Modelling of a Control System of Static Var Compensator Type "Thyristors Controlled Reactors with Fixed Capacitors" for Simulation in the Microtran

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Abstract — **This work presents the structural design of a control system of a Static Var Compensator (SVC) on the type Thyristor Controlled Reactors with Fixed Capacitors (TCR/FC), six pulses, for simulation in the electromagnetic transients program Microtran. This equipament is intended for compensation the load in a 60 Hz three-phase system, unbalanced and strong consumer of reactive power. Thus, the control system developed, makes use of an individual phase control, in open loop, for the correction of power factor and the unbalance of load phase currents. Moreover, as a second priority in the compensator task, a feedback control is foreseen, aiming to regulate the voltage in values approximated to the rated voltage of the electric system.**

keywords: reactive power, control system, thiristor controlled reactors, unbalanced loads

1. INTRODUCTION

With the recent alteration of the brazilian legislation regarding the power factor, which points in direction to the measurement of the power reactive accomplished from hour to hour, the interes about Static Var Compensator grows higher in the country; once it permits a dynamic correction of the reactive power consumed in the industrial electric systems. In this way, it becomes interesting to have the use of the models of its power circuits and control systems in digital programs of evidenced reliability. This makes simpler to analyse the operation of SVC, in steady state, as well as in situations of transients in the electric network.

A control systems is analysed, in an abbreviated way, making use of Thyristor Controlled Reactors with Fixed Capacitors (TCR/FC), when compensating arc furnaces and other unbalanced loads, showing some important aspects to be considered. Thus, in the electromagnetic transients program Microtran, a TCR/FC is modelled, acting in the compensation of these kind of loads. The strategy of the compensator control system which is over analysis, aims for turning into symmetrics the currents of loads, correcting the power factor of the instalation for the unit, in addition to the regulation of the voltage in rated values at the point of common coupling between the electric power system and industrial consumer.

2. THE MICROTRAN PROGRAM

The program for the calculation of electromagnetic transients Microtran was developed by Prof. H.W. Dommel from the program of transients of The University of British Columbia. This software is a version of the Electromagnetic Transients Program (EMTP), which is normally used by several companies, of which reliability and speed is know by the technical-scientific comunity [1]. One of the main advantages of this program is the existence of a supression routine of the numerical oscillations [2], which are fundamental to simulate systems which contain power semicondutors, turning more simple the insertion of SVC systems, for instance, the goal of the present work. As an alternative, there is also the option of making no use of this routine, making the solution similar to that one of the EMTP.

A helpful characteristic of this program is the possibility of the insertion of control systems for static power converters by the Alpha subroutine, which can reached by the program, according to the user's necessities [3]. Its objective is to control the ignition angles of power semicondutors that are designated in the input file, and also written in FORTRAN language. That is the tool used in simulations in order to work out control strategies for SVC. Most of the characteristic and advantages of Microtran program are identical to the ones of the EMTP, and are widely know in the specialized technical literature.

3. CONTROL SYSTEMS OF TCR/FC

The Thyristor Controlled Reactors with Fixed Capacitors (TCR/FC), are especially recomended for the compensation arc furnaces and single phase railway loads. In these cases, due to the strongly unbalanced loads, it's necessary the use of an individual phase control. By this philosophy, three basical solutions are normally adopted [4]. The first alternative is an open loop controller (feed forward controller) where repeatedly a whole of appropriated equations of steady state are solved, to find the value of susceptance which is adequated to the load correction. This solution is extremely fast, immune to instabilities of the control system, but it's rather sensible to the alterations in the systems parameters. As a second option, there is a feedback control, in which the compensating susceptances are controlled on close loop, aiming for reducing the error signal when compared to a greatness adopted as a reference. This solution, despite being subject to instabilities, has advantages such as precision, as well as the independence of the changings that can eventually come to happen in the parameters used on it. The third alternative is a combination of the two first techniques, that is, the load compensation is done by the use of a feed forward controller, while the voltage regulation is accomplished according to a feedback controller.

The technique of open loop control is based in the hypothesis that the load, as well as the whole electric system, is operating in steady state, between two consecutive changing instants in the load currents and compensating susceptances. So, between these two timebreaks, the load currents and the voltages applied can be measured and the compensating susceptances (or currents, or even powers) can be obtained by the equations of control found in [4]. The compensating susceptances calculated, transformed into compensation currents, will provide the basic conditions for the choice of the ignition angle of the semiconductors valves, by the control of TCR/FC. It's important to remember that the variation limits of the firing angle of the compensator are 90 and 180 grades, when a single phase TCR and zero of the supplying voltage are taken as reference. Obviously, the first limit represents full current in the reactor, while the second, a null current. Gyugyi, Otto and Putman showed, in [4], all the details of the equationing necessary to be accomplished by the SVC so that the load correction can be performed.

The feedback control systems is basically used in voltage regulation in AC transmission network. However, this kind of solution is normally found accompanying the open loop systems, previously described. The basis principle of functioning consists in an increasing variation of firing times of TCR/FC thyristors, that correspond to an error signal generated by the difference between the greatness of interest measured, and the value adopted as reference. In this way, when an alteration on the error signal occurs, it results in a contrary variation in the effective value of the susceptance of the thyristor controlled reactor. The aim, naturally, is to maintain the error signal close to zero.

It's important to point out that the parameters of the electric systems chosen to be controlled mustn't contain any harmonics or electric noises, for they could conduct to firing angles which would mask the results. The use of values rms is suggested, measured in one, or even half-cycle of AC voltage.

4. SIMULATION OF TCR/FC IN THE MICROTRAN

4.1. ELECTRIC SYSTEM MODELLING

The basic oneline diagram of the electric system for the analysis in Microtran is presented in figure 1. The power electric system "seen" of the point of common coupling (bus PCC) was considered as a power of 150 MVA short- circuit, reason X/R equal to 6, beyond rated voltage of 13.8 kV. Thus, the resistance and inductance of the system were

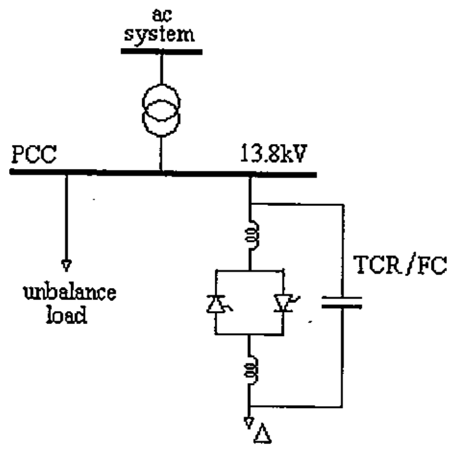


Fig. 1 - Oneline diagram of the electric system modelled

modelled making use of lumped linear elements branches. The unbalanced load, that must be corrected by the Static Var Compensator is connected en delta, and it's power demands and power factor in the rated voltage are the following:

- Connection between the phases A and B:
  - P_{AB} = 8.40 MW;
  - Q_{AB} = 7.00 MVAr;
  - Power factor = 0.77.
- Connection between the phases B and C:
  - P_{AB} = 6.70 MW;
  - Q_{AB} = 5.80 MVAr;
  - Power factor = 0.76.
- Connection between the phases C and A:
  - P_{AB} = 9.60 MW;
  - Q_{AB} = 5.00 MVAr;
  - Power factor = 0.89.

The load was represented as being of constant and defined impedances for the rated voltages, considering the consumption previously quoted. The power factor of the three-phase load obtained in this situation was of 81%. Even the phase currents have shown unbalance, due to unequal loading between the phases.

On regards to the TCR/FC modelling, there was no necessity of a more detailed representation, since this is not the aim of the present study. However, it stands out, for example, that the protection circuits RC (snubber) of the equipament thyristor, can be easily represented, from the model hereby used. The compensator for the load correction is connected in delta, and for each branch was defined the following reactive power of compensation:

- $Q_{CAPACITOR}$ = 14 MVAr;
- $Q_{REACTOR}$ = 21 MVAr.

It's pointed out that the reactive powers provided above were used, along with a rated voltage of electric system for the calculation of the capacitances and inductances to be represented in the transients program, as well that the tunned filters were not included in the modelling for the current harmonics generated by TCR/FC, since the response of the control system is the only aim of the simulations in this phase of the work.

4.2. TCR/FC CONTROL SYSTEM MODELLING

An previously commented, the user must make use, in program Microtran, of the subroutine Alpha, when the aim of the simulation is to control power semiconductors. In this way, it was modelled, by FORTRAN language, a control system for the TCR/FC with the purpose of balancing the load, correcting its power factor , besides regulating the voltage in values as closer as possible to the rated voltage.

The system created is of the type "individual phase controller", in open loop for the correction of the load (equationed through average power consummed by the load [4]), and a feedback loop for the voltage adjustment. In figure 2, it can be observed the basic scheme of the control system implemented, inserted in oneline diagram of the electric system.

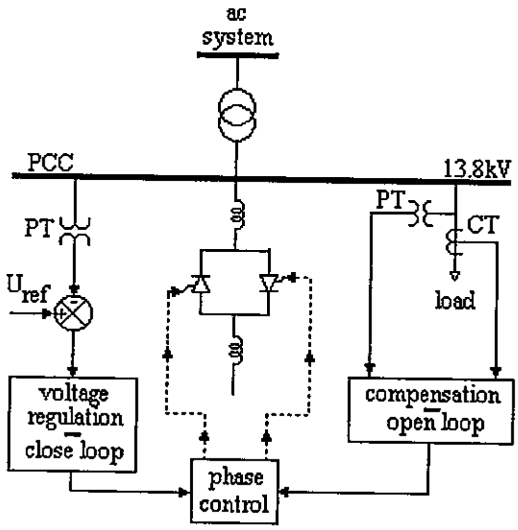


Fig. 2 - Basic scheme of TCR/FC control system

Having in mind the individual phase controller, in the conception of control system of the compensator, was included the characteristic of modern static converters, which is the production of equidistant firing pulses of 180 grades for the thyristors of the same branch of TCR/FC. This technique of firing static converters independs on the unbalances of AC supplying voltages, and on its distortions. It's possible, with some alterations, to adapt this characteristic to a three-phase controller on six pulses (case of HVDC systems and TCR/FC performing in balanced three-phase systems), obtaining a 60 grades spacing between the firing pulses of the converter. Another characteristic also considered in the model implemented is the blockade for minimum firing angles (91 grades) and maximum (175 grades), being assured there isn't the possibility of misfire in the commutation between the thyristor of SVC.

Aiming to facilitate the comprehension of the system implemented, it's below presented, the sequence of procedures used in subroutine Alpha:

- **STEP 1** - In the first DELTAT of time, the minimum and maximum firing angles are defined (91 and 175, respectively, besides the phase-to-phase voltage of reference;

- **STEP 2** - While the time of simulation is shorter than 16.667 miliseconds (first cycle), the greatnesses of interested are measured and returns to the main program;

- **STEP 3** - Up-dating of the greatness measured;

- **STEP 4** - Calculation of the reactive power necessary for the correction of the power factor and symmetrization of the phase currents, used in the open loop control;

- **STEP 5** - Definition of gain to be incremented in the firing angles to be used on feedback loop for the voltage regulation;

- **STEP 6** - Storage of results envolving the phase currents and voltages compensated in time, at each integration step, having its plottings in view. Moreover, also aiming at plottings, it's calculated, in each time step, the phases and three-phase installation power factor;

- **STEP 7** - Verification of the instant on which the six thyristor of TCR/FC has conditions to receive ignition pulses. Basically, this step can be divided into four others, discriminated as follows:

  - **STEP 7.1** - In the first firing condition of one of the thyristors, it's calculated the ignition angle necessary for the load compensation according to delta's branch of the thyristor that was adequately polarized;

  - **STEP 7.2** - Comparison between the up-dated voltage measured and the value adopted as reference:
    * If higher, it's subtracted the gain fixed in STEP 5 of the angle calculated in STEP 7.1;
    * If lower, the gain fixed in STEP 5 is added to the angle calculated in step 7.1;

  - **STEP 7.3** - Comparison of the firing angle obtained in

STEP 7.2 to the maximum and minimum angles fixed in STEP 1:

* If it´s lower than the minimum angle, the recent-polarized thyristor is blockaded at the minimum angle, as well as that one connected in 180 grades antiparallel after;
* If it´s higher than the maximum angle, the recent-polarized thyristor is blockaded at the maximum angle, as well as that one in 180 grades antiparallel after;
* If the angle calculated is in the break between minimum and maximum angles, the firing angle of the recent-polarized thyristor is defin ed, as well as that connected n 180 grades antiparallel after.

- **STEP 7.4** - The minimum and maximum firing angle of the recent-polarized thyristor, which firing angle is defined, are put forward in one cycle. Return to the main program.

As it can be observed, the ignition angles necessary to the compensation, as well as the increases used in the routine for the voltage regulation, are up-dated at each cycle, turning the TCR/FC response faster and efficient.

It´s pointed out that the fixed gain established in feedback control modelled by subroutine Alpha is of 2 grades, which value was taken in arbitrary character. However, an adequate transfer function can be with relative simplicity included in STEP 5 previously described, to turn the equipament response to the voltage variations more efficient. On the item concerned to the simulations results, 2 grades represented a good performance for the SVC.

4.3. SIMULATED CASES

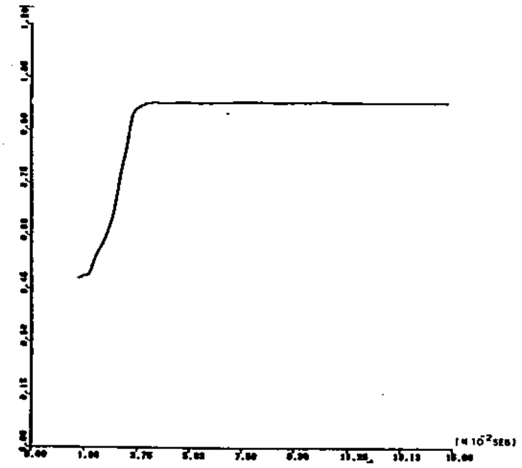
Upon the connection of the control subroutine created on the program Microtran, several situations were simulated for the systems presented at sections 4.1 and 4.2. The basic file used, considered the loads of constant impedance, reactors and capacitors of the compensator as previously described. Moreover, the firing angles of TCR/FC was fixed initially in order to have a full current in all its reactors. The aim is to avoid the need of calculating the initial conditions of the currents and voltages by the introduction of components with frequencies that are different of 60Hz in the simulations. The rest of the cases simulated involved just brusque alterations and variations on the load, aiming to verify the SVC response to the brusque disturbs. The cases simulated were:

- **Case 1** - Compensated load: $S_{AB} = 8.40 + j7.00$ MVA; $S_{BC} = 6.70 + j5.80$ MVA; $S_{CA} = 9.60 + j5.00$ MVA.
- **Case 2** - Ditto case 1, but with a withdraw of the load connected between the phases C and A;
- **Case 3** - Ditto case 1, but with switching of the load existing in phase CA on the 90 miliseconds.

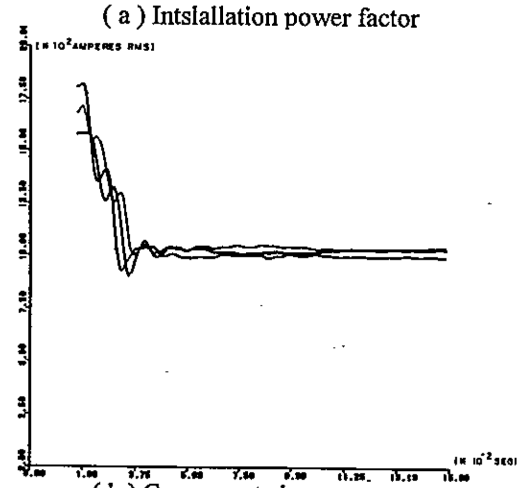
4.4. THE RESULTS OBTAINED

A) Case 1

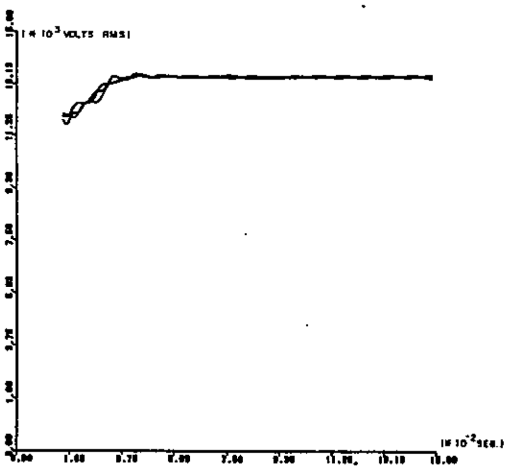
Figure 3, following, shows the power factor evolution of the load installation and TCR/FC, of the currents and voltages rms compensated. The beginning if the simulation is not show because of the measuring process of the greatnesses used in the control system. The power factor after the action of the control system is of 0.99, while the initial (without the action of subroutine Alpha) is of 0.47. Obviously, in the initial power factor is being considered the presence of all the reactors of TCR/FC according to the firing angles initially arbitrated. The time spent in the compensation process was of 24 miliseconds, wherent to what was expected (maximum of 33 miliseconds). The currents, according to the theoretical equationing provided in [4], should have become symmetric at about 1025A. For the results of the rms currents plotted in figure 3(b), 1015, 1035 and 1030A were obtained, which can be considered balanced. On regard to the phase-to-phase voltages, this ones were compensated at about 13420V, since the control system implemented performs, prioritarily, the load compensation, and has a "certain" control on the voltage.



(a) Intslallation power factor



(b) Compensated rms currents



(c) Compensated phase-to-phase voltage
Fig. 3 - Power factor , currents and voltages rms in time

B) Case 2

This situation simulated represents a bigger seek for SVC, for the load connected between phases C and A was withdrawn. The results on the correction of the power factor compensated is show in figure 4.

The power factor reached, in this case, is of 97%, which value is acceptable in practice. It's important to emphasize that this compensation results in a more unbalanced operation for the TCR/FC, and a bigger quantity of third harmonics currents damage the power factor. On regard to the compensated phase currents (not show), they have reached the values of 655, 649 e 665A, respectively, for the phases A, B and C, which are rather acceptable. The time it took the compensator to perform the compensation was also, in this case, of 24 miliseconds.

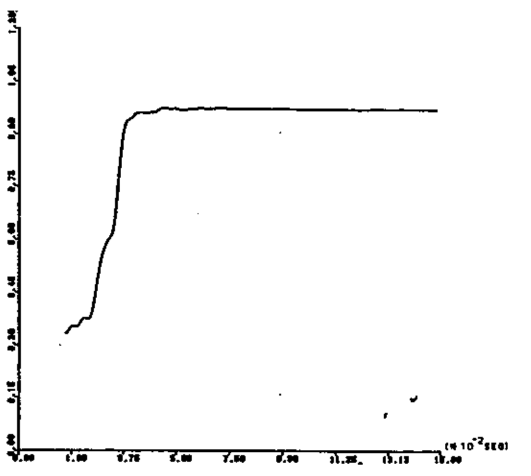


Fig. 4 - Installation power factor in time

C) Case 3

Concluding the simulations, the withdraw of the load connected between the phases C and A was considered at 90 miliseconds. In this way, after the TCR/FC performs the compensation of the unbalanced three-phase load, a new readjustment occurs in the control system, to attend the condition imposed by the load parcel output. In figure 5, are show the results of the power factor in the phases, that can be observed the correct performance of the control system implemented.

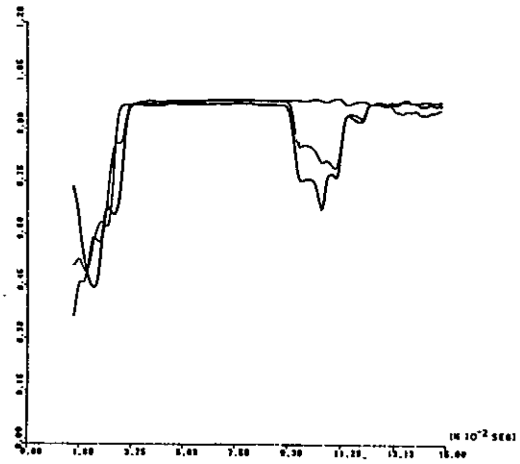


Fig. 5 - Power factor in the phases

5. CONCLUSIONS

The results presented allowed to evalluate the efficiency of the control system implemented. Besides compensating the load power factor, the three currents of phase balanced each other in values fairly close to the ones expected. The voltages were also regulated in an efficient way, in the face of the priority to the load compensation and not to the inclusion of the transference function for the control of this variables.

The cases simulated also showed the influence of the distortions of the wave shape in the installation power factor. It was because of in the case of three-phase load, the small quantity of current harmonics injected in the system, doesn't influence decisively on the pre-established values. As the load unbalance is accentuated, like in the case of two-phases load, the currents of third harmonics become more pronounced deteriorating the power factor. In the case of single phase (not show), the injection of third harmonics is so elevated, that although the control system calculates the right angles for the compensation, the power factor results rather impaired. In these cases, the necessity of filters for the harmonics of third level is indispensable. It's pointed out that control systems of the SVCs of the type simulated, are complex functions, dominated by a few manufacturers, and its performance is also dependent on the transference function for the voltage control. As previously mentioned, its implementing in the model proposed, is of a simple conception, and is a suggestion for future works. Moreover, from the model of the electric system used, it becomes easy to include filters for the preponderant harmonics, as well as to create more complex models, either for the power system or for the SVC.

6. REFERENCES

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