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MATHEMATICAL MODELLING OF TRANSIENT PROCESSES IN THE CAPACITIVE TAKE-OFF POWER NETWORK

نموذج رياضى للحالات العابرة فى شبكة قوى سعوية

BY

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ملخص:-

يقدم هذا البحث نموذج رياضى للحالات العابرة فى شبكة قوى سعوية يمكن استخدامة أيضا فى شبكة حثية.وهذا البحث يقدم تصورا امدى تأثير المفاتيح على الشبكات الكهربية وذلك بفرض أن بها معاوقة صغيرة القيمة.والنموذج المقترح يعتمدعلىالمعادلات اللاخطيةالناتجةمن حدوث قصروكذلك من الفيض الهارب والمرتبط بالملفات المنفصلة.والبحث أيضا يتعرض لكيفية تقليل الجهد العالى أثناءفترة القصر ويقترح طريقة عددية لحل المعادلات التى تم الحصول عليها. ولقد توصل البحث الى ضرورة التحقق من النتائج الرياضية بتطبيقها على النموذج الطبيعى مما يؤكد مدى صحة هذة النتائج وكذلك بعثر توصيل مقاومةعلى التوالىمع المحاثة عامل هام لتقليل الجهد العالىوالتوافقيات فى شبكة القوىالسعوية.

ABSTRACT

This paper 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 transformer. 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 theb solution manner using programme techniques. The final results and conclusions are presented.

KEYWORDS

Mathematical model, transient process, take-off power, capacitive network, magnetic flux, low and large disturbances.

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 processes 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].

For practical purposes, 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 characteristics and modify parameters in wide ranges, which represent serious problems in the case of any physical model [3].

TRANSIENT PROCESS STUDY

As shown in Fig. 1, 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 pereventation ferroresonance stable conditions [4].

At large disturbance, the reactor volt-ampere characteristic (Fig. 2) 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

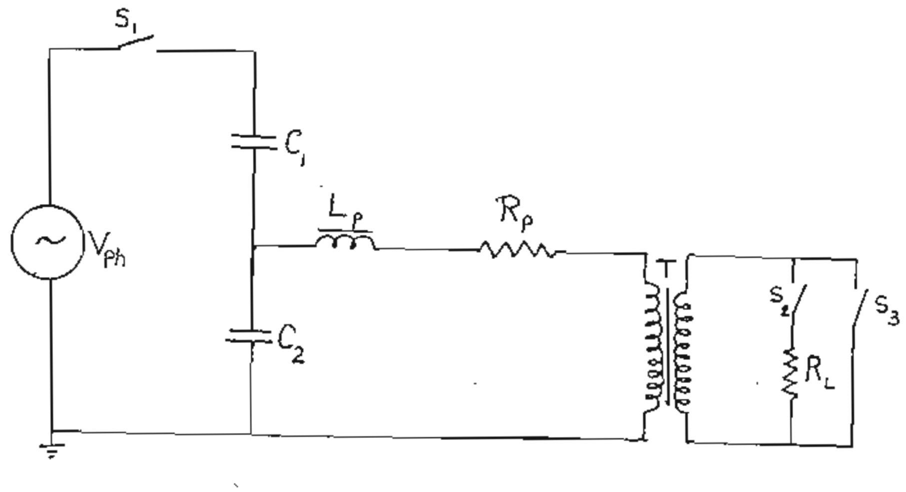

Fig 1 Capacitive take-off power network model

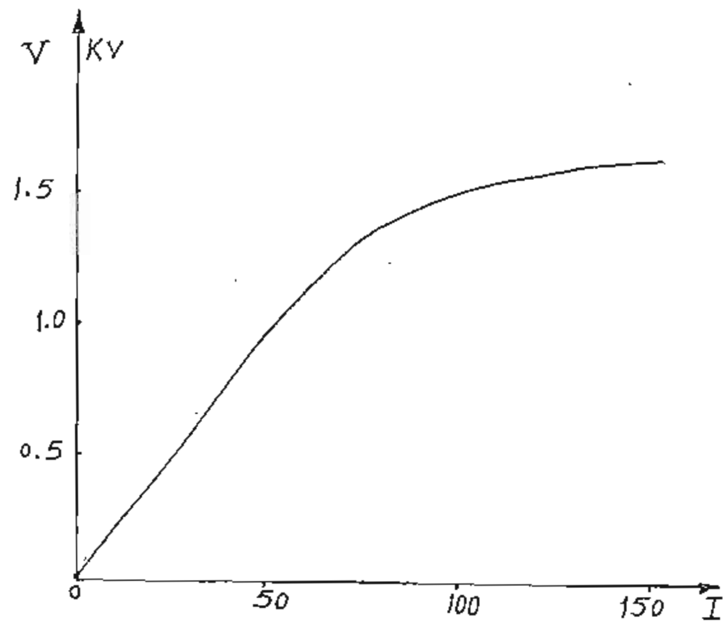

Fig. 2 Compensating reactor volt-amper characteristic.

intermediat 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. Leakage flux is coupled with seperated coils, which are closed out side of core. Constructed T-nominal equivalent circuit by these models is very suitable to represent normal loads operations and transient processes conditions. But these models are unsuitable for researching conditions of transient processes in the case of seperated coils unsymmetrical loading, for example magnetization current surge.

For satisfying this and other requirements, it is necessary to use the Π-nominal equivalent circuit of transformer. The transient process in networks with capacitive take-off power research, can be classified into three modes (Fig. 1). 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&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 f·· analyzing transient processes as in capacitive take-off networks, like in inductive networks (Fig. 3).

From This Figure:

$$V_{ph} = V_{d1} + V_{d2} + V_{s1} \qquad (1)$$

$$V_{d1} = \frac{1}{C_1} \int i_{d1}\, dt \quad ;$$

$$V_{d2} = \frac{1}{C_2} \int i_{d2}\, dt \quad ;$$

$$V_{s1} = i_{d1} Z_{s1}$$

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

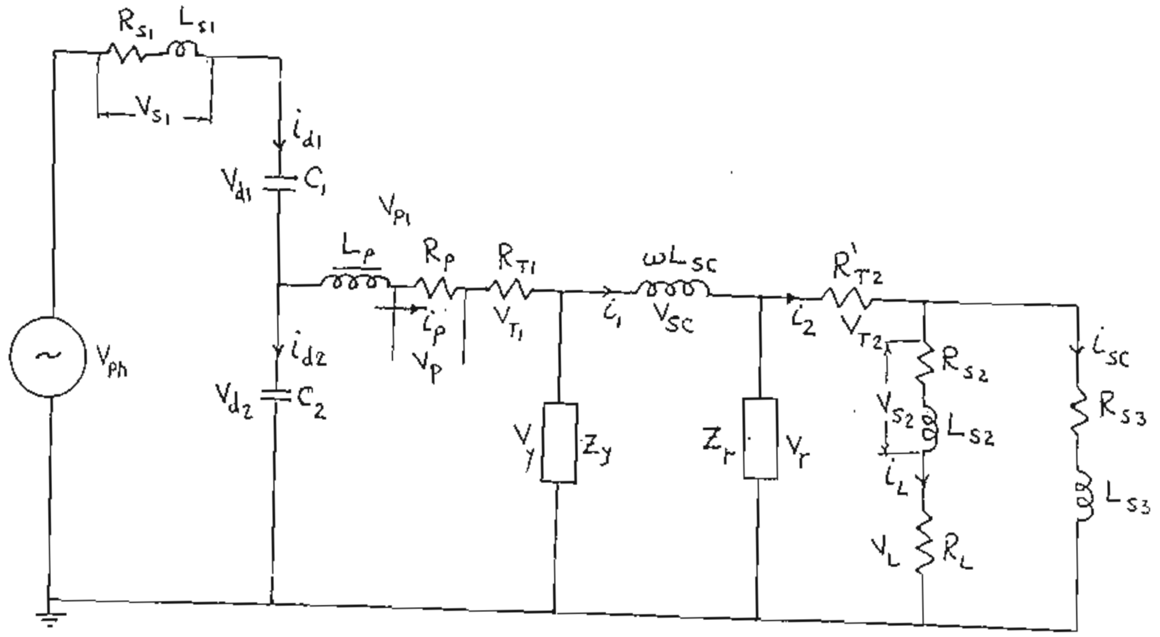

Fig 3 Capacitive take-off power calculated network model.

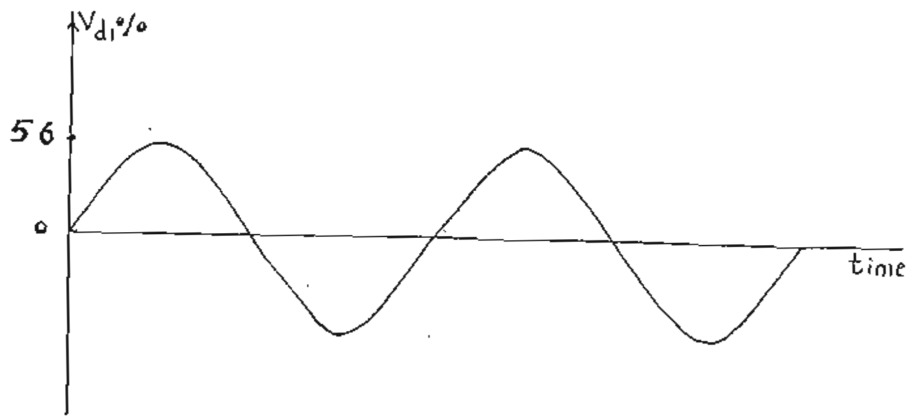

Fig 4 No-load or loading system transient processes results (voltage divider element is C_1).

From Eq.(1)

$$V_{ph} = \frac{1}{C_1} \int i_{d1}\, dt + \frac{1}{C_2} \int i_{d2}\, dt + i_{d1} R_{s1} + L_{s1} \mathcal{P} i_{d1} ; \qquad (2)$$

$$i_{d1} = i_{d2} + i_p ; \qquad (3)$$

$$V_{d2} - L_p \mathcal{P} i_p - V_p - V_{T1} - V_y = 0$$

$$V_{d2} - (L_p \mathcal{P} - R_p - R_{T1}) i_p = N_1 A_r \mathcal{P} (B_r - L'_{sc}) ; \qquad (4)$$

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

$$N_1 A_y \mathcal{P} (B_y - L'_{sc}) - L_{sc} \mathcal{P} i_1 - N_2 A_r \mathcal{P} B_r = 0 ; \qquad (5)$$

$$V_r - V_{T2} - V_{s2} - V_L = 0$$

$$N_2 A_r \mathcal{P} B_r - i_2 R'_{T2} - i_L (R_L + R_{s2} + L_{s2} \mathcal{P}) = 0 ; \qquad (6)$$

$$B_y = B_r (A_1 / A_y) - F_s / (A_y R_m) ;$$

$$i_2 = i_L + i_{sc} ;$$

$$i_1 = (l_y H_y - F_s) / N_1 ;$$

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

Where

$$L'_{sc} = F_s L_{sc} / (N_1^2 A_y) ;$$

$$F_s = R_s \phi_s ;$$

$$R_s = N_1^2 / L_{sc1} = N_2^2 / L_{sc2} ;$$

$$V_y = N_1 A_r \mathcal{P} (B_r - L'_{sc}) ;$$

$$V_r = N_2 A_r \mathcal{P} B_r ;$$

$$\mathcal{P} = d/dt .$$

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. Ofcourse 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:

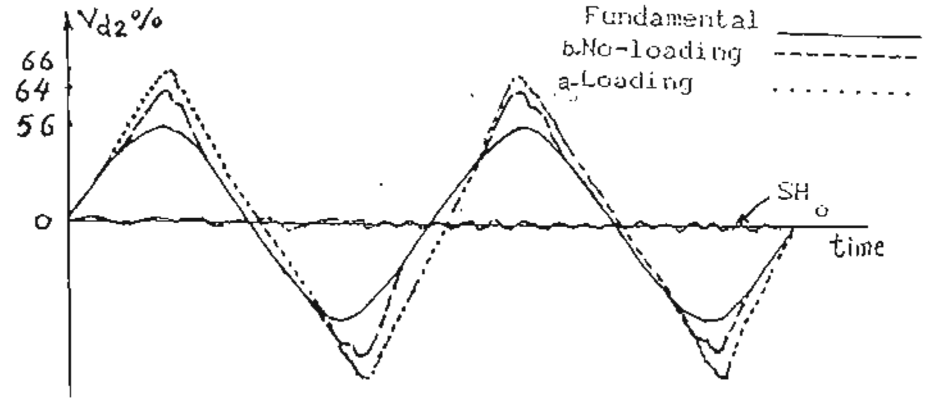

Fig. 5 No-loading and loading system transient processes results (voltage divider element is C_2).

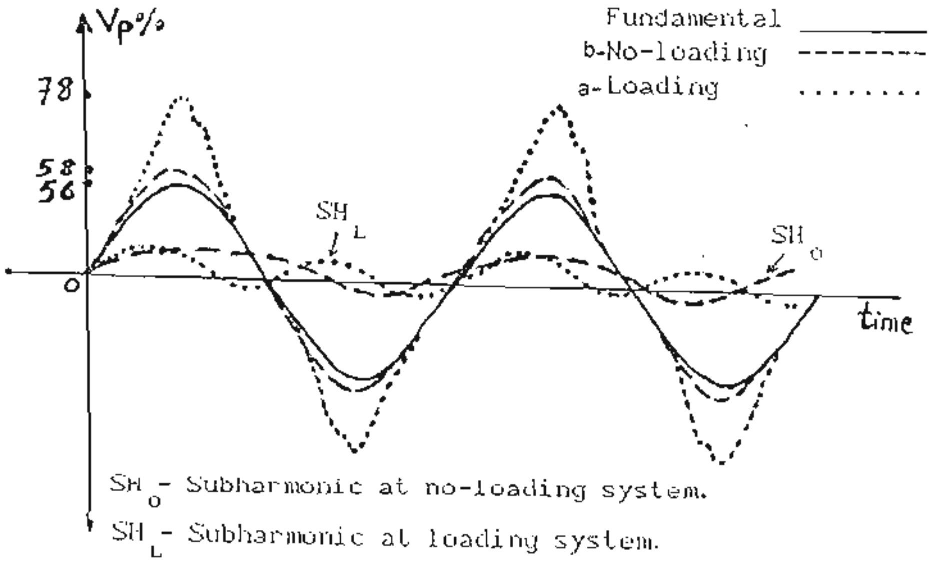

Fig 6 No-loading and loading system transient processes results (voltage divider element is reactor).

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_{sc10}, L_{sc20}, ...) are calculated.

3- Use the subroutine of Rung-Kutta method to compute the different values of voltages by changing time t from t=0 to $t=t+\delta\tau$. Where $\delta\tau$ is choosed suitable interval to obtain high degree of accuracy.

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 mathematical model to calculate 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.4,it is noticed that the amplitude variation is the same in(a) or (b). But in Fig. 5 in case (a) it is shown that a sudden change in voltage is occured and becomes nonsinsiodal waves. The change does not exceed 2% of the fundamental harmonic. In the case (b) harmonics are noticed.

From Fig. 6 it is noticed that, the amplitude is not changed in the case (a) and another harmonics are appeared.But in case (b) the voltage amlitude 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 (figures 4,5&6) are proved, that short circuit at transformer intermediat outputs has no effects 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 cases of: second arm loaded system and compensation reactor loaded or unloaded system.

CONCLUSIONS

1- For researching the influence of transient processes (short circuits) on the elements of voltage divider,the paper has proposed a suitable mathematical model. This model is a universal one and may be used as for capacitive as for inductive voltage divider. Determined divider network may be simulated with specified parametrs and applied researching. Mathematical results are checked for physical models. This check verifies correctness of mathematical models.

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

3- Connection of active resistance in series with the compensating reactor is considered as the most effective agents for supressing overvoltage and subharmonic in capacitive take-off power network.

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NOMENCLATURE

V_{ph} Phase voltage;

V_{d1} & V_{d2} Potential difference between two parallel plates of

	C_1 & C_2 (divider arms 1&2) respectively;
i_{d1} & i_{d2}	The currents 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_r & A_y	Transformer core and yoke cross-sectional areas respectively.
l_r & l_y	Transformer core and yoke magnetic circuit length respectively;
H_r & H_y	Transformer cor and yoke magnetic circuit magnetizing forces respectively;
ϕ_s	Leakage flux;
R_s	Magnetic reluctance;
R_{s1} & R_{s2} & R_{s3}	Active resistances of switchs S_1 , S_2 , and S_3 respectively;
R_L , R_{T1} & R_{T2}	Active resistances of load , transformer primary and secondary winding respectively;
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 & S_3 respectively;
B_r & B_y	Transformer core and yoke magnetic circuit flux denisities respectively;
L_{sc1} & L_{sc2}	Transformer short circuit inductance (1&2 are related to the primary and secondary windings).