NEW LOSS-OF-LOAD PROBABILITY MODELS FOR STAND ALONE WIND TURBINE GENERATORS

نموذج جديد لاحتمالية فقد حمل مولدات تربينات الرياح المستقلة

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خلاصة - يقدم البحث نموذج جديد بحسب " احتمالية فقد الحمل " مولدات تربينات الرياح المستقلة . ويحتوى النموذج المقدم على خصائص منحنى الحمل لتوضيح الفترة الزمنية التى يتسبب الخرج خلالها فى نقد الحمل . والبحث يقترح أيضا نماذج رياضية جديدة اخرى تعبر عن التغير فى " احتمالية نقد الحمل " مع تغيير العوامل الهامة التالية :

١- معدل الخروج الاضطرارى لمولدات تربينات الرياح
٢- عدد التربينات المستخدمة (مع الحفاظ على قدرة مقننة كلية ثابتة)
٣- النسبة بين الحمل الاعظم والحمل الاصغر لمنحنى الحمل
٤- النسبة بين سرعة القطع والسرعة المقننة للتربينة
٥- السرعة المقننة للتربينات المستخدمة

النماذج الرياضية المستنتجة توضح ان قيم " احتمالية نقد الحمل " تتغير خطيا مع العوامل السابقة عدا العامل الاخير (السرعة المقننة للتربينات المستخدمة) . هذه النماذج تتنبأ باحتمالية لفقد الحمل وبالتالى تحدد اعتمادية مولدات تربينات الرياح المستقلة . والبحث يعرض فى نهايته تطبيق رقمى شامل يطبق فيه النموذج الرياضى المقترح لحساب " احتمالية نقد الحمل " ويناقش التطبيق تاثير العوامل المذكورة سابقا على ثمانية مواقع مصرية لها منحنيات سرعة رياح متميزة . وقد عرض البحث النتائج الهامة على رسومات توضيحية وجداول هامة ومناقشتها تفصيليا .

ABSTRACT :

This paper presents a novel approach to find the loss-of-load probability (LOLP) of a stand - alone wind turbine generator (WTG) . Introduced is the load duration curve to reflect the period during which an outage would cause a loss of load . New mathematical models are deduced describing the behaviour of LOLP against the salient factors , like forced outage rate , number of units , L_{min} / L_{max} and V_c V_R ratios and the rated wind speed . Except the later , the LOLP models have a linear characteristic against FOR . These models enable to predict the LOLP for any condition and thus evaluating the WTG reliability .

1 - INTRODUCTION

Importance and need for evaluating reliability of WTG either stand - alone or integrated ones are growing . The most important and essential measure is to estimate LOLP . This is because of increasing interest in WTG particularly for remote sites .

Previous methods for estimating such index have suffered from several problems . They were associated with the lack of good statistical wind data , the lack of a realistic wind turbine model , and the lack of planner's desire for what was considered to be a novel and relatively expensive source . Through the last decades , wind energy has become an attractive choice for electrical utilities and governments to be installed either as stand - alone or as integrated system . Large scale windfarms are being planned and installed in several sites world wide especially in the developed countries .

These considerations stimulate the planners and designers to evaluate the reliability of such generators . The loss - of - load probability as most significant index has been modeled , in this paper , for a stand - alone wind turbine generators hypothetically located in eight sites of discriminative wind data . Several mathematical models are developed to describe the LOLP variation against the forced outage rate taking into consideration the load demand and wind turbine generator characteristics . The composite effect of the units and wind speed regimes are also taken into account .

2 - STATEMENTS OF THE PROBLEM

The derivation of LOLP models for a wind turbine generator necessitates consideration of the following effects :

1 - The random nature of the wind
Thus a probabilistic model must be taken to approximate the wind characteristics at a particular site .

2 - The relation between the power output and the wind speed
This relation can be characterized by the operating parameters of the WTG considered that is the cut - in , cut - out and the rated wind speeds .

3 - The forced outage rate of the WTG
It expresses - in a probabilistic form , the level to which mechanical and / or electrical failures will modify the machines power output . The estimates of the forced outage rate (FOR) for turbine exist can be obtained from industry literature . Thus ,a cumulative distributation factor (CDF) for a single WTG,s capacity can be easily constructed .

4 - For a windfarm made up of many individual WTGs
The convolution of the CDSs of each turbine's capacity is performed as applied for combination of several thermal or hydro units . Here , the general equation for the output CDF of a windfarm made up of many individual WTGs published in Ref.[1] is used. It uses the product , rather than the sum of independent random variables .

5 - The daily load duration curve

Alternative ratios of L_{min} . L_{max} are investigated aiming at finding their unique effect on LOLP under certain turbine and wind speed conditions .

3 - METHODOLOGY OF SOLVING THE PROBLEM

Fig. 1 shows the flow chart of the solution algorithm . It can be stated in the following manner :

3.1 - WTG's output power

The output power of any wind turbine generator exposed to certain wind speed regime is estimated applying the following Equation [1] :

$$P_c(V) = \begin{cases} 0 & V < V_c \\ (A + BV + CV^2) . P_R & V_c < V < V_R \\ P_R & V_R < V < V_f \\ 0 & V > V_f \end{cases} \qquad (1)$$

where A, B, and C are constants found as functions of V_c and V_R defined as :

$$A = [1/(V_c - V_R)^2] \{V_c (V_c + V_R) - 4 V_c . V_R (V_c - V_R)^3 / 2V_R\} \qquad (2)$$

$$B = [1/(V_c - V_R)^2] \{4 (V_c + V_R) (V_c + V_R) / 2V_R - (2V_c + V_R)\} \qquad (3)$$

$$C = [1/(V_c - V_R)^2] \{2 - 4 (V_c + V_R) / 2V_R\} \qquad (4)$$

There is another form of $P_o(V)$ with a simple construction stated as :

$$P_o(V) = \begin{cases} 0 & V < V_c \\ (P_R / (V_R - V_c)) . (V - V_c) & V_c < V < V_R \\ P_R & V_R < V < V_f \end{cases} \qquad (5)$$

Shown in Fig.2 is the behaviour of $P_o(V)$ against wind speed as described by Equation (5) .

3.2 - WTG's output power probability distribution

Applying Equation (1) , (2) , (3) , and (4) with the insertion of wind speed groups , a discrete probability density function and / or cumulative distribution function may be determined as follows [1] :

a- The WTG's output power states as fraction of the rated power output are defined .

b- The total number of times that wind speeds result in a power output falling within one of the output states previously defined in a , is found .

c- The probability for each power state is computed by dividing the total number of occurrences for each state by the total number of data points .

3.3 - WTGS availability table

This table indicates the probability of some number of units being available at the windfarm . It is constructed using forced outage rates for the WTGs .

The WTG forced outage rates are as yet well defined . This is ascribed by the absence of long term operating data.Electrical and mechanical failures may result in these outages which include problems in the drive train , rotor , nacelle, or tower . Manufacturer's information indicates a FOR of less than 4 % while other sources lie in the 10 - 20 % range [1] .

A wind turbine generator can be represented by two states model : availability or unavailability . Thus the cumulative distribution function for a single wind generator i may be expressed by the discrete function F [1] :

$$F_i(x) = g_i u(x) + (1-g_i) u(x-1) \tag{6}$$

where , g_i = forced outage rate , and

$u(x)$ = unitstep function

Also , the probability distribution function , $f(x)$ is given by :

$$dF(x) / dx = f(x) \tag{7}$$

thus ,

$$F_i(x) = q_i (x) + (1-q_i)(x-1) \tag{8}$$

where , $F(x)$ = impulse function

If T is the total number of wind generators available ,then

$$T = I_1 + I_2 + \dots + I_n \tag{9}$$

where , I_i is a function defined as :

$$I_i = \begin{cases} 0 & \text{with probability } g_i \\ 1 & \text{with probability } 1-g_i \end{cases} \tag{10}$$

when n is the total number of WTGs at the site considered .Thus :

$$T_1 = I_1 \quad , \quad T_i = T_{i-1} + I_i \quad , i = 1,2,3,\dots,n \tag{11}$$

The CDF for T_i is given by [1] :

$$F_{T_i}(x) = \text{Prob}(T_i \le x) = \text{Prob}(T_{i-1} + I_i \le x) \tag{12}$$

conditioning on I_i given

$$F_{T_i}(x) = \int_{-\infty}^{\infty} P(T_{i-1} + I_i \le x \mid I_i = y)\, f_{I_i}(y)\,dy \tag{13}$$

$$= \int_{-\infty}^{\infty} F_{T_{i-1}}(x-y)\, f_{I_i}(y)\,dy \tag{14}$$

which is the convolution integral .

It can be simplified to [1] :

$$F_{T_i}(x) = F_{T_{i-1}}(x)\, g_i + F_{T_{i-1}}(x-1)(1-g_i) \tag{15}$$

But for WTG , statistical dependence must be considered because of the fact of if the wind is driving one turbine , it is surely driving the other as well .

Thus the capacity distribution function of a windfarm using only one type be installed at a site , so [2] ,

$$F_w(x) = \sum_{i=0}^{k} \left(\sum_{j=0}^{s} q_{ju}(x/i) - C_j \right) P_i \qquad (16)$$

where ,

s = number of wind capacity states .

c_j = j th capacity state ,

k = number of wind turbine at the farm .

P_i = probability of i units being available , and

q_j = probability of a wind turbine operating output state c_j .

3.4 - Loss - of - load probability [2]

The system capacity outage probability is combined with the system load duration curve to give the expected risk of loss of load . When the load exceeds the available generating capacity , a loss of load occurs [2] . Fig.3 shows a load duration curve .

Let :

O_g = Magnitude of gth outage in the capacity outage probability table .

P_g = Probability of an outage of capacity equal to O_g , and

t_g = Duration of time for which an outage of magnitude O_g would cause a loss of load .

If the magnitude of capacity outage is O_g , the remaining capacity which is available for supplying load is C_g .The load exceeds C_g only for the duration t_g . For the remaining duration , the load demand is less than the available capacity C_g . Therefore , the outage of magnitude O_g would cause a loss of load for time t_g .

The relative contribution of this outage to the overall system loss of load is the product of the probability of the existence of this outage (P_g) and the time for which this outage would cause a loss of load (t_g) . The total expected loss of load probability LOLP is the summation of all contributions due to the different capacity outages thus ,

$$LOLP = \sum_{g=1}^{n} P_g \cdot t_g \qquad (17)$$

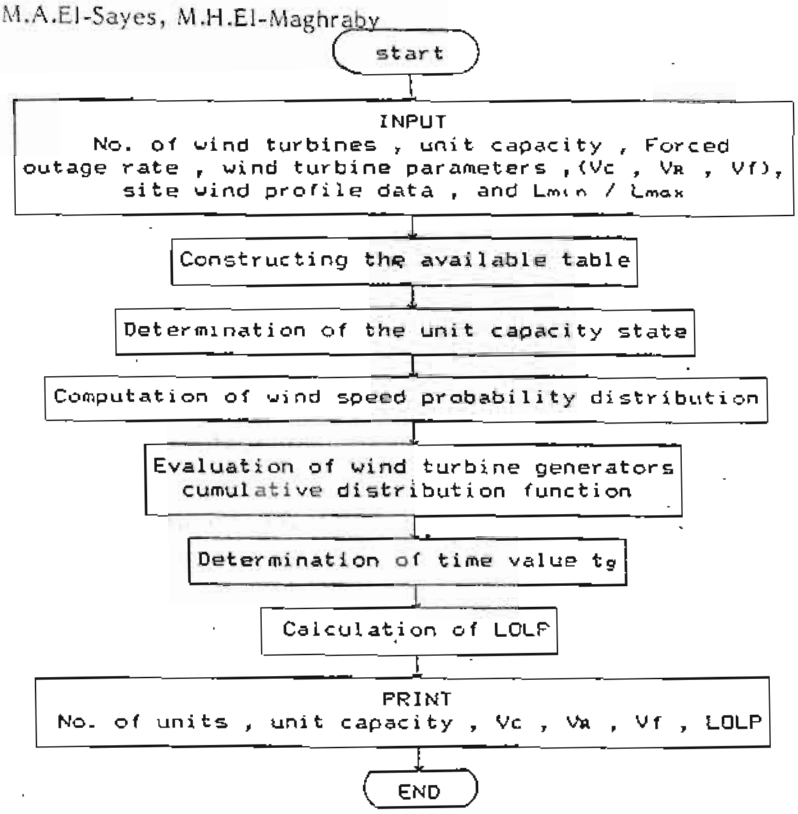

Fig.1 Flow Chart of the Solution Algorithm

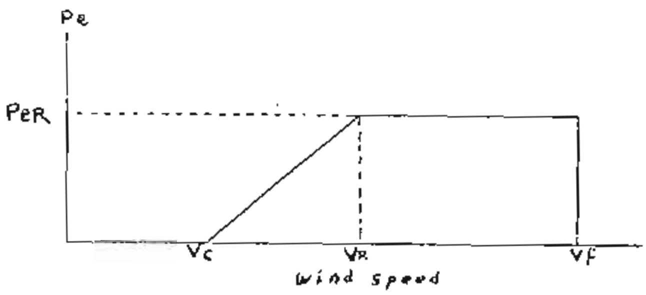

Fig.2 Wind Turbine Output Versus Wind Speed

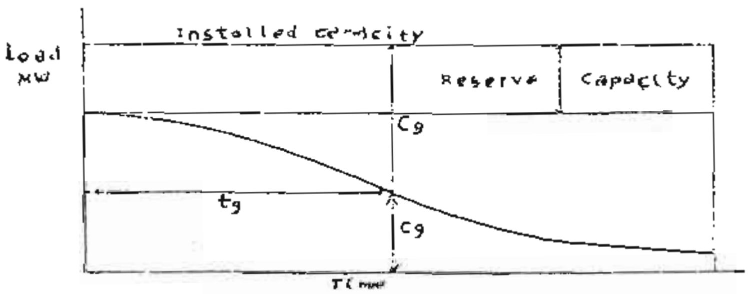

Fig.3 Load Duration Curve , Outage state , and Time

4 - NUMERICAL APPLICATION

The primary aims of this application is to carry first a complete analysis and discussion of the salient factors affecting LOLP . New mathematical models are developed as the second aim describing the behaviour of LOLP against such factors .

Eight sites are investigated with distinctive wind speed regime data . Different numbers of units composing the WTG rating are taken . Effect of alternative forced outage rates has been explored and analyzed .

The main characteristic of the daily demand is also varied to assess its influence on LOLP . The explicit influence of the rated wind speed has been determined for all examined sites . The relation between the cut - in and rated speeds has clear effect on LOLP of the WTG on having certain forced outage rate .

All these results are also plotted with full discussion as follows :

4.1 - Composite effect of number of WTG units and forced outage rate

For site 1 Fig.4.a shows the change of the LOLP versus the forced outage rate . The installed capacity of WTG is 16 MW .This can be obtained either by one unit of 16 MW rating (c) or of 2 units each of 8 MW (c) or 16 units each of one MW rating (c) . This number (N) is taken here as a parameter as shown . Linear characteristics are attained , however the lowest number of units (one only) has the highest LOLP . The following is the model developed out of the results obtained :

$$LOLP = m(FOR) + C \qquad (18)$$

where ,

$$m_1 = 26.0799\ (N)^{0.30425}$$

$$c_1 = \text{constant} = 66.665097$$

The coefficients here depend of course on the site and the following constraints and conditions :

$V_c = 4$ m/s , $V_R = 8$ m/s and $V_f = 10$ m/s

all concerning with site 1 .

For site 4 :

$$m_1 = 50.924769(N)^{.473745}$$

$$C_1 = 44.893857$$

Figs. 4.b , 4.d ,and 4.f display the behaviour of m against N for site 1 and 4 respectively . Figs. 4.c and 4.e show the variation of LOLP versus FOR for sites 4 and 5 . The FOR taken is ranged from 4 % till 20 % .

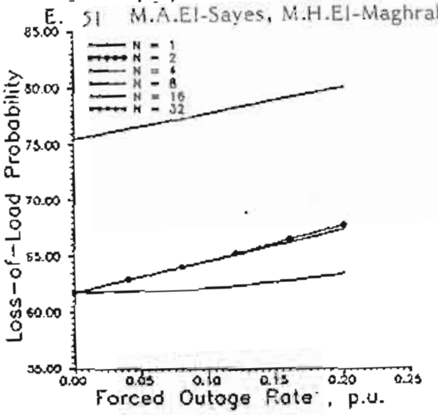

Fig.4.a EFFECT OF WIND TURBINE GENERATORS NUMBER ON LOSS-OF-LOAD PROBABILITY (SITE 1)

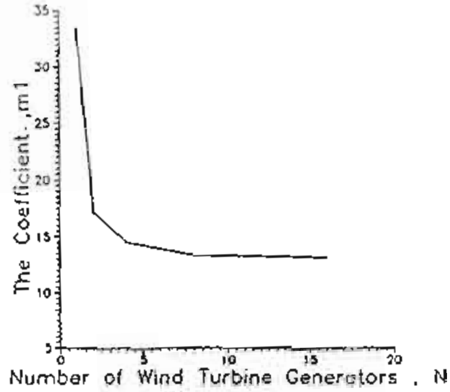

Fig.4.b The Coefficient , m1 for Different Number of Wind Turbine Generators , N (Site 1)

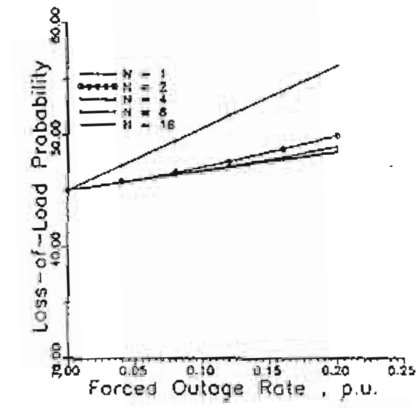

Fig.4.c Effect of the Number of the Wind Turbine Generators on the Loss-of-Load Probability (Site 4)

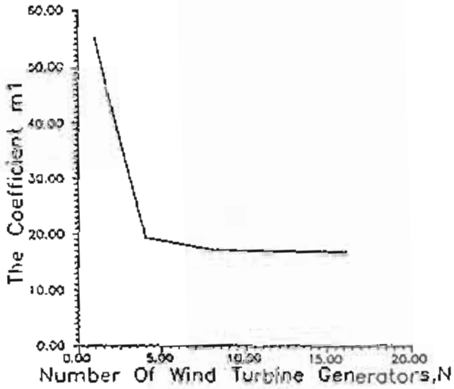

Fig.4.d THE COEFFICIENT m1 FOR DIFFERENT NUMBERS OF WIND TURBINE GENERATORS ,N (SITE 4)

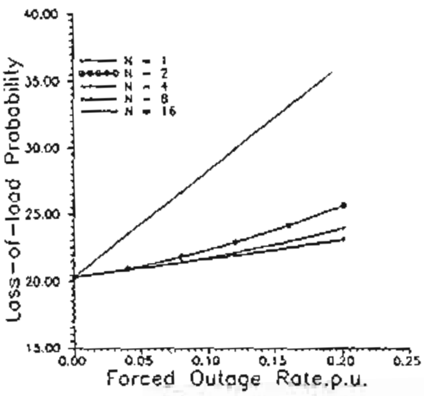

Fig.4.e THE EFFECT OF THE NUMBER OF THE WIND TURBINE GENERATORS ON THE LOSS-OF-LOAD PROBABILITY (SITE 5)

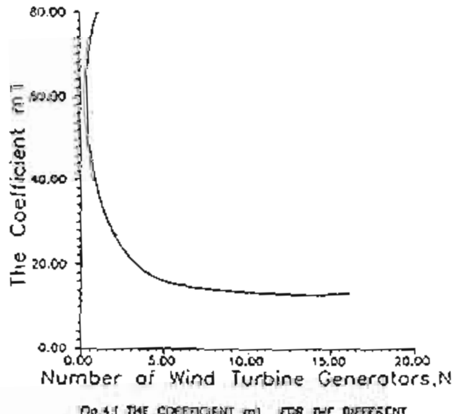

Fig.4.f THE COEFFICIENT m1 FOR THE DIFFERENT NUMBER OF WIND TURBINE GENERATORS , N (SITE 5)

4.2 - Effect of load characteristics

This is expressed as the ratio of minimum load (L_{min}) to maximum one (L_{max}), i.e. L_{min}/L_{max} . Case studies are accomplished for all eight sites however , the results for sites 1 , 3 , and 5 are only drawn and modeled as in preceeding item (4.1) . For site 1 Fig.5.a reveals the behaviour of LOLP against FOR with L_{min}/L_{max} ratio as a parameter . The following constraints are considered ; $N = 4$, c / unit = 4 MW , L_{max} = 8 MW , $v_c/v_R = 0.5$,

L_{min}/L_{max} = 0.2 , 0.4 , 0.6 , 0.8 , and 1.0 .

Derived is the mathematical model giving directly the effect of load characteristic on LOLP . Thus ,

$$LOLP = m_2 \; FOR + C_2 \qquad (19)$$

where ,

For site 1 :

$$m_2 = 13.25277 \; Exp \; (1.845030 \; (L_{min} / L_{max}))$$

$$C_2 = 80.114219 \qquad (FOR = 80 \%)$$

For site 4 :

$$m_2 = 27.418809 \; Exp \; (1.549085 \; (L_{min} / L_{max}))$$

$$C_2 = 62.445148 \qquad (FOR = 80 \%)$$

For site 5 :

$$m_2 = 47.827144 \; Exp \; (1.85426 \; (L_{min} / L_{max}))$$

$$C_2 = 54.630618 \qquad (FOR = 60 \%)$$

Figs. 5.c and 5.e show the LOLP - FOR relation for sites 4 and 5 taking L_{min}/L_{max} as a parameter . Figs. 5.b , 5.d , and 5.f display the behaviour of the coefficient m_2 against L_{min}/L_{max} for the sites 1 , 4 , and 5 respectively .

As L_{min}/L_{max} approaches unity , the LOLP index has larger ratios with the same FOR . This is clear for all sites .

4.3 - Rated wind speed

In this section the influence of v_R on LOLP has been estimated and plotted for several cases . Figs. 6.a , 6.d , and 6.g reveal the characteristics against FOR with v_R as a parameter . The following are the models against FOR :

$$LOLP = m_3 \; e^{C_3 (FOR)} \qquad (20)$$

where ,

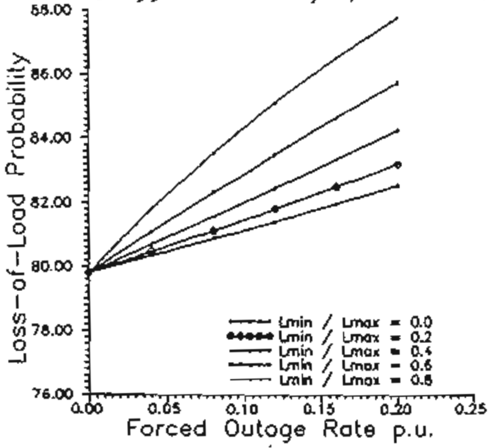

Fig.5.a LOSS-OF-LOAD PROBABILITY VERSUS FORCED OUTAGE RATE AND Lmin / Lmax IS TAKEN AS A PARAMETER (SITE 1)

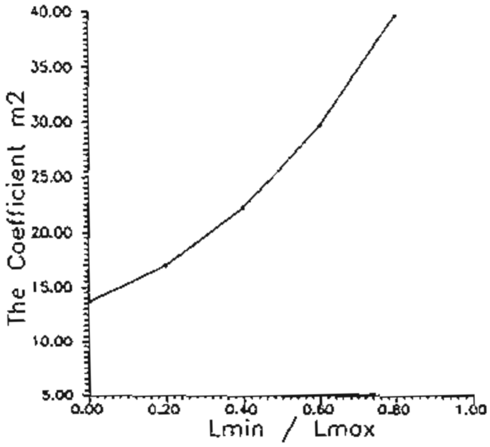

Fig.5.b THE EFFECT OF Lmin / Lmax ON THE LOSS-OF-LOAD PROBABILITY (SITE 1)

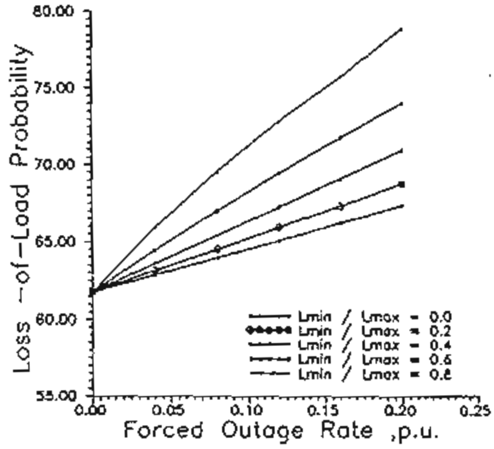

Fig.5.c THE EFFECT OF Lmin / Lmax ON THE LOSS-OF-LOAD PROBABILITY (SITE 4)

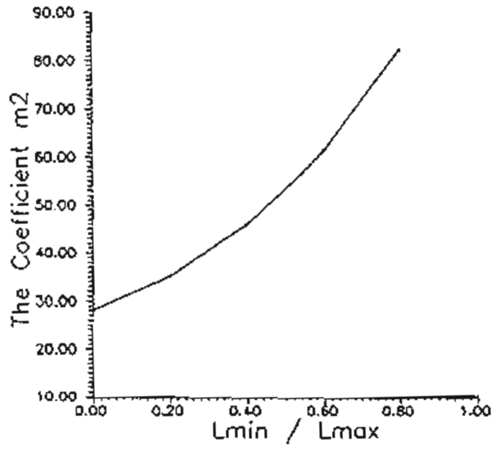

Fig.5.d THE COEFFICIENT m2 FOR DIFFERENT VALUES OF Lmin / Lmax (SITE 4)

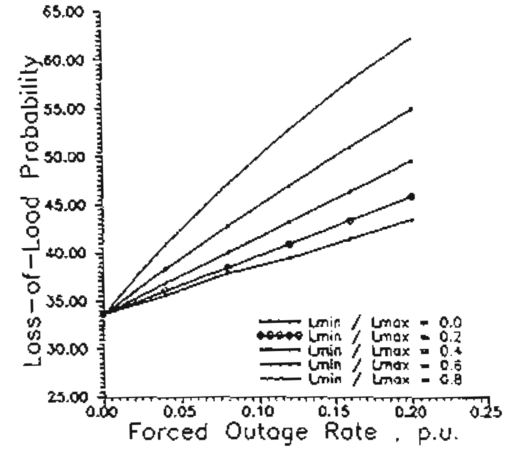

Fig.5.e THE EFFECT OF Lmin / Lmax ON THE LOSS-OF-LOAD PROBABILITY (SITE 5)

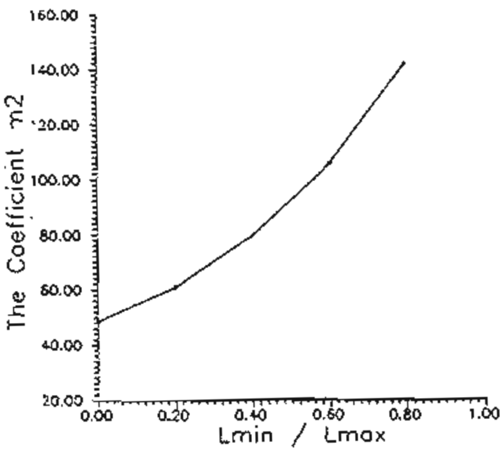

Fig.5.f THE COEFFICIENT m2 VERSUS Lmin / Lmax . (SITE 5)

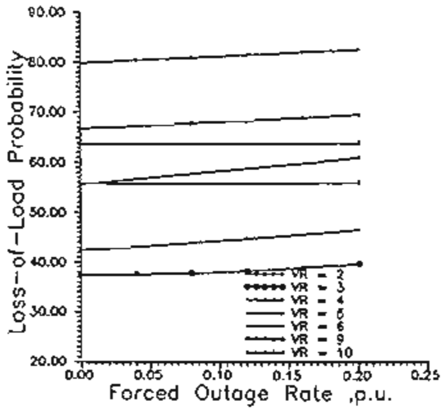

Fig.6.a EFFECT OF RATED WIND SPEED ON THE LOSS-OF-LOAD PROBABILITY (SITE 1)

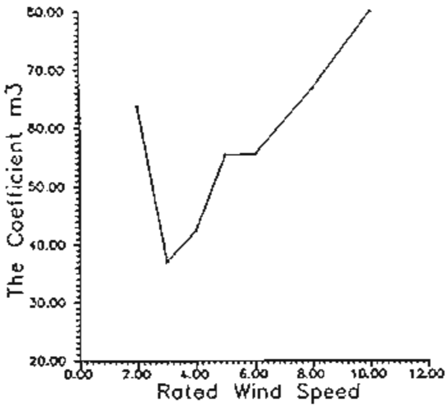

Fig.6.b THE COEFFICIENT m3 FOR DIFFERENT RATED WIND SPEEDS (SITE 1)

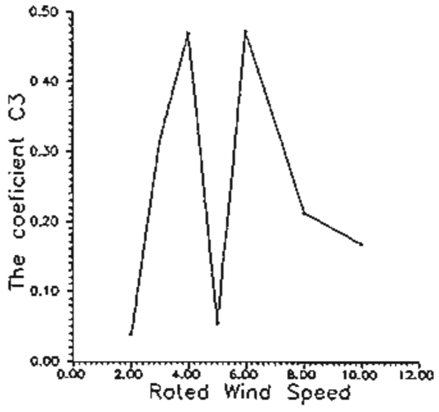

Fig.6.c THE COEFFICIENT C3 FOR DIFFERENT RATED WIND SPEEDS (SITE 5)

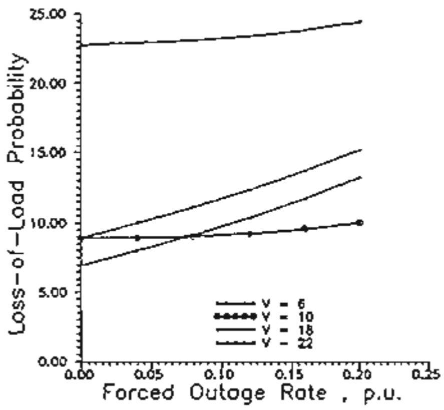

Fig.6.d LOSS-OF-LOAD PROBABILITY AGAINST FORCED OUTAGE RATE FOR DIFFERENT RATED,CUT-IN, AND CUT - OFF WIND SPEEDS (SITE 3)

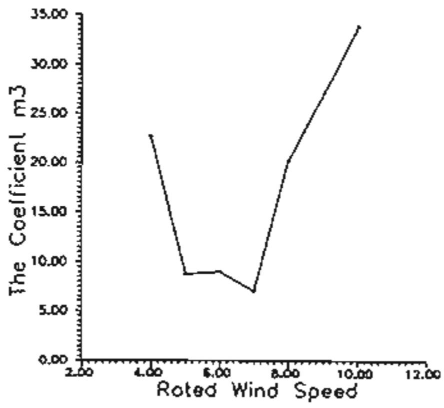

Fig.6.e THE COEFFICIENT m3 FOR DIFFERENT RATED WIND SPEEDS (SITE 5)

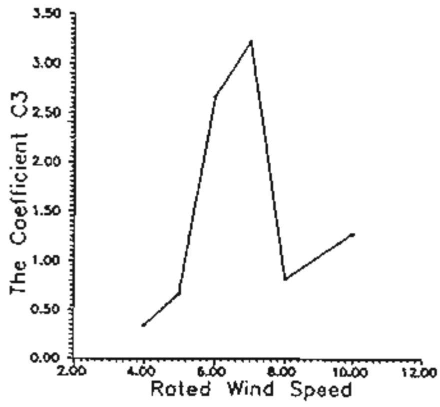

Fig.6.f THE COEFFICIENT C3 FOR DIFFERENT RATED WIND SPEEDS (SITE 5)

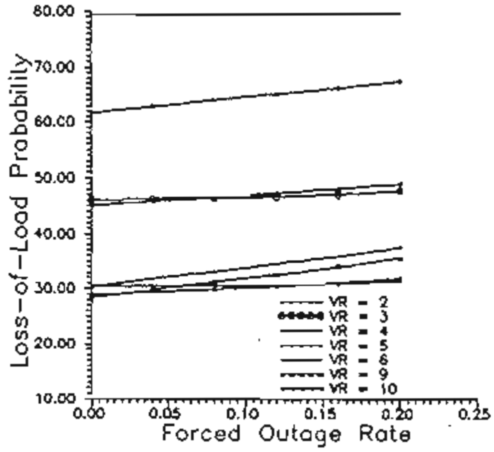

Fig.6.g THE EFFECT OF THE RATED WIND SPEED ON THE LOSS-OF-LOAD PROBABILITY OF THE WIND TURBINE GENERATORS , (SITE 4)

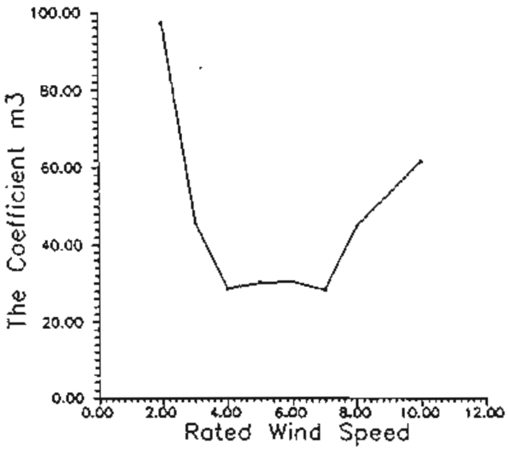

Fig.6.h THE COEFFICIENT m3 FOR DIFFERENT RATED WIND SPEEDS , (SITE 4)

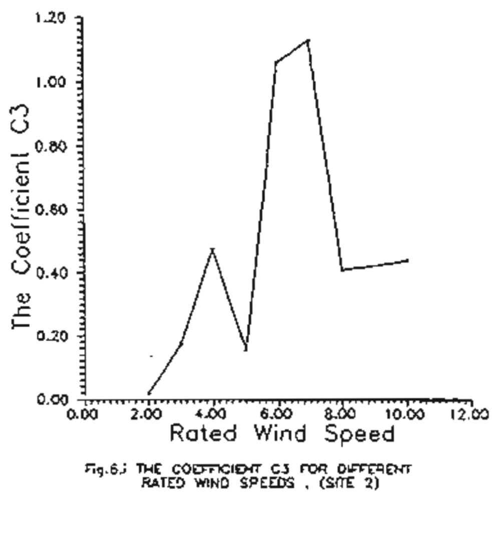

Fig.6.i THE COEFFICIENT C3 FOR DIFFERENT RATED WIND SPEEDS , (SITE 2)

v_R	site 1		site 4		site 5	
m/s	m_a	c_a	m_a	c_a	m_a	c_a
2	96.550	0.098	79.954	0.010	66.095	0.018
3	97.050	0.912	45.800	0.179	19.956	0.179
4	42.950	0.469	28.491	0.478	22.566	0.491
5	55.490	0.059	90.220	0.159	8.702	0.669
6	66.545	0.472	90.400	1.059	8.955	2.651
8	66.020	0.218	45.025	0.411	20.170	0.815
10	79.790	0.167	61.700	0.437	55.769	1.278

The following conditions are taken :

$v_c = 0.5\ v_R$, $v_r = 2\ v_R$, $L_{max} = 8$ MW . $L_{min} = 0$. $N = 4$ (each of which is 4 MW) .

The plot of the coefficients m_a and c_a versus v_R is shown in Figs. 6.b , c , e , f , h , and i for the aforementioned sites . One can remark the clear variation in their values on both dimensions : v_R and site . This consequently affects pronouncly LOLP .

4.4 - V_c / V_R ratio effect

The LOLP has been found here for several FORs with different v_c/v_R ratios ranged from 0.3 till 0.8 . The problem is also solved for all sites and revealed graphically for sites 1 , 4 , and 5 as shown in Figs. 7.a , 7.c , and 7.c , respectively . The relation of LOLP against FOR with v_c/v_R as a parameter is described mathematically as follows :

$$LOLP = m_4 . (FOR) + c_4 \qquad (21)$$

m_4 and c_4 are coefficients dependent appreciably on v_c/v_R ratio and the site under research . This can be explained in the following Table :

v_c/v_R	site 1		site 4		site 5	
	m_4	c_4	m_4	c_4	m_4	c_4
0.3	10.024	86.579	49.098	75.419	41.190	57.416
0.4	14.692	79.755	30.042	61.090	52.590	99.599
0.5	12.031	79.779	29.195	61.[illegible]	48.557	[illegible]
0.6	5.966	79.421	8.455	61.596	14.040	99.266
0.7	1.393	79.740	4.572	39.446	4.572	99.496
0.8	1.256	81.772	4.497	35.491	1.197	95.481

Figs. 7.d , e , and f reveal the change of m_4 versus v_c/v_R ratio for these sites .

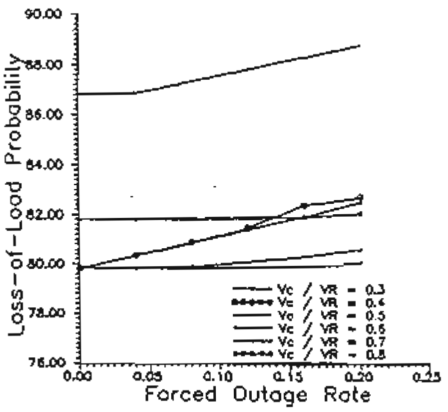

Fig.7.a EFFECT OF THE RELATION BETWEEN THE CUT-IN AND RATED SPEED ON THE LOSS-OF-LOAD PROBABILITY OF THE WIND TURBINE GENERATORS , (SITE 1)

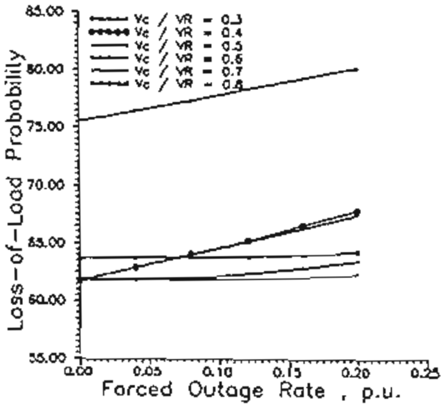

Fig.7.b THE EFFECT OF THE RELATION BETWEEN THE CUT-IN AND RATED SPEEDS ON THE LOSS-OF-LOAD PROBABILITY OF THE WIND TURBINE GENERATORS , (SITE 4)

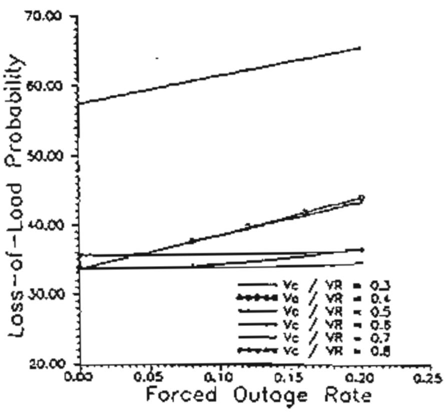

Fig.7.c EFFECT OF THE RELATION BETWEEN THE CUT-IN AND RATED SPEEDS ON THE LOSS-OF-LOAD PROBABILITY OF THE WIND TURBINE GENERATORS . (SITE 5)

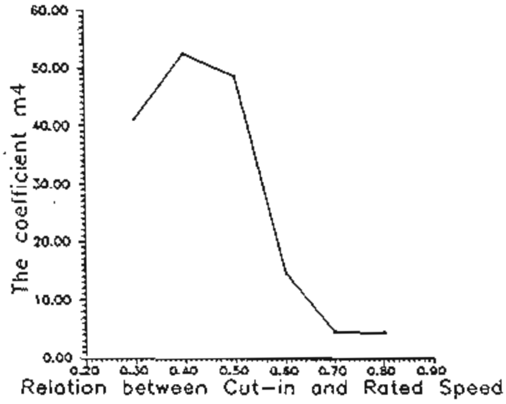

Fig.7.f THE COEFFICIENT m4 FOR DIFFERENT RATIOS OF Vc/Vr , (SITE 3)

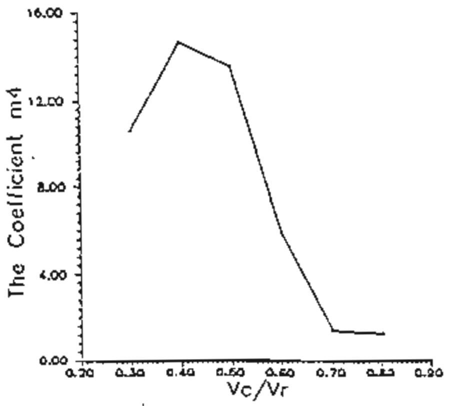

Fig.7.d THE COEFFICIENT m4 FOR THE DIFFERENT RATIOS OF Vc/Vr , (SITE 1)

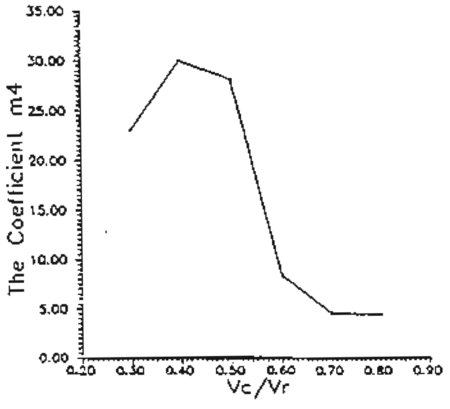

Fig.7.e THE RELATION BETWEEN THE VALUE OF THE COEFFICIENT m4 AND THE RATIO OF Vc/Vr (SITE 4)

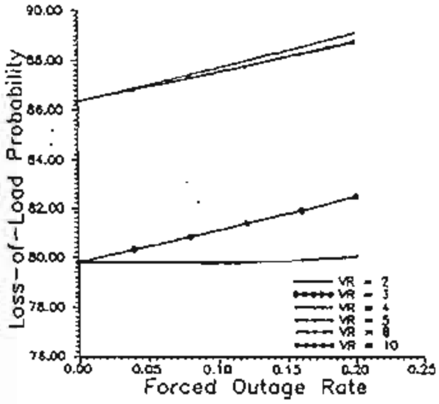

Fig.8.a EFFECT OF RATED SPEED ON THE LOSS-OF-LOAD PROBABILITY OF WIND TURBINE GENERATORS (SITE 1)

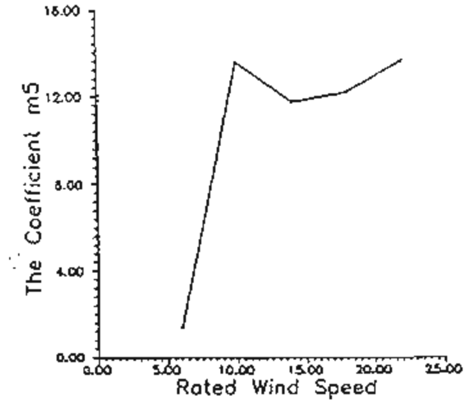

Fig.8.b THE COEFFICIENT m5 FOR DIFFERENT VALUES OF Vr (SITE 1)

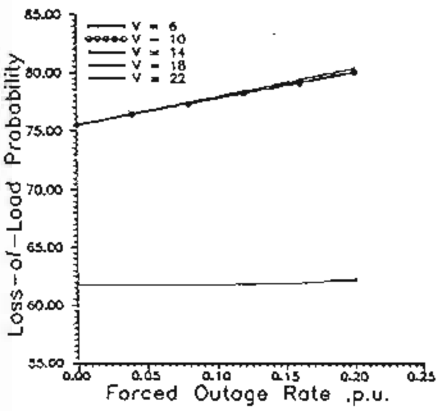

Fig.8.c EFFECT OF Vr ON THE LOSS-OF-LOAD PROBABILITY OF THE WIND TURBINE GENERATORS (SITE 4)

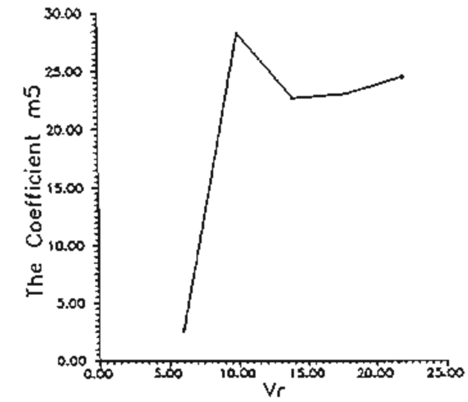

Fig.8.d THE COEFFICIENT m5 FOR DIFFERENT VALUES OF Vr (SITE 4)

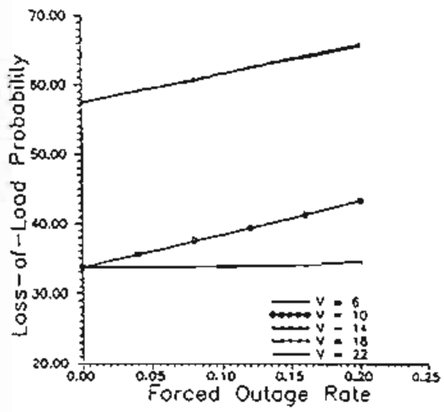

Fig.8.e EFFECT OF Vr ON THE LOSS-OF-LOAD PROBABILITY OF THE WIND TURBINE GENERATORS (SITE 5)

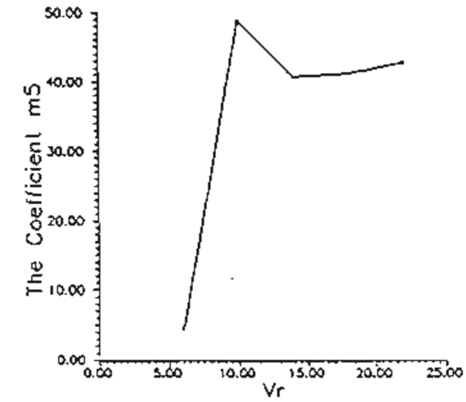

Fig.8.f THE COEFFICIENT m5 FOR DIFFERENT VALUES OF Vr (SITE 5)

4.5 - Effect of V_R and FOR with V_c , V_i , and N constants

Keeping v_c . v_i , and N units being constants , LOLP is computed for different FOR with v_R as a parameter . Figs. 8.a , c , and e show these variations against FOR for sites 1 , 4 , and 5 respectively . Their models are found in a simple linear form with m_5 as a slope and c_5 as the intersect with vertical axis . Thus we have :

$$LOLP = m_5 \cdot (FOR) + c_5 \qquad (22)$$

m_5 and c_5 are estimated for all v_R studied and sites considered and be tabulated in the following way :

v_R	site 1		site 4		site 5	
	m_5	c_5	m_5	c_5	m_5	c_5
6	1.992	79.740	2.095	81.068	4.572	38.496
10	13.021	79.772	28.234	81.790	48.812	39.010
14	11.754	90.369	22.082	75.495	40.732	57.420
18	12.181	80.348	23.098	75.475	41.159	57.410
22	12.034	80.308	24.509	75.489	42.809	57.829

m_5 coefficient is drawn for these sites in Figs.8.b , d , and f respectively .

5 - CONCLUSIONS

A novel approach is suggested here to estimate the most important reliability index (LOLP) for the wind turbine generators . Introduced is the load duration curve to reflect the effect of the time period during which an outage would cause a loss of load . The approach considers this index for the WTG units which are affected and dependent on the same input i.e. wind power .

The numerical application covers all the possible and important factors influencing LOLP . New mathematical models have been developed describing LOLP behaviour against each of these factors . Despite of their simplicity , all have good accuracy and matching the calculated values . Except the rated wind speed , the LOLP has a linear relation with FOR taking the number of WTG units , L_{min} / L_{max} , and v_c - v_R as a parameter in the following form :

$$LOLP = m \cdot (FOR) + c$$

However , with v_R as a parameter , LOLP has a model of the form :

$$LOLP = m \cdot e^{[illegible] \cdot FOR}$$

REFERENCES

[1] Paul Giorsetto , and Kent F.Utsurogi , " Development of a new procedure for reliability modeling of wind turbine generators " , IEEE Transactions on Power Apparatus and Systems , Vol. PAS - 102 , No. 1 , January 1983 .

[2] Imad Abouzahr , and R.Rakmakumar , " Loss of power supply probability of stand - alone wind electric conversion systems " , IEEE Transactions on Energy Conversion , Vol.3 , No.3 , September 1989 .

[3] Gary L.Johnson, " Wind Energy Systems ", Prentic - Hall . INC. Englewood Cliffs , N.J.07632. 1985 .

[4] Gary L.Johnson, " Economic Design of Wind Electric System, IEEE Transactions on power appratus and systems , Vol. PAS-97, no.2, March/April 1978 .