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CALCULATIONS OF CAPACITIVE TAKE-OFF POWER(CTP) FROM HIGH VOLTAGE TRANSMISSION LINES

حسابات القوى السعوية من خطوط الجهد العالى

BY

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ملخص البحث: يقدم هذا البحث نموذج رياضى للحالات العابرة فى شبكة قوى سعوية ويمكن استخدامه أيضا فى شبكة حثية. وهذا البححث يقدم تصورا لمدى تأثير المفاتيح على الشبكات الكهربية وذلك بفرض قيم معاوقة لها. والنموذج المقترح يعتمد على المعادلات اللاخطية الناتجة من حدوث قصر وكذلك من الفيض الهارب والمرتبط بالملفات المنفصلة. والبحث أيضا يتعرض لكيفية تقليل الجهد العالى أثناء فترة القص: ويقترح طريقة عددية لحل المعادلات التى تم الحصول عليها. ولقد توصل البحث إلى ضرورة التحقق من النتائج الرياضية بتطبيقها على النموذج الطبيعى مما يؤكد مدى صحة هذه النتائج. وكذلك يعتبر توصيل مقاومة مع الحاثة على التوالى عامل هام لتقليل الجهد العالى والتوافقيات فى شبكة القوى السعوية.

ABSTRACT. This paper presents the constructions of capacitive take-off power (ctp) networks in different countries .Also,this paper illustrates the effect of switches on the stability of the network.

The station antena is built by connecting capacitive part of networks consisting of some condensers in specific arrangement.This arrangement of each type has series of specific singularities.The presented analysis of uses a technique that divides the problem into two parts; firstly,the capacitive condensers and reactors selection calculations; secondary, calculation of take-off power antena.

Also,it presents a mathematical modelling of the transient processes in a capacitive take- off power network.This model is based on the calculation of magnetic flux of a single -phase, two-winding transfomer.This model is represented by non-linear equations. The short circuit occurs along the steel core.and the leakage flux coupling the separated coils closes out the side of core. The mathematical model is developed to investigate the conditions of transient process analysis in a capacitive take-off power network. The reduction of overvoltage during short circuit period is also studied in this paper.Also, this paper suggests the solution algorithm using programme techniques. The final results and conclusions are presents.

INTRODUCTION. Special singularity of capacitive take-off power network may be considered as a resonance circuit consisting of a capacitive divider and non-linear inductive of transformation device.Therefore.the voltage of this capacitive transformer at transient process may induce appreciable distortion of secondary voltage.This is depended on the network parameters,moment of switching, disturbance type, character and value of secondary load current.At unsuitable relationships of parameters, ferroresonance appears in capacitive transformer voltage network [1 & 2].

Converting properties of compensating voltage dividers (CVD) are represented by 3-phase star connection of capacitances and inductances.CVD secure the tuning of their networks in industrial frequency,at which summation* of reactive addmittance arms equal to zero. An urgent problem during calculations is security of small voltage at selection condenser in the case of maximum load.It allows apply as self condensers,like auxiliary apparatus which have low isolation class for obtainning low cost network.The light loads of extra high voltage transmission lines (LLEHTL) may be used in the case of economical source reliability.Ordinary connection methods of LLEHTL,which are removed from the source and distribution systems,could't admit suitable economic.

For practical purpose,it must be known how autoparametrical oscillating conditions initiate, like dynamic transient process.For evaluation of capacitive take-off power networks special computer programmes are used.The computer programmes allow regenerate non-linear characteristic and modify parameters in wide range,represent serious problems in the case of any physical model [3].

CONVERTING PROPERTIES OF COMPENSATING VOLTAGE DIVIDERS

The converting properties of compensating voltage dividers [CVD] are represented by 3-ph.star connection of capacitances and inductances (Fig.1). First and second arm of CVD (fig.1-a) are connected between feeding line and earth,but third arm feeds the load.

CVD secure the tunning of their networks in industrial frequency,at which summation of reactive admittance arms Y_1,Y_2,and Y_3 equal to zero,and the resistance arms have different signs.This condition is expressed by the following formula:-

$$Y_1 + Y_2 + Y_3 = 0 \qquad (1)$$

Arms Y_1 and Y_2 are connected between the line and earth,which are represented by voltage divider and change in requiring line voltage relation.The third arm Y_3 fulfils compensation in industrial frequency of Y_1 & Y_2 and secure them from overloading. Voltage dividers, at which reactive admittances Y_1 and Y_2 have one homogeneous case, and an unhomogeneous case with different sign.

Main CVD parameters are output voltage, which couple with feeding voltage of transmission line and divider coefficient, K_d,

$$K_d = V_{ph} / V_{eq} = [Y_1 + Y_2] / Y_1 \qquad (2)$$

where:- V_{eq}- equivalent voltage,equal to load voltage at open circuit.

For substation with capacitive voltage dividers (SCVD):-

$$K_d = V_{ph} / V_L = [C_1 + C_2] / C_1 \qquad (3)$$

For substation with inductive voltage dividers (SIVD):-

$$K_d = [L_1 + L_2] / L_2 \qquad (4)$$

The vector diagrams of SCVD and SIVD are homogeneous with load current I_L at lagging power factor.From the previous equations induce that the voltage vector V_L be in phase with phase voltage V_{ph} and have low value.This secure their operate in decreasing line voltage condition in the low side of transformers.

CALCULATION OF CAPACITIVE NETWORKS TAKE-OFF POWER (CTP).

An urgent problem during calculations is security of small voltage at selection condenser in the case of maximum load.It allows apply as self condenser, like auxiliary apparatus which have low isolation class for obtainning low cost network. Decreasing voltage V_{c2} may be controlled by increasing selection condenser capacitance. More accuracy may determine optimal parameters by comparing different variables. But choosing of orientation ability condenser capacitive at known value of capacitance determine the relationship of it's cost with equivalent voltage value.The cost of condenser approximately may be written an expression:-

$$A = K_1 . C . V^2 \qquad (5)$$

where:- K_1- coefficient,which characterise construction data type ;

C and V- capacitance and voltage of condenser.

From equation(5) and according to condenser cost A_{c2}:-

$$V_{c2} = [A_{c2} / (K_1 C_2)]^{1/2} = \{ (A_{c2} V_{eq}) / [K_1 (V_{ph} - V_{eq}) C_1] \}^{1/2} \ ; \qquad (6)$$

$$C_2 = C_{eq} - C_1 = C_1 [(V_{ph} / V_{eq}) - 1] \qquad (7)$$

Voltage on lower divider element (Fig. 1.a) is determined by voltage on transformer and reactor with constant part of $V_L = V_T = V_{eq}$ and variable part of V_L, which are changed in value and phase:-

$$V_{c2} = V_{eq} + V_L = V_{eq} + j\, I\, X_{Leq} \qquad (8)$$

Absolute voltage value is :-

$$V_{c2} = \{ V_{ph}^2 (C_1 / C_{eq})^2 + (2 S \sin O / w C_{eq}) + S^2 / (V_{ph} w^2 C_1^2) \}^{1/2}$$

$$= \{ V_{eq}^2 + (2 P \tan O / w C_{eq}) + P^2 / (V_{eq}^2 w^2 C_1^2 \cos^2 O) \}^{1/2} \qquad (9)$$

By comparison between Eq.(9) and Eq.(6),obtain the relation $A_{c2} = f (V_{eq})$.For simplification of analysis without errors maybe removed negative elements, which have the following relation :-

$C_1 \qquad C_2 \quad C_{eq}$ then:-

$$A_{c2} = V_{eq} V_{ph} K_1 C_1 + (S^2 K_1 / V_{eq} V_{ph} w^2 C_1) + (2 S K_1 \sin O) / w \qquad (10)$$

Equivalent voltage value, which according to minimum cost of selection condenser is occured by equating the derivative of expression(10) by V_{eq} to zero,from this :-

$$V_{eqmin} = S / w C_1 V_{ph} = V_{Lmax} \ ; \qquad (11)$$

$$V_L = P / (w C_{eq} V_{eq} \cos O) = P / (w C_1 V_{ph} \cos O) \qquad (12)$$

More suitable specify equivalent voltage approach to voltage drop on reactor at full load. By using the value of V_{eq} V_L uniquely is occured condenser capacitance value :-

$$C_2 = C_1 [(V_{ph} / V_{eq}) - 1] \qquad (13)$$

From this discussion remark that,at large take-off powers,which give rise to high value of V_L and V_{c2}, may be indicated suitable specify decreasing value V_{eq} for reducin transformer insulation and auxilliary equipments. In these cases, when allowable voltage value of selection condenser is given condition at computing take-off network, may use for determining its capacitance by differentiate formula (9):-

$$C_{eq} = \{(w\,C_1^2V_{ph}^2)/(w^2C_1^2K_2^2V_{ph}^4 - S^2)\}.\{S\sin O + [w^2C_1^2K_1^2V_{ph}^2 - S^2\cos^2 O\,]^{1/2}\} \quad (14)$$

where:- $K_2 = V_{c2} / V_{ph}$

At choosing of divider upper elements , its capacitance is found at selected power and allowable voltage drop on reactor values.From Eq.(12):-

$$C_1 = P / (\,w\,V_{ph}V_L\cos O\,) \quad (15)$$

For take-off power networks, when linear relation of condenser is used,the relationship V_{c1max} V_{ph} is regorously specified condition.Check of its observance may be fulfilled by the following formula :-

$$S = S = w\,C_1V_{ph}^2\,\{(C_2 / C_{eq})\sin O + [\,1 - (C_2^2/ C_{eq}^2)]^{1/2}\,) \quad (16)$$

With the calculation of preceding may be specified following sequence of devices *main paramerters of capacitive take-off power :-*

1) V_{Lmax} is determined by given values of S_1 , C_1 and V_{ph} ;

2) V_{eq} may be chosen according to V_{Lmax} (V_{eq} V_{Lmax}) ;

3) Capacitance values are $C_{eq} = C_1(\,V_{ph} / V_{eq}\,)$; $C_2 = (\,C_{eq} - C_1\,)$;

4) Manufacturing evaluation of V_{c2max}; V_{Lmax} and V_{eq} ;

5) By take-off power S and equivalent voltage may determine step-down transformer parameters and choose transformer type ;

6) Check allowable given load by voltage value of condenser C_1 ;

7) For all regions of loads with transformer current I_x calculation, selection device characteristics V_{c2} , V_{c1} and V_L are determined by analysing or graphic method ;

8) On the base of obtained characteristics, main and auxilliary devices insulation degree are ability their security is checked at using capacitive equipment ;

9) Make calculation of take-off power device external characteristics check at approximately variable equipments active resistance values.

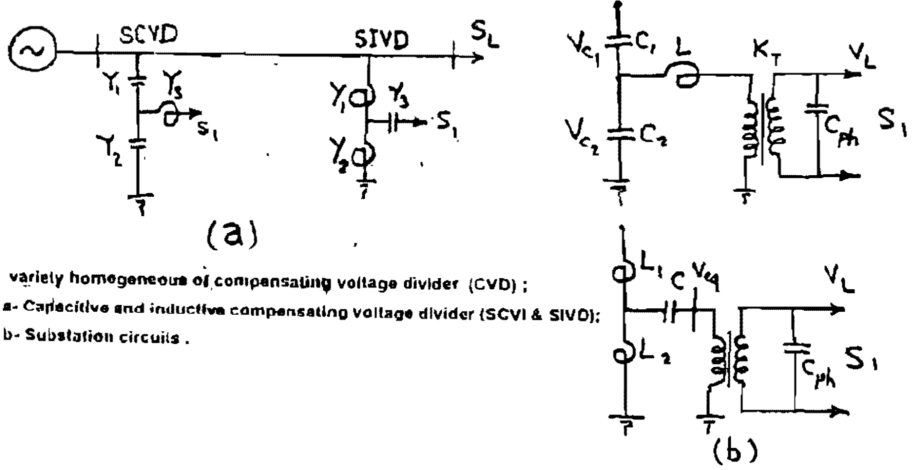

Fig.1 variety homogeneous of compensating voltage divider (CVD) ;
a- Capacitive and inductive compensating voltage divider (SCVI & SIVD);
b- Substation circuits .

INDUCED VOLTAGE AND ARRESTOR CAPACITANCE CALCULATIONS

The Problem is solved by the use of mirror image method.At the calculation of conductor sag must take into account the replacement of conductor by equivalent conductors.The equivalent conductors height may be determined from the following equation:-

$$d = H - (2/3)\, h_s \qquad (17)$$

where:- H- support points height from the ground;

h_s- conductor sag.

Take into account the consideration system is linear,which induced voltages V_4 & V_5 on conductors arrestor may define as a resultant of all conductors interaction summations:-

$$[V] = [a] \cdot [q] \qquad (18)$$

where:- [V] - matrix of phase voltages;

[a] - matrix of potential coefficients;

[q] - matrix of linear charges.

Potential coefficients of self a_{nn} and mutual a_{nm} are determined by the following forms:-

$$a_{nn} = K_{eq}\, b_n (2 h_n / r_n);$$

$$a_{nm} = K_{eq}\, b_n (B_{nm} / a_{nm}) \qquad (19)$$

where:- K_{eq} - electrostatic coefficients = 18 X 10^6 km/F;

r_n -radius of n<u>th</u> conductor;

h_n - height of n<u>th</u> conductor over ground surface;

B_{nm} - distance between conductors n and image conductor m;

a_{nm} - distance between conductors n & m.

Capacitances are determined by geometrical parameters and dielectric permeability of surrounding medium.The capacitances are suitablly calculated as follows: -

a) determine capacitances with self values counting as follows:-

$$C_{nm} = C_{nm} + {}^{5}\{[(C_{in}C_{im})/(C_{in}+C_{im})]-[(C_{nn}C_{nm})/(C_{nn}+C_{nm})]-[(C_{mm}C_{nm})/(C_{mm}+C_{mn})]\} \qquad (20)$$

where:- C_{nm}, C_{in}, C_{im}, C_{nn} and C_{mm}- are partial capacitances of conductors.

b) determine self capacitances ofconductors as follows:

$$C_{nn} = {}^{5}\ C_{in} \qquad (21)$$

c) determine capacitances with counting of self capacitances as follows:-

$$C_{nm} = C_{nm} + (C_{nn}\, C_{nm}) / (C_{nn} + C_{nm}) \qquad (22)$$

TRANSIENT PROCESS STUDY

As shown in Fig.3,the experimental investigations of voltage capacitive divider simulator by extent of exposure can be considered as two typical disturbance types:-

i) Light or small disturbance - occurs when voltage capacitive divider (VCD) networks are connected; and

ii) Heavy or large disturbance - occurs when short circuit at intermediate transformer terminals,is switched off.

Transient process analysis,at small disturbances, is very important for determining values and durations of secondary voltage distortion. Also, it is suitable, at large disturbance, for preventation ferroresonance stable cnditions [4]. At large disturbance, the reactor volt-ampere characteristic (Fig.4) may affect the transient process initial conditions.This is true because short circuit current value depends on the non - linear inductive compensating degree [5]. For studying transient processes,selection of transformer equivalent circuit is very important because resonance property is mainly determined by the relationship of volt-amperes characteristic of intermediate transformer divider at no-load.

The known non-linear models of local single-phase,two-winding transformer are based on the distribution or division of the magnetic flux, generally, for two transformer coils. These coils are closed by the steel core. Large flux is coupled with separated coils, which are closed out side of core.Constructed T- models equivalent circuit by these models is very suitable to represent normal loads operations and transient processes conditions. But these models are unsuitable for research conditions of transient processes in the case of separated coils unsymmetrical loading,for example magnetization current surge.For satis-fying this and other requirements,it is necessary to use the -nominal equivalent circuit of transformer.The transient process in networks with capacitive take-off power research,can be classified into three modes(Fig.3).These modes are:-

i) Connecting capacitive take-off power device,in this mode key S_1 is closed and keys S_2 & S_3 are opened;

ii) Connecting load, in this mode keys S_1 and S_2 are closed and key S_3 is opened, and

iii) Short circuit of load,in this mode all keys S_1 & S_2 and S_3 are closed.

MATHEMATICAL MODEL

In this work, the proposed mathematical model is constructed to represent all the above three cases.This model may utilize for analyzing transient processes as in capacitive take-off networks,like in inductive networks (Fig.5). From this figure:-

$$V_{ph} = V_{d1} + V_{d2} + V_{s1} \qquad (23)$$

where:- $V_{d1} = (1/C_1) \quad i_{d1}\, dt$;

$V_{d2} = (1/C_2) \quad i_{d2}\, dt$;

$V_{s1} = i_{d1} Z_{s1} = i_{d1} R_{s1} + L_{s1}\, p\, i_{d1}$;

From Eq. (23):-

$$V_{ph} = (1/C_1) \quad i_{d1}\, dt + (1/C_2) \quad i_{d2}\, dt + i_{d1} R_{s1} + L_{s1}\, p\, i_{d1} \; ; \qquad (24)$$

$$i_{d1} = i_{d2} + i_p \; ; \qquad (25)$$

$$V_{d2} - L_p\, p\, i_p - V_p - V_{T1} - V_y = 0$$

$$V_{d2} - (L_p\, p - R_p - R_{T1})\, i_p = N_1 A_r\, p\, (B_r - L_{sc}) \; ; \qquad (26)$$

$$V_y - V_{sc} - V_r = 0$$

$$N_1 A_y\, p\, (B_y - L_{sc}) - L_{sc}\, p\, i_1 - N_2 A_r\, p\, B_r = 0 \; ; \qquad (27)$$

$$V_r - V_{T2} - V_{sc} - V_L = 0$$

$$N_2 A_r p B_r - i_2 R_{T2} - i_L (R_L + R_{s2} + L_{s2} p) = 0 \quad ; \qquad (28)$$

$$B_y = B_r (A_r / A_y) - F_s / (A_y R_m) \quad ;$$

$$i_2 = i_L + i_{sc} \quad :$$

$$i_p = (l_y H_y - F_s 0 / N_1 \quad ;$$

$$i_2 = (l_r H_r + F_s) / N_2$$

where:- $L_{sc} = F_s L_{sc} / (N_1^2 A_y)$; $F_s = R_s O_s$; $R_s = N_1^2 / L_{sc1} = N_2^2 / L_{sc2}$;

$V_y = N_1 A_r p (B_r - L_{sc})$; $V_r = N_2 A_r p B_r$; $p = d / dt$.

To solve these equations, a self- constructed mathematical model is used. This model is based on the solution of a simple first order differential equation using any suitable numerical method.Here,in this paper,Rung-Kutta method is used to calculate magnetic flux then find V_{d1}, V_{d2} and V_{p1} against time. Of course the proposed mathematical model is accomplished carry out on the computer using its algorithm and FORTRAN program.

To carry out it,it must be accompanied by the following procedures:

1- Input data (e.g. N_1, N_2, l_r, l_y, A_r, A_y,..........) are known;

2- Initial conditions(variable values at t=0 e.g. I_{Lo},B_{ro},B_{yo},i_2,L_{sc1o},L_{sc2o},.....) are calculated.

3- Use the disturbance of Rung - Kutta method to compute the different valuse of voltages by changing time t from t = 0 to t =t+ where is choosed suitable interval to obtain high degree of frequency.

4- Repeat the previous step to obtain the final results.

5- Repeat the above two steps(2&3) for load equal to zero (i.e. no-load condition).This is fulfilled by opening key S_2.

OBTAINED RESULTS

After using the mathematical model to solve the equations,the obtained final results are recorded in the form of relations between voltages and time in two cases:-

a-closing the key S_2 (i.e. system is loaded);

b-opening the key S_2 (i.e. system is unloaded).

From Fig.6,it is noticed that the amplitude variation is the same in case(a) or (b).But in Fig.7, in case (a) it is shown that a sudden change in voltage is occured and becomes nonsinusiodal waves.The change does not exceed 2 % of the fundamental harmonic. In the case (b) harmonics are noticed.

From Fig.8,it is noticed that,the amplitude is not changed in the case (a) and another harmonics are appeared.But in case (b) the voltage amplitude is changed, overvoltage surge does not exceed 13% of the fundamental amplitude and another harmonics are also appeared. Obtained short circuit results at the reactor in capacitive take-off network (figs. 6, 7 & 8)proved, that' short circuit at transformer intermediate outputs has no effect on the divider voltage elements of first arm (arm of C_1).But it affects the second arm (arm of C_2) elements and also the compensation reactor.Many subharmonics are appeared in the case of second arm loaded system and compensation reactor loaded or unloaded system.

CONCLUSIONS

1)This paper presents the construction of capacitive take -off power (CTP) networks and their calculations for high voltage transmission lines (HVTL).

2) The paper has proposed a suitable mathematical model for obtaining the influence of transient processes (short circuits) on the elements of voltage divider .This model is a universal one and may be used as for capacitive as for voltage divider.Determined divider network may be simulated with specified parameters and applied researching. Mathematical results are checked for physical models.This check verifies the applicability of mathematical models.

3)Reducing the phase voltage decreases the overvoltage at divider elements during the short circuit across the compensating reactor of take-off power.

4)Connection of active resistance in series with the compensating reactor is considered as the most effective agent supressing overvoltages and in capacitive take - off power networks.

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NOMENCLATURE

V	Phase voltage;
V_{c1} & V_{c2}	Potential difference between two parallel plates of C_1&C_2(divider arms 1&2);
i_{c1} & i_{c2}	The current in the first and second arm respectively;
i_p & i_2	Reactor and transformer secondary winding current respectively;
i_L & i_{sc}	Load and short circuit currents respectively;
N_1 & N_2	Transformer primary and secondary turns number respectively;
A_c & A_y	Transformer core and yoke cross-sectional areas respectively;
l_c & l_y	Transfomer core and yoke magnetic circuit length respectively;
H_c & H_y	Transfomer core and yoke magnetic circuit magnetizing forces respectively;

O_s	Leakage flux;
$\Re_s$	Magnetic resistance;
R_{s1}&R_{s2}&R_{s3}	Active resistances of switches S_1, S_2 and S_3 respectively;
R_L&R_{T1}&R_{T2}	Active resistances of load,transformer primary and secondary winding;
R_p & L_p	Active resistance and self inductance of reactor;
C_1 & C_2	First and second arm capacitors;
L_{s1}&L_{s2}&L_{s3}	Self inductances of switches S_1 ,S_2 and S_3 respectively;
B_r & B_y	Transformer core and yoke magnetic circuit flux denisities respectively;
L_{sc1} & L_{sc2}	Transformer short circuit inductances (1 & 2 are related to the primary and secondary windings).

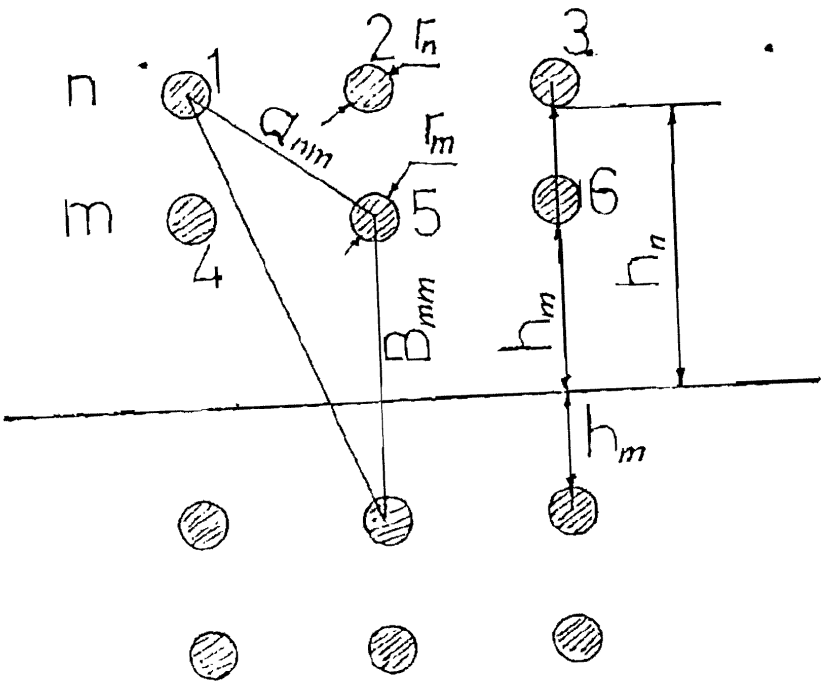


Fig.2 Arrangement of conductors relatively the earth and their mirror images .

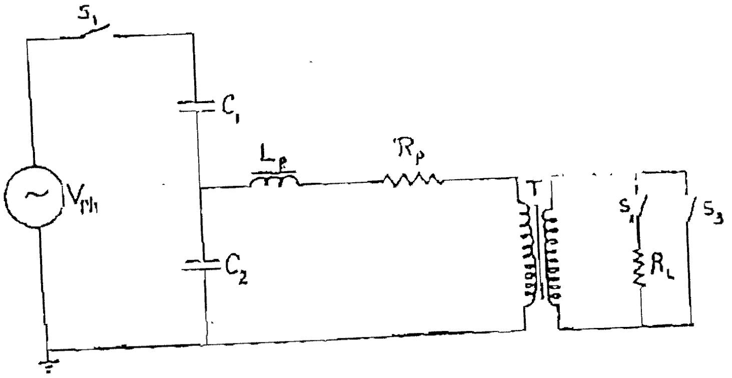


Fig.3 Capacitive take-off power network .

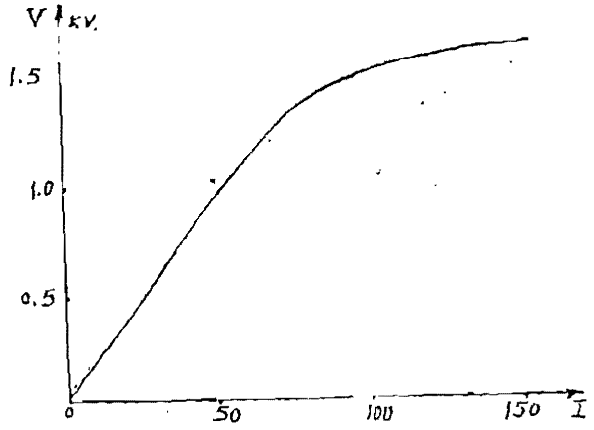


Fig.4 Compensating reactor volt-amper characteristic.

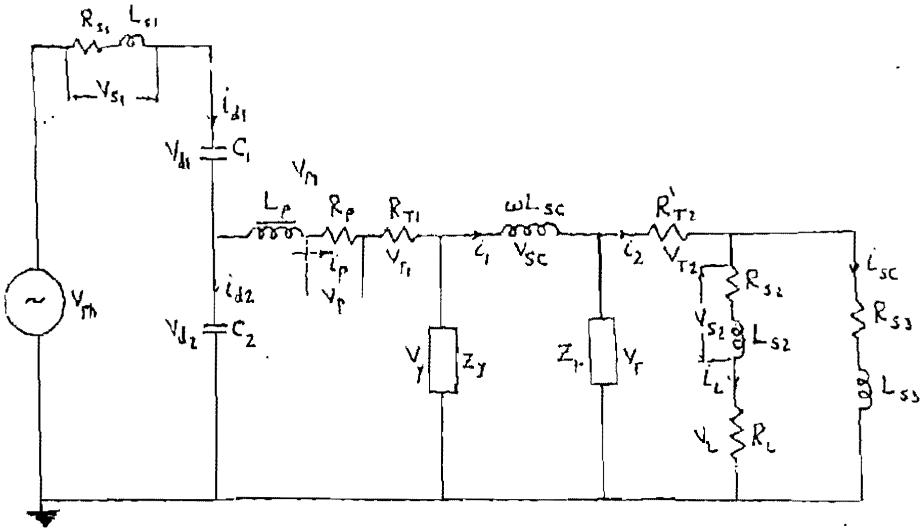


Fig.5 Capacitive take-off power calculated network model.

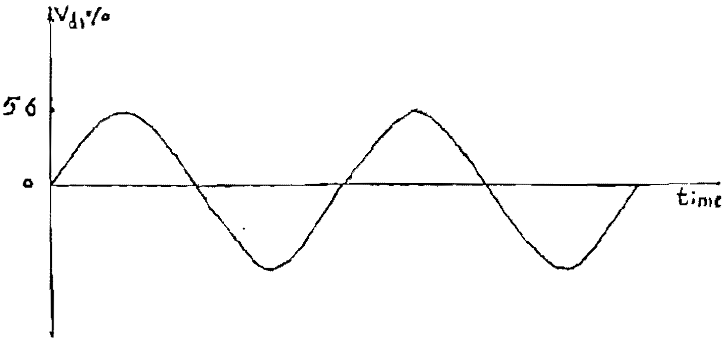


Fig.6 No-load or loading system transient processes results (voltage divider elements is C_1).

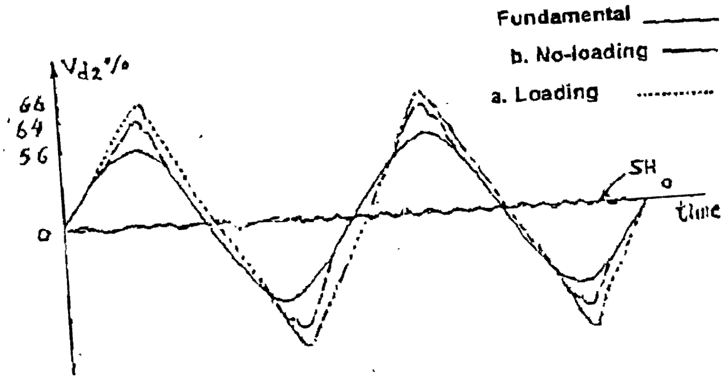
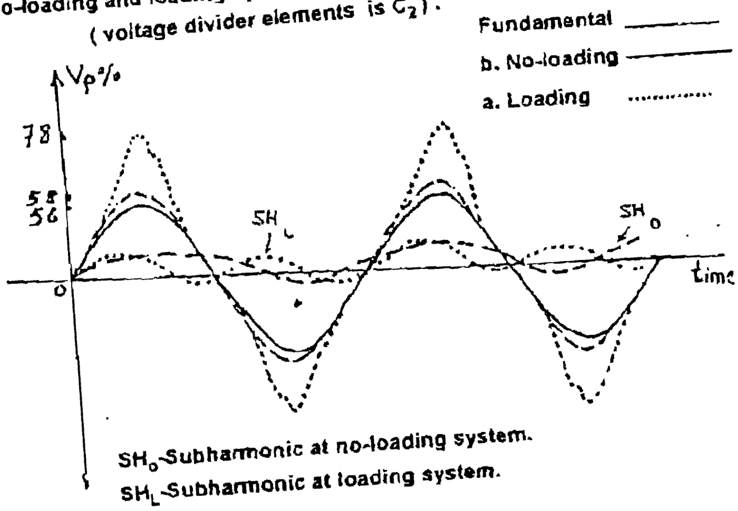


Fig.7 No-loading and loading system transient processes results (voltage divider elements is C_2) .



SH$_o$-Subharmonic at no-loading system.
SH$_L$-Subharmonic at loading system.

Fig.8 No-loading and loading system transient processes results (voltage divider elements is reactor) .