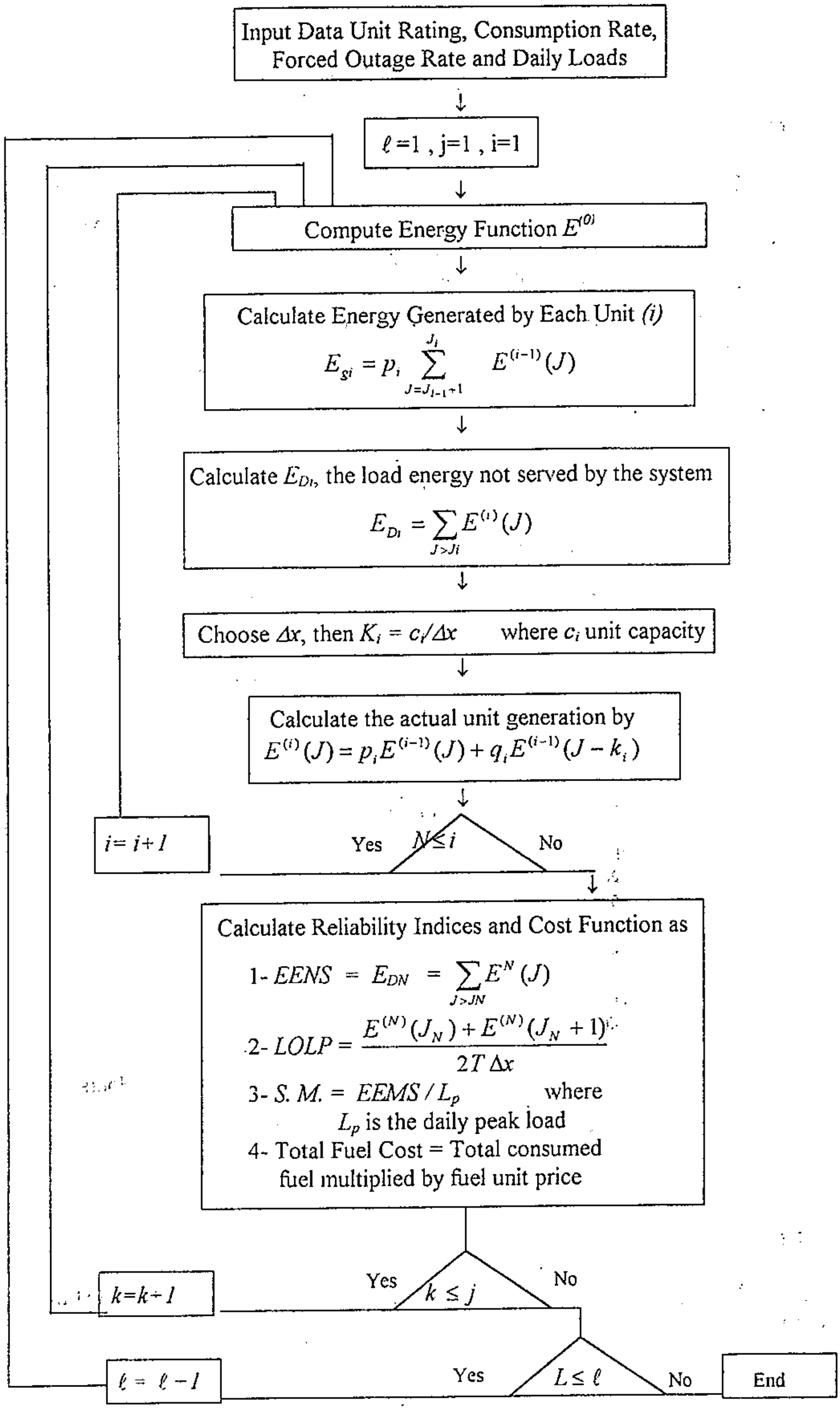

Fig (1) Flow chart of modified equivalent energy function method (MEEF)

4. Compute the total system's fuel consumption and the corresponding cost on the basis of every generating unit's energy output.

The flow chart of the above process is shown in Fig.(1)

3- Test System and Computational Procedures for the MEEF method:

3-1- Tested Power System

Abu-Qir thermal power plant located 25 km to the east of Alexandria and including five thermal units, their actual fuel consumption rate, power ratings and forced outages rate are given in Table (1) based on Jan. and Feb. 1998 operating conditions. The corresponding load curves are shown in Fig. (2).

Table (1) Generating units data

Unit	Rating (MW)	Forced Outage rate (h/day)	Fuel Consumption rate (g/kwh)
A	150	0.1900	225
B	150	0.3500	230
C	150	0.0100	232
D	150	0.1235	238
E	325	0.0300	210

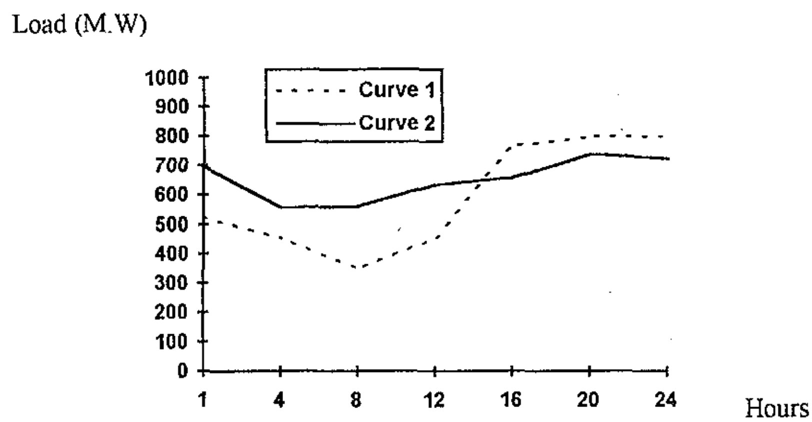

Fig. (2) Load curves

3-2 Computational Procedures

Among the probable operation states (120) we chose only 5 states that shown in table (2).

Table (2) Operation sequences of the chosen states

State of operation	Sequence of units of power plant
1	A - B - C - D - E
2	B - C - D - E - A
3	C - D - E - A - B
4	D - E - A - B - C
5	E - A - B - C - D

Using the data given in the table (1), the results given in table (3) (4) & (5) are obtained through a computer program.

Table (3) Calculated reliability indices and cost (load curve 1)

State	LOLP	EENS	SM	TGE	Cost
1	0.619	399	0.500	13344	45458
2	0.546	-31	-.0388	13775	46516
3	0.546	319	0.400	13424	45113
4	0.546	601	0.754	13142	43541
5	0.546	162	0.203	13281	44509

Table (4) Calculated reliability indices and production cost (load curve 2)

State	LOLP	EENS	SM	TGE	Cost
1	0.889	3152	4.26	12514	43228
2	0.454	681	0.920	14985	50419
3	0.454	526	0.712	15140	50465
4	0.454	1064	1.439	14602	48290
5	0.803	97	1.067	15587	51449

Table (5) Total Energy Generated
(Jan st *1998 & Feb* st *1998)*

Unit	1 Jan 1998	Feb. 1st 1998
1	2916.000	2916.00
2	2440.000	2340.00
3	3279.927	3564.00
4	2339.548	3034.00
5	2468.948	659.874

4- Results

Referring to Figure (3), in state 1, when the units 1-4 operated firstly and the unit 5, the LOLP is reached 0.889 while in state 2, when the unit 5 is operated firstly the LOLP is reached 0.4032 only.

EENS is very low in state 5, its 79.66 Mwh while in state 1 reached 3152.79 Mwh, state 2 reached 681.2, state 3&4 reached 526.9, 1064.898 Mwh respectively, this is display the importance of both unit size (capacity) , unit fuel consumption rate and opportunity synchronizing of units.

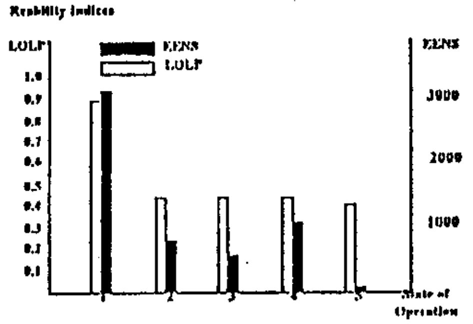

Fig (3) Reliability indices versus state of operation
Load Curve 1

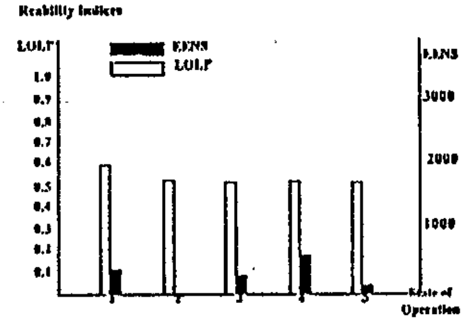

Fig (5) Reliability indices versus state of operation
Load Curve 2

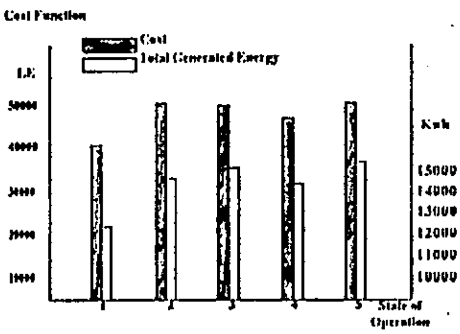

Fig (4) Cost function versus state of operation
Load Curve 1

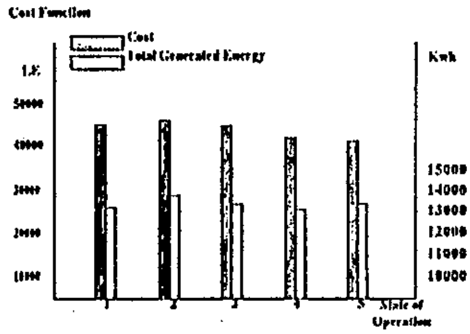

Fig (6) Cost function versus state of operation
Load Curve 2

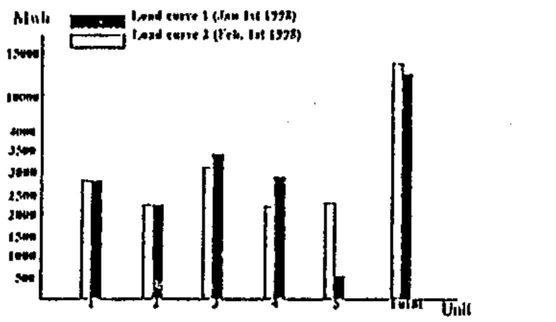

Fig (7) Generating unit energy through Jan 1st and Feb 1st 1998

Referring to Figure (4), the total energy generated in state 5 rather than other states, while it in state 3 higher than 1,2,4 which reflect the importance of synchronizing the fuel consumption rate of units.

The total cost of generated energy affected by the state of quotation, i.e. fuel consumption rate, unit synchronizing, fuel price and load curve profile. If we compare the results in table (3) & table (2), we found a large difference, this is due to the variation of load curve of connected loads to the power plant.

Figure (7) illustrate the generating unit energy at Jan. st and Feb. st, 1998 respectively.

5- Conclusions

The paper presents a new approach for calculating indices for the generating power plant corresponding to the production cost and reliability. The process of calculation takes into consideration the actual system data as load curve variation, actual fuel consumption rate, the probable sequence of unit operation, and the unit outage rate. The program is flexible. By aging of units the fuel consumption incremental is changed so the program is able to give the actual cost of operating according to that change.

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حساب مؤشرات الإعتمادية وتكاليف إنتاج
وحدة الطاقة الكهربية لمحطات التوليد الحرارية

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ملخص البحث

البحث يقدم طريقة "دالة الطاقة المكافئة المعدلة" (MEEF) لحساب تكلفة إنتاج وحدة الطاقة الكهربية المستهلكة (kwh) وحساب مؤشرات الإعتمادية المصاحب لها.

والطريقة المقترحة (MEEF) تعتمد على القدرة الإسمية لوحدات التشغيل ومنحنى الحمل اليومى لمحطة التوليد

الحرارية ومعدل استهلاك الوقود الفعلى لوحدات التوليد ومعدل ساعات الخروج من الخدمة للوحدات كما تأخذ فى الإعتبار حالة التشغيل أى ترتيب دخول الوحدات فى خدمة التشغيل اليومى.

والطريقة المقترحة تعتمد على البيانات الفعلية للمحطة ووحدات التوليد الحرارية حيث يتم حساب تكلفة انتاج وحدة الطاقة الكهربية المستهلكة (kwh) وحساب مؤشرات الإعتمادية وهى (LOLP) "إحتمال فقد الحمل" ، (EENS) "الطاقة الكهربية التى لم تُورد" وكذلك معامل (SM) "النسبة بين الطاقة التى لم تُورد على اقصى حمل يومى".

ولقد تم برمجة الطريقة المقترحة (MEEF) وتطبيقها على محطة توليد الكهرباء بأبو قير بالإسكندرية حيث تم إستخدام البيانات الفعلية لقدرات وحدات التوليد بالمحطة ومعدل إستهلاك الوقود الفعلى لكل وحدة وساعات الخروج الفعلية بسبب الأعطال وتم حساب تكلفة إنتاج الطاقة الكهربية المستهلكة الفعلية وكذلك مؤشرات الإعتمادية المصاحبة لها عند حالات تشغيل مختلفة وعند منحنى أحمال يومية مختلفة على المحطة.

ولقد أظهرت النتائج دقة ومرونة إستخدام الطريقة المقترحة (MEEF) حيث يمكن تعديل أى بيانات خاصة بوحدات التشغيل نتيجة لقدم الوحدات أو تغيير شكل الحمل على المحطة أو ترتيب دخول الوحدات خدمة التشغيل.