AES SUL'S EXPERIENCES USING SERIES COMPENSATION ON DISTRIBUTION SYSTEM

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ABSTRACT

This work relates the experience of AES Sul on implementing series compensation to solve voltage drop problems on feeders. First, measures from a system, which present over-compensation, will be showed. During the energizing, that feeder presented significant voltage oscillation. It occurred on every test was made due to the coupled between series capacitor and three-phase induction motors used in pumps on rice farms. The analyze of that situation showed significant voltage instability what makes impossible its work. After the analyze of damp insertion on electromagnetic transient programs, it was decided to install this series capacitor in another feeder. On that other feeder, the results were good, obtaining an elevated compensation level and a well voltage behavior.

INTRODUCTION

Series compensation is large used on transmissions systems to obtain a better transient stability improving the electric energy transport capacity. The use of this compensation technology on medium-voltage distribution systems also presents technique and economic advantages as many designs have demonstrated. On that case, the main objective was to reduce the voltage drop acquiring a better voltage regulation on the system. Nowadays, the necessity of improving power quality level makes interesting the use of series capacitors to reduce flickers and voltage waveform distortions. Despite this advantages as instantly regulation, reduction of voltage regulation values, start motor's supplying, its disadvantages have been studied for years and are caused by phenomena of ferroresonance and subsynchronous oscillations [4],[5]. On that work will be presented the study and the results of installing series compensation in two 23kV distribution feeders of AES Sul Utilities. The first system used to implement this technology had three voltage regulators installed and still presents an elevated voltage drop. Even that, it is basically to supply pump motors during the rice cultivation in West of Rio Grande do Sul state in Brazil. This feeder is located in Uruguaiana City and supplies many motors between 200 and 400 HP which start using compensation. After the study and the design definition made by a consulter, the system was implemented to change two automatic voltage regulators for two series capacitors of 35Ω equivalent reactance each one. When the series capacitors had been energized, voltage oscillations were observed that provoked instability on the system what made impossible its work on system normal condition. After we simulated on electromagnetic transient software where we concluded that is impossible to use series compensation on this feeder, we looked for another feeder to install this capacitor obtaining good results.

ORIGINAL DESIGN

The feeder 110 of Uruguaiana's system supplied on 23kV presented 12MVA of maximum load when that study was made under 90% of inductive power factor. Naturally considering the influence of three shunt capacitors bank of 600 kVAr each one installed on that feeder. To adjust the voltage drop on steady state, there was three voltage regulators of 32 steeps and 200 amperes connected on grounded Y. However, it still presented voltage drop of 15% on some critical points what makes the necessity of implementing a new solution to keep the voltage level. The oneline diagram of that system before the design is showed on figure 1 where every conductor was ACSR (aluminum cable steel reinforced) used in Brazilians rural areas networks.

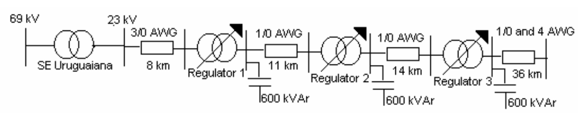

Figure 1 - Oneline Diagram of Feeder AL-110 from Uruguaiana

According to the design of the consulter contracted by AES Sul, two voltage regulators would be replaced for two identical series capacitors bank of 35Ω capacitive reactance and 5.1MVAr each one to get a better voltage regulation as showed on figure 2.

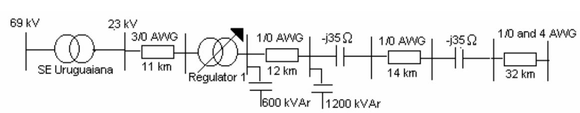

Figure 2 - Design's Oneline diagram

The shunt capacitors bank under that condition would be relocated on the bars before the first compensator to do not minimize its effects. Note that the first bank had an elevated level of compensation around 280% and the second had its X_C/X_L relation around 180%. The necessity of theses overcompensation originated by the elevated power factor of this feeder associated to the elevated resistance of the conductors, mostly ACSR 1/0 AWG. Even that, the load of this feeder is basically three-phase induction motors had nominal power between 50 and 400HP.

RESULT OF THIS PROJECT

After the equipment was installed, it was energized. The first bank was energized when the main loads of that system were connected (three-phase induction-motors used on rice farm's pumps). When this series capacitor bank was energized, critical voltage oscillations were observed. Immediately this bank was taken out of the system using its manual vacuum protection. The figure 3 shows the behavior of RMS voltage, which values were not constant what could be seen on consumer's lights. The figure 4 shows the wave shape when these oscillations were happening. Analyzing the voltage behavior and its shape, an equivalent frequency around 8Hz could be observed. Others additional energizing was made which also presented critical voltage oscillation. So, with the first bank out of the system we opted to use the second bank energized what didn't caused any voltage oscillation. However, it did not present the regulation that was expected. Than, the first bank was energized again what caused an elevated over-voltage on the system. It was probably occasioned by the Ferro-resonance phenomenon on the potential transformer installed on the second bank protection system or in distribution transformers operating with no load. So the first series capacitor bank was by-passed again.

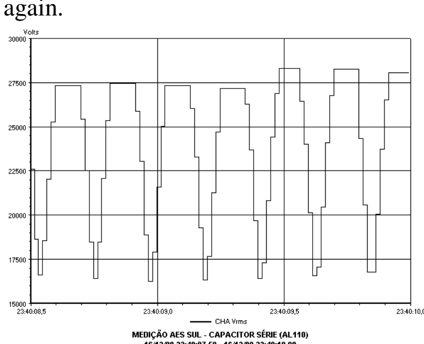

Figure 3 - RMS voltage behavior during the oscillations

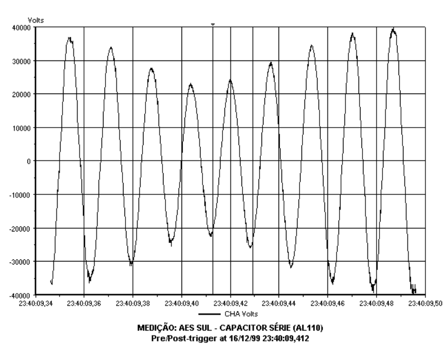

Figure 4 - Waveforms during sub-synchronous oscillation

SIMULATIONS RESULTS

To study the proposed systems and its conditions related to sub-synchronous resonances on induction-motor's start were simulated many different cases on Microtran transient software whose results were presented.

Induction-motor´s start

The system presented as the main load induction-motors, so three-phase induction-motor's start was analyzed connected on a feeder which had a series capacitor bank. The figure 5 show start current of motor of 150 HP connected on low-voltage system of 380V after the series compensation. Note that increasing the motor power, the possibility of sub-harmonic oscillation increase together when there is series compensation connected on the system [1].

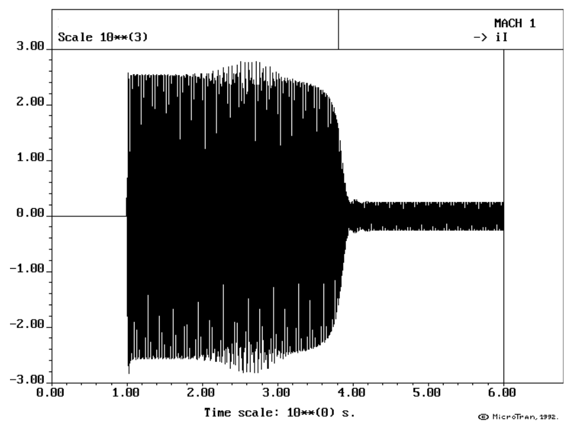

Figure 5 - Current of 150 HP induction motor start

On figure 5, the current shows a little tendency to oscillate, but even with this tendency, the motor entered on steady state normally. Considering a bigger motor (200 HP), as showed the figure 6, the current didn't entered on normal steady state and the motor didn't accelerated until the normal conditions what characterized sub-synchronous oscillations as the speed graphic on figure 7. To motors of higher power the result is similar.

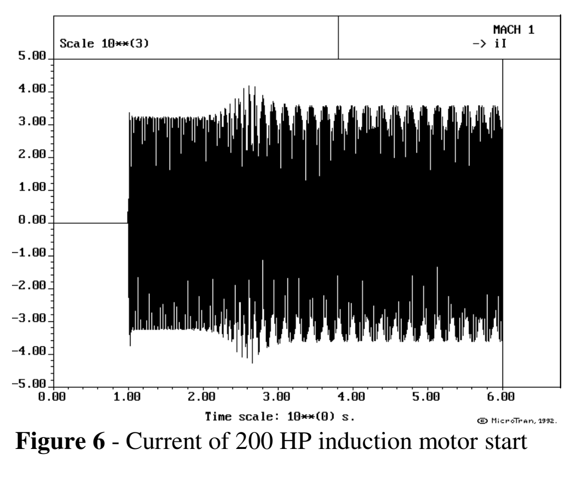

Figure 6 - Current of 200 HP induction motor start

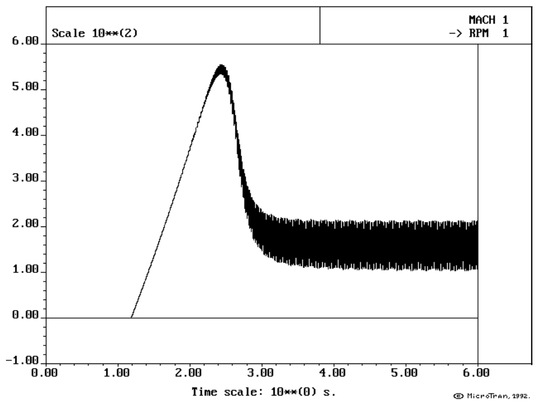

Figure 7 - Speed of the 200 HP motor

Alternatives to reduce voltage oscillation

Analyzing the voltage oscillation occurred on that feeder, some alternatives were studied to solve this problem. The first alternative considered was reduce the compensation level of this system what would reduce the possibility of this phenomenon occur. Considering a compensation level of 200% together with the start of many 200 HP motors the oscillations was observed. Figure 8 shows the compensation of 150% where motors entered on steady state with no problem on the system. However this compensation level didn't increase the voltage level, as it was necessary.

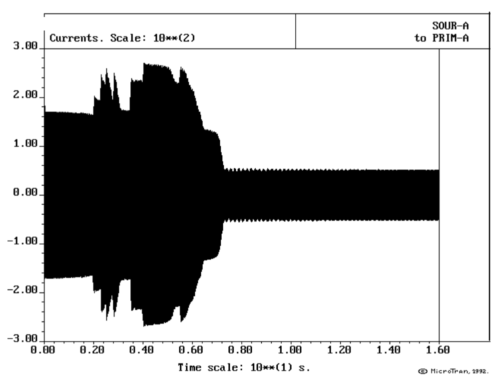

Figure 8 - Total current of 150% compensation

Damping resistor

Another method to reduce auto-excited oscillations during the motor start is using damping resistor [2]. The parallel resistor normally is around 5 and 10 Xc. To analyze that case, a 100Ω resistor were added at 8 seconds and opening at 17 seconds as it is around 5 times bigger than the bank reactance. On that case it was simulated with ten motors of 200 HP starting on different times. When the resistor was operating, the system is normal, when it was opening, the oscillations came back what characterized an auto-excitation not only on motors start, but also on steady state. According to [6], this phenomenon occurs on parabolic loads as pumps and compressors on series compensation. It is know as Hunting causing disturbances related to flickers.

RLC filter

Other solution for resonance on series compensation system is a RCL filter [3]. It is based on using LC elements to induce a resonance parallel to the industrial frequency and to frequencies under the synchronous the equivalent resonance is reduced.

ADJUSTING THE SERIES CAPACITOR ON ANOTHER SYSTEMS

Despite simulations determined some alternatives to obtain a well result on this system, related to voltage oscillation, an economic analyze determined that is better to install that series capacitor in another feeder. After the steady state analyze, the feeder 3 of UJAC-320 located in Salto do Jacuí was chosen. This feeder also from AES Sul has around 5MVA of maximum load under 92% of power factor and rated voltage of 23kV. This feeder had two voltage regulators and voltage drop of 9% on its most distant consumers. A simple diagram of this system after implemented that design is showed on figure 9 where is propose just to change a voltage regulator for a series capacitor bank. It's important to say that the compensation level is similar to the second bank which was proposed to be installed in Uruguaiana around 180%. The expected results of this study was a voltage drop of 7% on maximum load. On this case no oscillation were detected due to the higher damping of that system.

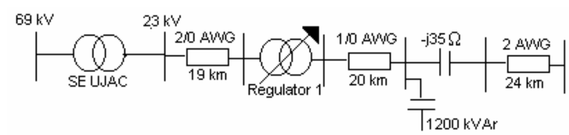

Figure 9 - Diagram of Salto do Jacuí feeder

Simulation results

Even the induction motor load is not important on that feeder, it was simulated to observed this critical condition. To make that study a motor of 200 HP was modeled near the series capacitor bank where no problems occurred as showed on figure 10.

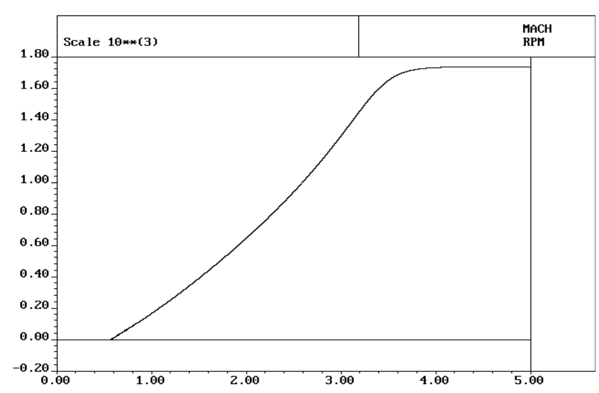

Figure 10 - Speed of 200 HP motor

Real results

The series capacitor bank was installed and a picture of it is showed on figure 11.

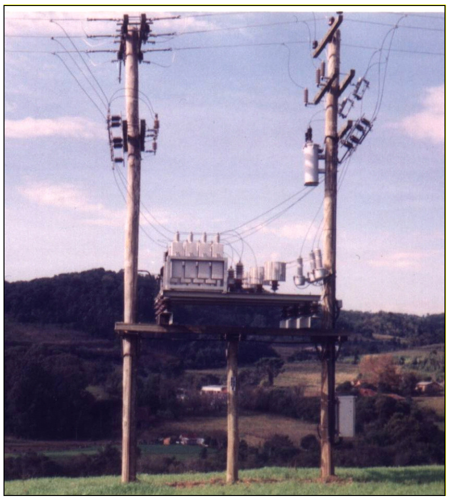

Figure 11 - Series capacitor bank implemented

This system was energized under normal conditions obtaining considerable voltage level increase at some periods of load. No oscillations were verified. The figure 12 shows the behavior of RMS voltage on the input and output of the capacitor displaying the final part of that project.

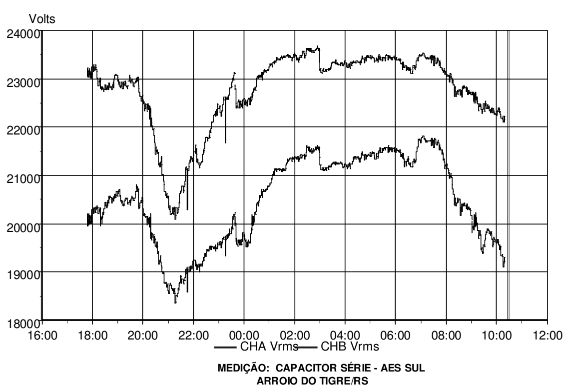

Figure 12 - RMS voltage at the series capacitor bank

So, as the results showed, the series capacitor bank operation is more appropriate those others alternatives studied mainly referring to the two voltage regulators used before. After eleven months of the series compensation full operation, the input and output voltage were registered again obtaining a voltage level increase between 5 and 14%.

CONCLUSION

This paper elucidates two different experiences on Series Compensation on system using over-compensation on two 23kV feeders from AES Sul Utilities. Considering the rural characteristics of these feeders where resistor and voltage drop are prominent, over-compensation is necessary to obtain a higher voltage level what increase the risk of resonance. The results demonstrated oscillations on the first bank energizing caused by an elevated induction motor load connected to that feeder. So the equipment, which objective was to reduce the regulation level and flickers effect, produced considerable voltage oscillations that could not maintain on the system due to the higher compensation level. After that, another detailed study was made in which the main characteristics of that system was considered and modeled on electromagnetic transient programs analyzing some technique to eliminate the oscillations which were possible to occur on steady state (Hunting) and also the auto-excited start motors phenomenon when damping resistor was studied. As it was impossible to install that capacitor at the feeder in which was firstly project, the necessity to install that compensation at another feeder appeared. On that case, the results were as expected demonstrating the advantages of a series capacitor to over-compensate systems when there is no resonance. Concluding, the series compensation system was installed at Salto do Jacuí's system where presented a good regulation.

REFERENCES

[1] A. A. Mahmoud, T.H. Ortmmeyer, and R.G. Harley, 1980, "Effect of reactive compensation on induction motor dynamic performance", *IEEE Trans. on Power Apparatus and Systems*, vol. PAS-99, no. 3, 841-846.

[2] L.O. Larsson, J. Samuelson, J.J. Lombard, P. Berneche and G. Aliard, 1995, "Applications of a new concept for a compact series capacitor scheme for distributions networks", *Canadian Electrical Association*, Vancouver, Canada.

[3] IEEE Subsynchronous Resonance Working Group of the system Dynamic Performance - Subcommittee Power System Engineering Committee, 1980, "Countermeasures to subsynchronous resonance problems", *IEEE Transactions on Power Apparatus and Systems*, Vol. PAS-99, no 5, 1810-1818.

[4] J.W. Butler and C. Concordia, 1937, "Analysis of series capacitor applications problems", *AIEE Transactions*, vol. 56, 975-988.

[5] C.F. Wagner., 1941, "Self-excitation of induction motors with series capacitor series capacitor" *AIEE Transactions,* vol.60, 1241-1247

[6] Westinghouse, 1964, *Electrical Transmission and Distribution Reference Book*, Westinghouse, 1964, 258.