THE ANALYSIS OF SEQUENTIAL GROUND FAULTS ON A SIX PHASE GENERATOR IN PHASE CO-ORDINATES

تحليل الأخطاء الأرضية المتتابعة لمولد سداسى الأوجه

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__الخلاصة:__

نظرا لوجود حدود لكميات القدرة التى تستطيع خطوط النقل الكهربائية ثلاثية الأوجه نقلها فقد أستدعت الحاجه لنقل كميات ضخمة من القدرة الكهربائية من مكان لأخر. البحث عن نظم نقل بديلة للخطوط ثلاثية الأوجه. وتعتبر نظم النقل سداسية الأوجه من أنسب تلك للبدائل من الناحيتين الفنية والأقتصادية. ونظرا لأن تلك النظم لازالت فى طور البحث فان المعلومات المتاحة عن تحليل الأخطاء بها ونظم الوقاية المناسبة لها لازالت قليلة. ويمكن أعتبار هذا البحث محاولة لأثراء المعلومات المتاحة عن تحليل الأخطاء بتلك النظم.

ويتطرق هذا البحث بالتحليل لواحدة من أهم أنواع الأخطاء التى تتعرض لها نظم النقل سداسية الأوجه الا وهى الأخطاء الأرضية المتتابعة. ولهذا الغرض تم أستنباط نموزج رياضى يستخدم دالة خطوة الوحدة المتأخرة ونظرية أستمرارية التيار فى الممانعات الكهربية لحساب التيارات والجهود الخاصة بمولد كهربائى سداسى الأوجه عند تعرضه لأنواع مختلفة من الأخطاء الأرضية المتتابعة على أطرافه. وقد أوضحت النتائج التى تم الحصول عليها أنه يمكن أستخدام النموذج الرياضى المقترح لحل مشكلة حساب الكميات الكهربائية الناتجة عن الأخطاء الأرضية المتتابعة بشكل مباشر.

__ABSTRACT:__

Transmission of bulk power over high phase order transmission lines HPOT, is being eonsidered as a potential alternative to the conventional three phase lines. In practical, six phase systems appear to be favored. Should HPOT prove to be economieally and technically viable, the problem of fault analysis, in particular the analysis of sequential faults on HPOT system appears to be a complicated one.

When a ground fault on power system involves more than one terminal, the fault usually develops in sequence. This paper presents a generalized treatment of sequential ground faults on the terminal of an initially unloaded six phase symmetrical generator. No restriction is placed either on the sequence in which the ground fault develops or on the instants at which the various phases are grounded. Expressions for transient phase currents and transient terminal voltages have been given. An expression for the neutral current which is an important variable for any protection scheme has also been given. The method given in the paper ean be applied to a power system of any number of phases by suitably adjusting the summation index in general equations. The analysis has been done in actual phase variable. Finally, the results for an arbitrary sequential ground fault on the terminals of a fictitious six phase generator have heen given.

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INTRODUCTION

The possibility of transmitting bulk power over six or twelve phase transmission lines in preference to the conventional three phase lines has received the attention of many researchers. The advantages of multiphase transmission are higher transmission capacity of lines, lower conductor surface gradients with attendant reduction in corona power loss and radio interference, lower ground level field sand more economical utilization right-of-way. The last factor is bound to assume growing importance with the over increasing cost of land.

A case for multiphase transmission was presented by Barnes and Barthold [1] for meeting the future demand of electric energy. Subsequently many papers appeared on the feasibility of high phase order transmission [2-8]. The case for or against multiphase transmission must ultimately be decided by economic considerations. A survey of the literature reveals that if at all HPOT becomes economically and technically viable, six phase systems may be performed to twelve or higher phase systems. However, various problems associated with the change over to multiphase systems and with integrating multiphase systems with existing three phase grids must be thoroughly investigated both theoretically and experimentally. From the operational point of view the subject of fault analysis assume considerable importance in respect of protection, stability and reliability of multiphase systems. Bhatt et al [9] presented a complex transformation for the analysis of sustained faults on a six-phase system. This transformation is similar to the Fortescue transformation for the three phase systems. Individual faults were analyzed by some authors with the help of this transformation [10,11]. Sharma an Bhatt [12,13] presented a single equation based on this transformation, for the analysis of all ground faults. This equation could be applied to an n-phase system by modifying a few constants in the general equation. A generalized treatment of phase faults in symmetrical component co-ordinates has been given by Bhatt and Sharma [14]. For the transient analysis of six phase systems, two forms of Clark's transformation appear in [15,16]. However, the analysis of seqnential faults has not appeared in the literature as far as is known to the author.

This paper presents a method for the analysis of sequential ground faults on a six phase system. No restriction is placed either on the order of phases in which the sequential ground fault develops or on the instants of the voltage waves at which the phases are faulted. The analysis has been done in actual phase variables. The method has general nature and can be applied to a system of any number of phases by suitably adjusting the summation index in the general equations.

PRELIMINARY REMARKS

A six-phase symmetrical power system can be represented by a six-phase symmetrical generator, Fig.1. The resistance and inductance of each phase are r and L. The mutual inductance between any two phases is M. Closing switches S1 .....S6, not necessary in that order, simulates a sequential ground fault at the terminals of the generator. The switches S1 ....S6 are closed at instants t1 .....t6 respectively.

Define a diagonal matrix Ut by,

$$U_t = \begin{bmatrix} U_1 0.....0 \\ 0U_1 0....0 \\ 0.........0 \\ . \\ . \\ 0........U_6 \end{bmatrix} \quad (1)$$

where,

ui =u(t-ti) and u(t) is a unit step function. Also define a diagonal matrix U-t by,

$$U_{-t} = \begin{bmatrix} U_{-1} 0.....0 \\ 0U_{-2} 0....0 \\ . \\ . \\ 0........U_{-6} \end{bmatrix} \quad (2)$$

where,
u-i = u(ti-t)
obviously,
ut + u-t = u, the unit matrix. (3)

If the generator is symmetrical, the c.m.f vector $e = (e_1 e_2 ..e_6)^t$ can be written as,
e=column e_j.
where,
$e_j = \sin(\omega t - (j-1)\pi/3), ... j = 1,6$ (4)

The peak value of the e.m.f's has been taken as unity and the e.m.f of phase 1 has been taken as $\sin(\omega t)$.

THE CIRCUIT EQUATION

If the voltages across the switches of Fig.1 (terminal voltages) are $v = (v_1 v_2 ..v_6)^t$ when the generator phases carry currents $i = (i_1 i_2 ..i_6)^t$, the following equations can be written as

$$e_1 = v_1 + ri_1 + Li_1' + M(i_2' + ... i_6')$$
$$e_6 = v_6 + ri_6 + Li_6' + M(i_1' + ... + i_5') \quad (5)$$
or,
$$e = v + ri + (L - M)i' + MAi' \quad (6)$$

$$A = \begin{bmatrix} 11...1 \\ 11...1 \\ . \\ . \\ 11...1 \end{bmatrix} \quad (7)$$

and a dash over a variable indicates its time derivative.

TERMINAL CONDITIONS

There are twelve unknowns , six terminal voltages and six phase currents in Eq.(6). Beside this equation, six more independent equations, along with the initial conditions, are required for the complete solution for v and i. These equations are provided by the conditions at the terminals of the generator. The following statement is true for all terminals at any time.

At any time after a given phase has faulted to ground, its terminal voltage is zero and at any time before a given phase faulted to ground, the current throughout the phase is zero. These coditions can be written as,

$$U_t\, v = 0 \tag{8}$$

and

$$U_{-t}\, i = 0 \tag{9}$$

Example

If at any instant phases 1,2,5 and 6 have already been faulted to ground and phases 3,4 are healthy, then :

$$U_t = \begin{bmatrix} 100000 \\ 010000 \\ 000000 \\ 000000 \\ 000010 \\ 000001 \end{bmatrix} \quad \text{and}\; U_{-t} = \begin{bmatrix} 000000 \\ 000000 \\ 001000 \\ 000100 \\ 000000 \\ 000000 \end{bmatrix}$$

The presence of inductance in the circuit ensures that all phase currents are contiuous and the restriction of Eq.(10) will pose no problem when Eq.(6) is finally integrated between two switching instants.

TRANSIENT PHASE CURRENTS

Pre-multiplying Eq.(6) by Ut and substituting Ut V = 0, gives,

$$U_t\, e = r\, U_t\, i + (L-M)\, U_t\, i' + M\, U_t\, A\, i' \tag{11}$$

Since Ut will in general singular, it is not possible to obtain i from Eq.(11) by inversion However, adding $rU_{-t} + (L-M)U_{-t}\, i'$ (which is equal to zero from Eq.(9 and 10)) to the R.H.S of Eq.(11) and using Eq.(3), gives,

$$U_t\, e = r\, U\, i + (L-M)\, U\, i' + M\, U_t\, A\, i' \tag{12}$$

The matrix (L-M)U + MUt A is non-singular no matter how many terminals has been grounded at the instant considered. Now Eq.(12) can be solved for i by inversion.

Let,

$$P = (L-M)U + MU_t A \tag{13}$$

Equation (12) is then written as

$$i' + rP^{-1} i = P^{-1} U_t e \tag{14}$$

Both P^{-1} and Ut are, as cleared in fig.(2) discontinuous across any switching operation, but are constant between two successive switching instants. The integrating factor for Eq.(14) is $\exp(r\,t\,P^{-1})$, this gives,

$$d/dt\,(\exp(rtP^{-1})i) = \exp(rtP^{-1})P^{-1}U_t e \tag{15}$$

Integrating the above equation between t_α and t, $(t_\alpha \le t < t_{\alpha+1})$, gives

$$i = \exp(rtP^{-1})\left(\int_{t_\alpha}^{t} \exp(rtp^{-1}\,p^{-1}U_t\,e\,dt + \exp(rt_\alpha P^{-1})i_\alpha\right) \tag{16}$$

where i_α is the current vector at t_α. For the open time interval $(t_\alpha \le t < t_{\alpha+1})$, P^{-1} ant Ut are calculated by assuming S_α closed at t_α and $S_{\alpha+1}$ open at $t_{\alpha+1}$.

The particular structure of A enables one to evaluate i without the necessity of inverting P for each time interval.

Some useful properties of Ut and A are given in the appendix. The definition of α, β, S and the details of simplifying Eq.(16) are also given in appendix. The final expression for the current vector is,

$$\begin{aligned} i = {} & \frac{\alpha - bS}{S}\exp(-rt(\alpha - bS))\int_{t_\alpha}^{t}\exp(rt(\alpha - \beta S))U_t\,e\,dt \\ & + \alpha\exp(-rt\alpha)\int_{t_\alpha}^{t}\exp(rt\alpha)\left(U - \frac{U_t A}{S}\right)U_t\,e\,dt \\ & + \exp(-ta(t - t_\alpha))\left(\exp(rbS(t - t_\alpha))\frac{U_t A}{S} - \frac{U_t A}{S} + U\right)i_\alpha \end{aligned} \tag{17}$$

For computational purposes it is convenient to write the above expression in terms of the sequence reactance's of the machine. If the angular frequency of the e.m.f.'s is ω, the positive sequence reactance X1 and the zero sequence reactance X0 are defined by [11].

$X1 = \omega\,(L-M)$ and, $X0 = \omega(L+5M)$

Writing $X0/X1 = x$ and $6 + S(x-1) = y$, gives

$\alpha = \omega/X1$, $(\alpha - \beta S) = 6\omega/X1y$ and $\beta S = S\,\omega(x-1)/X1y$

Substituting the above variables in Eq.(17) and integrating it, the a.c and d.c components o the transient current in the jth phase can be found as,

$$i_j(ac) = \frac{U_j}{S}\sum_{k=1}^{6} U_k \sin(\omega t - (k-1)\pi/3 - \mu_1)/Z_1$$
$$-\frac{U_j}{S}\sum_{k=1}^{6} U_k \sin(\omega t - (k-1)\pi/3 - \mu_2)/Z_2$$
$$+U_j \sin(\omega t - (j-1)\pi/3 - \mu_2)/Z_2$$

and

$$i_j(dc) = -\frac{U_j}{S}\exp(-6\omega r(t-t_\alpha)X_1 y)\sum_{k=1}^{6} U_k \sin(wt_\alpha - (k-1)\pi/3 - \mu_1)/Z_1)$$
$$+\frac{U_j}{S}\exp(-\omega r(t-t_\alpha)/X_1)(\sum_{k=1}^{6} U_k \sin(\omega t_\alpha - (k-1)\pi/3 - \mu_2)/Z_2)$$
$$+\frac{U_j}{S}\exp(-r\omega(t-t_\alpha)/X_1)(\sum_{k=1}^{6} i_{\alpha k})(\exp(r\omega S(X-1)(t-t_\alpha)/X_1 y)-1)$$
$$-U_j \exp(-r\omega(t-t_\alpha)/X_1)\sin(\omega t_\alpha - (j-1)\pi/3 - \mu_2)/Z_2 + U_j \exp(-r\omega(t-t_\alpha)/X_1) i_{\alpha j} \tag{18}$$

where,

$$\mu_1 = \arctan(X_1 y/6r), \mu_2 = \arctan(X_1/r)$$
$$Z_1 = \sqrt{(r^2+(X_1 y)^2/36} \ldots \text{and..} Z_2 = \sqrt{(r^2+X_1{}^2)}$$

and $i_{\alpha j}$ is current in phase j at t_α the starting point of the time interval $t_\alpha \le t < t_{\alpha+1}$

Finally,

$$i_j = i_j(ac) + i_j(dc) \tag{19}$$

NEUTRAL CURRENT

For any protective scheme the neutral current i_n is an important quantity. It can be written as

$$i_n = Bi \tag{20}$$

where B = [1 1 1 1 1 1]

Equation (17) gives,

$$i_n = \frac{\alpha - \beta S}{S}\exp(-rt(\alpha-\beta S))\int_{t_\alpha}^{t}\exp(rt(\alpha-\beta S))U_t\, edt$$
$$+\alpha\exp(-rt\alpha)\int_{t\alpha}^{t}\exp(rt\alpha)\beta(U-\frac{U_t A}{S})U_t edt$$
$$+\exp(-r\alpha(t-t_\alpha))(\exp(r\beta S(t-t_\alpha)\frac{U_t A}{S}-\frac{U_t A}{S}+U)i_\alpha \tag{21}$$

Now,

$$BU_1 AU_1 e = S\sum_{k=1}^{6} U_k e_k \ldots \text{and} \frac{BU_1 A}{S} = B$$

Therefore,

$$i_n = \frac{\alpha - \beta S}{S}\exp(-rt(\alpha-\beta S))\int_{t_\alpha}^{t}\exp(rt(\alpha-\beta S))\{(\sum_{k=1}^{6} U_k e_k)\}dt$$
$$+\exp\{-r(\alpha-\beta S)(t-t_\alpha)\}i_{n(\alpha)} \qquad (22)$$

where $i_{n(\alpha)}$ is the neutral current at t_α

The a.c and d.c. components of the neutral current can be written as,

$$i_n(ac) = \sum_{k=1}^{6} U_k \sin(\omega t - (k-1)\pi/3 - \mu_1)/Z_1 \qquad (23)$$

$$i_n(dc) = \exp(-\delta\omega t(t-t_\alpha)/x_1 y)^*$$
$$\{\sum_{k=1}^{6} U_k \sin(\omega t_\alpha - (k-1)\pi/3 - \mu_1)/Z_1 + i_{n(\alpha)}\} \qquad (24)$$

Finally,

$$i = i\,(ac) + i\,(dc) \qquad (25)$$

If only the neutral current is desired, Eq.(23, 24&25) can be used to calculate it. However, if the phase currents have already been calculated, the neutral current can be obtained from Eq.(26).

For a sequential ground fault not involving all the six phases, the neutral current consists of a sinusoidal component and an exponentially decaying component with a time constant ($x1y\omega_t/6$). After all the six phases are grounded, the neutral current has no sinusoidal component, in this case,

$$\sum_{k=1}^{6} U_k \sin(\omega t - (k-1)\pi/3 - \mu_1) = 0.0 \qquad (26)$$

The corresponding neutral current is given by :

$i_{n(\alpha)} = \exp(-(t-t_\alpha)/(x_0/\omega_t))$ with a time constant ($x0/\omega_t$).

TERMINAL VOLTAGES

When all switches in Fig.(1) are open, the voltage across them are equal to the respective phase e.m.f's. During the faults, the terminal voltages are given by

$$v = e - ri - [(L-M)U + MA]\, i' \qquad (27)$$

Substituting for i' from Eq.(14) and using Eq.(A2) of the appendix for P^{-1}, gives,

$$v = e - ri - (U + aA)(U - \frac{a}{1+aS} U_t A)(U_t e - ri)$$

Simplification gives,

$$v = e - U_t e - \frac{a}{1+aS}(U - U_t) A U_t e + \frac{ar}{1+aS}(U - U_t) A i$$

or,

$$v_j = e_j - U_j e_j - \frac{a}{1+aS}\sum_{k=1}^{6} U_k e_k + \frac{a}{1+aS} U_j \sum_{k=1}^{6} U_k e_k + \frac{ar}{1+aS}\sum_{k=1}^{6} i_k - \frac{ar}{1+aS} U_j \sum_{k=1}^{6} i_k \qquad (28)$$

This equation can be written in terms of variables x and y as,

$$v_j = (1 - U_j)\{e_j - \frac{x-1}{y}(\sum_{k=1}^{6} U_k e_k - r i_n)\} \qquad (29)$$

It can be further simplified to :

vj = 0, Uj = 1 for faulty phases.

and

$$v_j = e_j - \frac{x-1}{y}\{\sum_{k=1}^{6} U_k e_k - r i_n\}, \ldots U_j = 0 \qquad (30)$$

for healthy phases

COMPUTER PROGRAM

A computer program was run to calculate the transient phase currents, terminal voltages and the neutral current. In fig.(3) are shown the six phase currents for a simultaneous 6-phase to ground fault at t = 0. The purpose of this run was to check the correctness of the program by observing that the current in phases (1, 4), (2, 5) and (3, 6) are equal and opposite and the neutral current is zero. Figures 4 (a....f) show the transient phase currents, their a.c. components and the terminal voltages when the six phases are grounded in an arbitrary sequence (1, 3, 2, 5, 6, 4) at t=0, 3.3, 6.7, 10, 13.3, and 16.7 ms, respectively. The frequency of the e.m.f's has been taken as 50 Hz. The neutral current for this set of sequential ground faults is shown in Fig.(5).

Although the total current in any phase is continuos across a switching operation, the d.c. and a.c. components are discontinues at each switching instant. The program incorporates the feature of bringing out this discontinuity. This is accomplished by calculating the a.c. and d.c. components of the current twice at any switching instant. : first assuming the switch open and secondly assuming it closed. The total current is, however, seen to be continuous as expected. The flow chart for the program is shown in Fig.(6).

CONCLUSIONS

By using delayed unit step functions and the principle of continuity of current in an inductive circuit, the problem of sequential ground faults in a multiphase power system can be solved by a fairly straight forward method.

APPENDIX

1- A property involving Ut and A

$$AU_t A = SA,.. \text{where } S = \sum_{k=1}^{6} U_k$$

where, U_k denotes the phase number already grounded at the instant under consideration.

Therefore,

$$(U_t A)^n = S^{n-1} U_t A \tag{A1}$$

2- Inverse of P

$$P = (L - M)\{U + aU_t A\}.\ a = \frac{M}{L - M} = (X_0 - X_1)/6X_1$$

$$P^{-1} = \frac{1}{L - M}\{U + aU_t A\}^{-1}$$

Expanding $\{U + aU_t A\}^{-1}$ as a power series in UtA and using Eq.(1) gives

$$P^{-1} = \frac{1}{L - M}\{U - \frac{a}{1 + aS} U_t A\} \tag{A2}$$

or,

$$P^{-1} = \alpha U - \beta U_t A \tag{A3}$$

with,

$$\alpha = \frac{1}{L - M} ..\text{and}.\ \beta = \frac{a\alpha}{1 + aS}$$

3- Simplification of Eq.(16)

$$\exp(rtP^{-1}) = \exp(rt\alpha)\exp(-rt\beta U_t A)$$

The six eigen values of $\beta U_t A$ are (βs,0, 0, 0, 0, 0). The diagonal matrix of the eigen values of $\beta U_t A$ is therefore, βsI, where I is the idempotent matrix.

$$\begin{bmatrix} 10\ldots0 \\ . \\ . \\ . \\ . \\ 0\ldots.0 \end{bmatrix}$$

If X is an eigen matrix of $\beta U_t A$ then ,

$$\exp(rtP^{-1}) = \exp(rt\alpha) X \exp((-rt\beta SI)X^{-1})$$

$$\ldots\ldots\ldots\ldots\ldots = \exp(rt\alpha)\{(\exp(-rt\beta s) - 1) XIX^{-1} + U$$

Since $\beta U_t A = X(\beta SI)X^{-1}$, then

$$XIX^{-1} = U_t(A/S)$$

Therefore,

$$\exp(rtP^{-1}) = \exp(rt\alpha)\{\exp(-rt\beta s)U_t(A/S) - U_t(A/S) + U\}$$

and

$$\exp(-rtP^{-1}) = \exp(-rt\alpha)\{\exp(rt\beta s)U_t(A/S) - U_t(A/S) + U\}$$

Substituting for $\exp(rtP^{-1})$,. $\exp(-rtP^{-1})$ and using

$P^{-1} = (\alpha U - \beta U_t A)$ in Eq.(16) gives Eq.(17).

REFERENCES

[1] L.O.Barthold, H.C.Barnes, "High phase order transmission" CIGRE study Committee No.31 Report, London 1972.
[2] S.S.Venkata, "Feasibility Studies of Higher Order Phase Electrical Transmission System (phase I)". Final Report to Allegheny Power System, Greensbrug, Pennsylvania, 1976-77.
[3] S.S.Venkata, "Feasibility Studies of Higher Order Phase Electrical Transmission System (phase II)". Final Report to Allegheny Power System, Greensbrug, Pennsylvania, 1977-78.
[4] S.S.Venkata, "Feasibility Studies of Higher Order Phase Electrical Transmission System (phase III)". Final Report to Allegheny Power System, Greensbrug, Pennsylvania, 1978-79.
[5] W.C.Guyker, W.H.Booth, M.A.Jansen, S.S.Venkata, E.K.Stanke, N.B.Bhatt, "138-KV, Six-Phase Transmission System Feasibility", Proceedings of the 1978 American Power Conference, Chicago, 11 Linois, April 25, 1978, pp.1293-1305.
[6] W.C.Guyker, W.H.Booth, M.A.Jansen, S.S.Venkata, "138-KV, Six-Phase Transmission System Feasibility. An Overview", Presented at the Pennsylvania Electric Association's Planning Committee Meeting, Valley Forge, Pennsylvania, May 1-2, 1979.
[7] W.C.Guyker. W.H.Booth, M.A.Jansen, S.S.Venkata, "138-KV, Six-Phase Transmission System Feasibility", Transmission and Distribution, October 1, 1979, pp.78-79.
[8] J.R.Stewart and D.D.Wilson, "Report on Feasibility of High Phase Order Transmission" (ERDA Contract and Development Administration), Feb. 1977.

[9] N.B.Bhatt, S.S.Venkata and others, "Six-Phase (Multi-Phase) Power Transmission: Fault Analysis" IEEE Trans.On PAS, Vol.96, May/June 1977, pp.758-767.
[10] J.L.Williams, "Fault Analysis and Components Schemes for Poly Phase Power Systems", Electrical Power and Energy Systems, Vol.2, pp.43-46, 1980.
[11] S.V.Tiwari and L.P.Singh, Six-Phase (Multi Phase) Power System: Some Aspects of Modelling and Fault Analysis", Electrical Power System Research Journal, No.6, 1983.
[12] R.D.Sharma and B.K.Bhatt, " A Generalized Treatment of Ground Faults in a Six-Phase Power System, Sequence Components and Equivalent Circuits", Journal of Institution of Engineers, India, Vol.68, pt EL I, August 1987, pp.12-20.
[13] R.D.Sharma and B.K.Bhatt, " A generalized Treatment of Ground Faults in a Six-Phase Power System-Circuit Breaker Currents and Voltage of Sound Phases", Journal of Institution of Engineers, India, Vol.86, pt EL I, August 1987, pp.21-29.
[14] B.K.Bhatt and R.D.Sharma, " generalized Treatment of Phase Faults on a Six-Phase Generator", Electric Power and Energy Systems, April 1988. in press.
[15] G.T.Heydt and R.C.Eurchett, "Discussion on Reference 9".
[16] S.N.Nanda, S.N.Tiwari and L.P.Singh, "Fault Analysis of Six Phase System", Electric Power System Research Vol.4, 1981, pp.201-211.

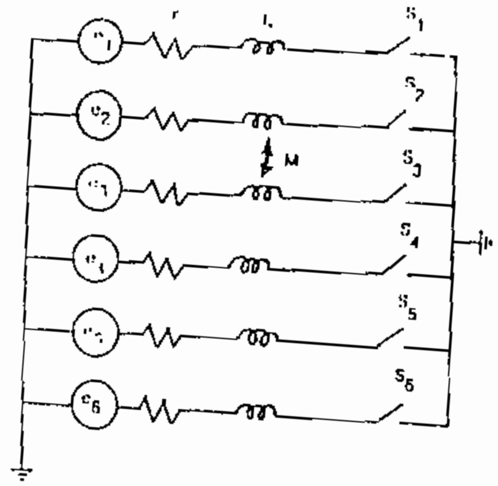


Fig. (1) A Six phase symmetrical generator.

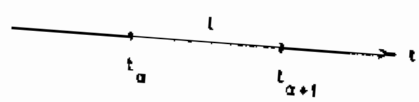


Fig. (2) Interval of integration

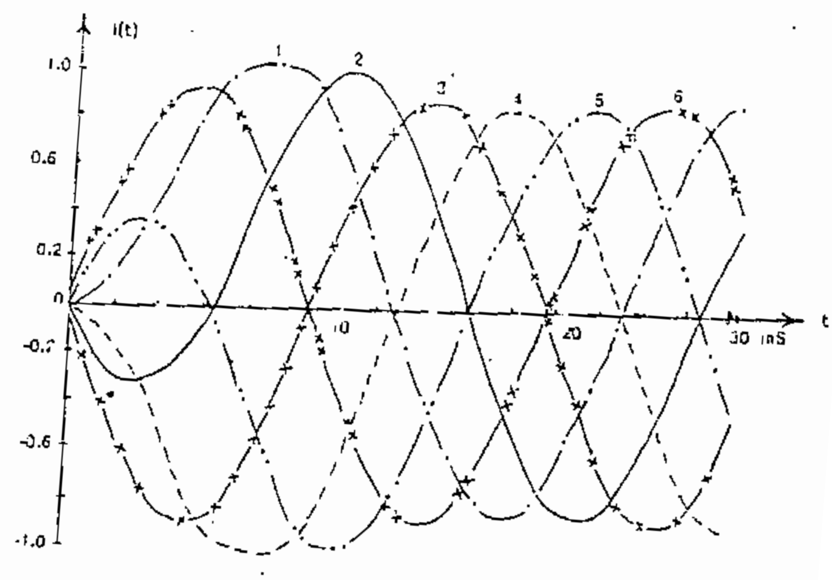
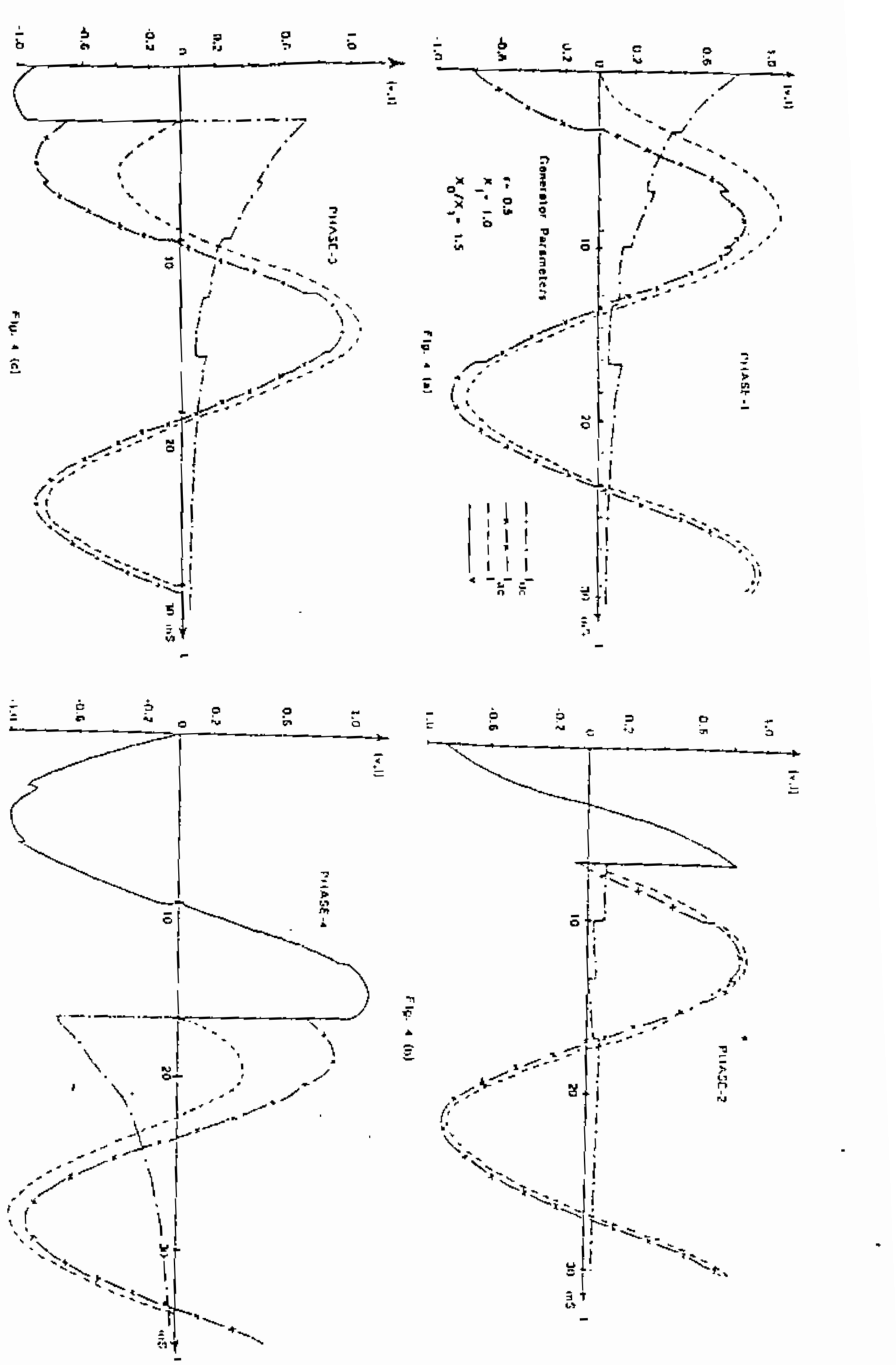


Fig. (3)

Simulteneous six phase to ground fault,

$r = 0.5$, $X_1 = 1.0$, $X_0/X_1 = 1.5$



4.(a...f) 1 3 2 5 6 4 - g sequential ground fault,
$r = 0.5$, $X_1 = 1.0$, $X_0/X_1 = 1.5$

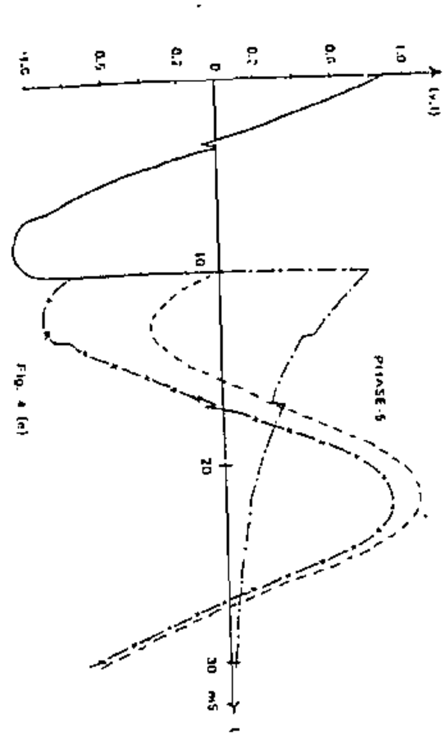


Fig. 4 (e)

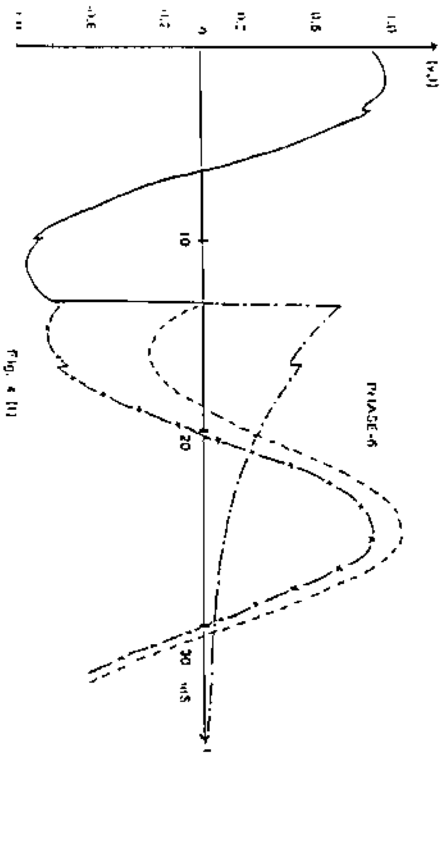


Fig. 4 (f)

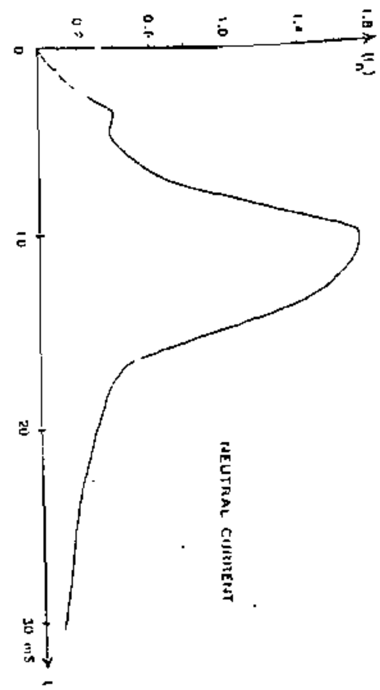


Fig. (5)

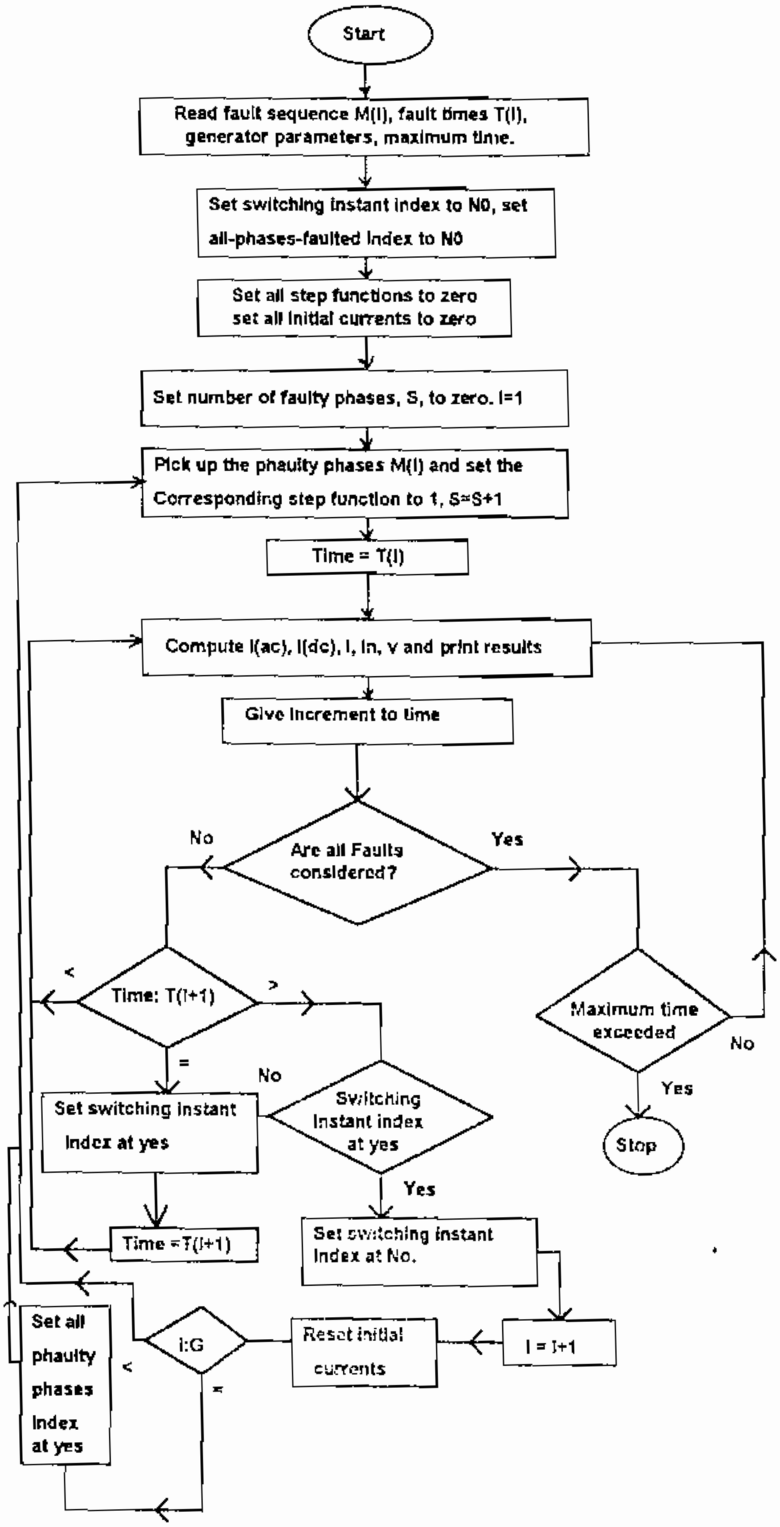

Start
Read fault sequence M(I), fault times T(I), generator parameters, maximum time.
Set switching instant index to N0, set all-phases-faulted index to N0
Set all step functions to zero set all initial currents to zero
Set number of faulty phases, S, to zero. I=1
Pick up the phaulty phases M(I) and set the Corresponding step function to 1, S=S+1
Time = T(I)
Compute I(ac), I(dc), I, In, v and print results
Give increment to time
Are all Faults considered?
No
Yes
Time: T(I+1)
<
>
=
Maximum time exceeded
No
Yes
Stop
Set switching instant index at yes
Switching instant index at yes
No
Yes
Time =T(I+1)
Set switching instant index at No.
Set all phaulty phases index at yes
I:G
<
=
Reset initial currents
I = I+1

Fig.(6)