

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

نموذج رياضي للحالات العابرة في شبكة قوى سعوية

BY

I. I. I. MANSY

A. M. M. ALY

S. S. ESKANDER

FACULTY OF ENGINEERING - UNIVERSITY OF SE-MANSOURA
SE-MANSOURA - EGYPT.

ملخص:-

يقدم هذا البحث نموذج رياضي للحالات العابرة في شبكة قوى سعوية يمكن استخدامه أيضا في شبكة حثية. وهذا البحث يقدم تصورا امدى لتأثير المفاتيح على الشبكات الكبيرة وذلك بفرض أن بنا معاوقة صغيرة القيمة. والنموذج المقترح يعتمد على المعادلات اللاخطية الناتجة من حدوث قصر وكذلك من الفيض الهارب والمرنط بالملفات المنفصلة. والبحث أيضا يتعرض لكيفية تقليل الجهد العالي أثناء فترة القصر ويقترح طريقة عددية لحل المعادلات التي تم الحصول عليها. ولقد توصل البحث الى ضرورة التحقق من النتائج الرياضية بتطبيقها على النموذج الطبيعي مما يؤكد مدى صحة حدة النتائج وكذلك يعتبر توصيل مقاومة على التوالي مع المحانة عامل هام لتقليل الجهد العالي والترانفيات في شبكة القوى السعوية.

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 the 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 autoperametrical 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 prevention 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

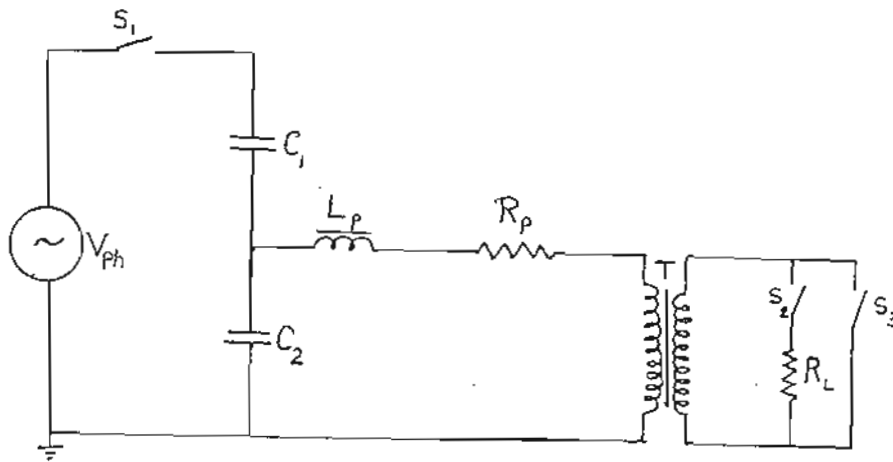


Fig 1 Capacitive take-off power network model

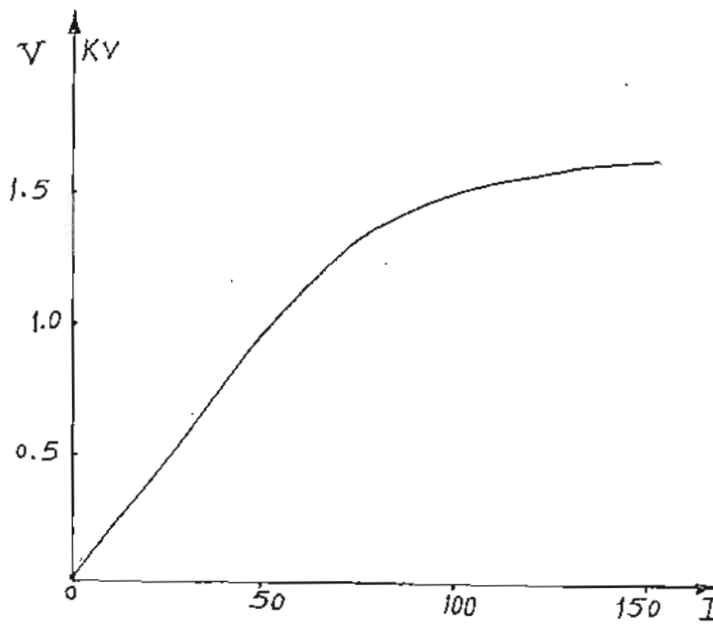


Fig. 2 Compensating reactor volt-ampere characteristic.

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 separated 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 separated 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 for analyzing transient processes as in capacitive take-off networks, like in inductive networks (Fig. 3).

From This Figure:

$$\begin{aligned}
 V_{pb} &= V_{d1} + V_{d2} + V_{d3} & (1) \\
 V_{d1} &= \frac{1}{C_1} \int i_{d1} dt & ; \\
 V_{d2} &= \frac{1}{C_2} \int i_{d2} dt & ; \\
 V_{d3} &= i_{d3} Z_{L3} \\
 &= i_{d3} R_{L3} + L_{L3} \frac{d i_{d3}}{dt} & ;
 \end{aligned}$$

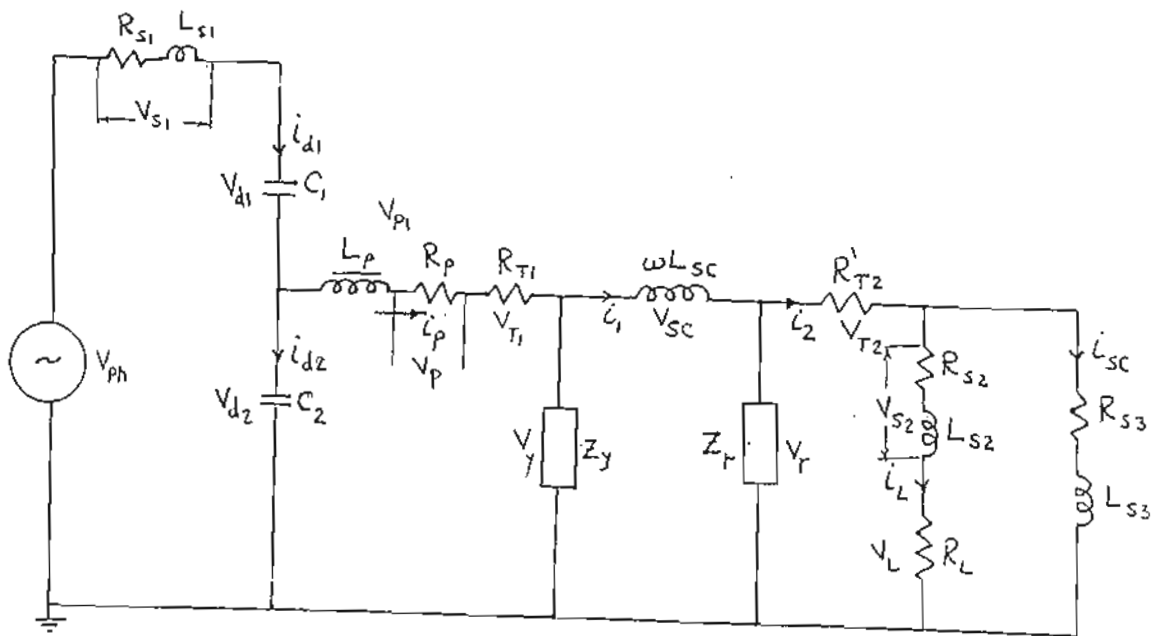


Fig 3 Capacitive take-off power calculated network model.

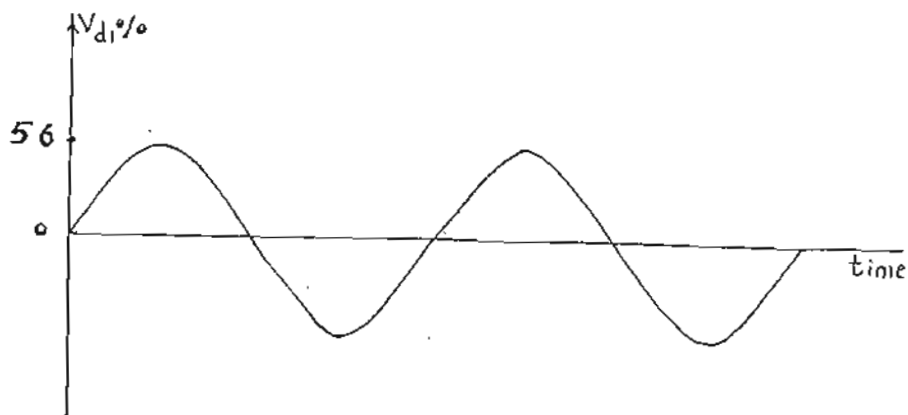


Fig 4 No-load or loading system transient processes results (voltage divider element is C_1).

From Eq. (1)

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

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

$$V_{d2} - L_p \frac{d}{dt} i_p - V_p - V_{T1} - V_y = 0$$

$$V_{d2} - (L_p \frac{d}{dt} - R_p - R_{T1}) i_p = N_1 A_r \frac{d}{dt} (B_r - L'_{sc}); \quad (4)$$

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

$$N_1 A_y \frac{d}{dt} (B_y - L'_{sc}) - L_{sc} \frac{d}{dt} i_1 - N_2 A_r \frac{d}{dt} B_r = 0; \quad (5)$$

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

$$N_2 A_r \frac{d}{dt} B_r - i_2 R'_{T2} - i_L (R_L + R_{s2} + L_{s2} \frac{d}{dt}) = 0; \quad (6)$$

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

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

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

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

Where

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

$$F_s = R_s \phi_s;$$

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

$$V_y = N_1 A_r \frac{d}{dt} (B_r - L'_{sc});$$

$$V_r = N_2 A_r \frac{d}{dt} B_r;$$

$$\frac{d}{dt} = d/dt.$$

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_{r1} 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:

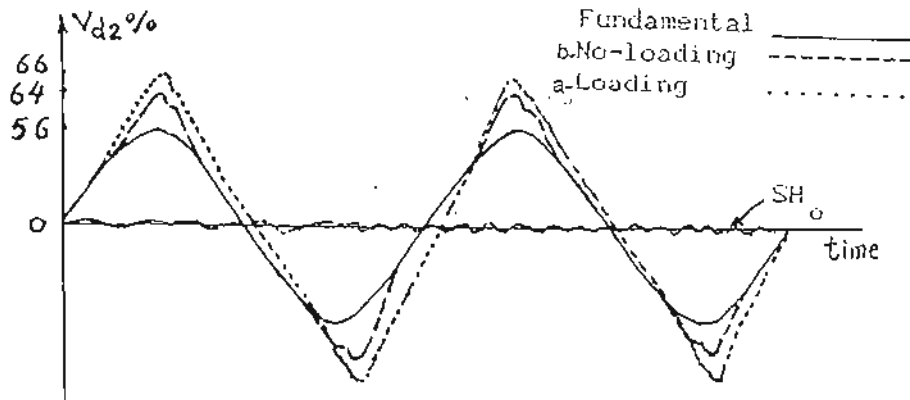


Fig. 5 No-loading and loading system transient processes results (voltage divider element is C_2).

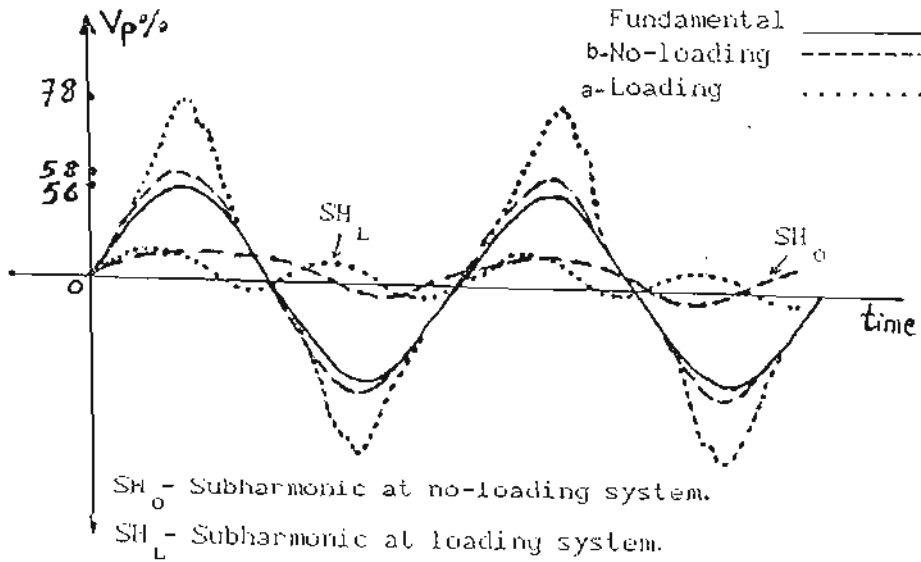


Fig. 6 No-loading and loading system transient processes results (voltage divider element is reactor).

- 1- Input data (e.g. $N_1, N_2, l, \frac{1}{\gamma}, A, A \dots \dots$) are known;
- 2- Initial conditions (variable values at $t=0$ e.g. $I_{L0}, I_{B0}, I_{C20}, L_{sc10}, L_{sc20}, \dots \dots \dots$) 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 parameters 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 suppressing overvoltage and subharmonic in capacitive take-off power network.

REFERENCES

- 1- C. Kiény " Application of the Bifurcation Theory in Studying and Understanding the Global Behaviour of a Ferroresonance Electric Power Circuit.", IEEE Trans. PAS, Vol. 6, April 1991, pp. 866-872.
- 2- G. W. Swift, " An Analytical Approach to Ferroresonance.", IEEE Trans. PAS, Vol. 88, Jan. 1989, pp. 42-46.
- 3- P.I. Fergested and T. Henriksen. " Transient oscillations in multi-winding Transformers.", IEEE Trans. PAS, Vol. 93, pp. 500-503, March/April 1974.
- 4- N.L. Kusters and W.J.M. Moore, " On the Definition of Reactive Power Under Nonsinoidal Condition.", IEEE Trans. PAS, Vol. 99, Sept. 1980, pp. 1845-1850.
- 5- A.E. Emanuel, " Powers in Nonsinoidal Situations A Review of Definitions and Physical Meaning.", IEEE Trans. PAS, Vol. 5, July 1990, pp. 1377-1383.
- 6- F. De Leon and A. Senlyen, " Efficient Calculation of Elementary Parameters and Transformers." IEEE Trans. PAS, Vol. 7, pp. 376-383, Jan. 1992.

NOMENCLATURE

- V_{ph} Phase voltage;
- $V_{d1} \& V_{d2}$ Potential difference between two parallel plates of

E.58 1.1.1. MANSY, A.M.M. ALY, S.S. ESKANDER

| | |
|--------------------------------|---|
| 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 switches 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 densities respectively; |
| L_{sc1} & L_{sc2} | Transformer short circuit inductance (1&2 are related to the primary and secondary windings). |