Electromagnetic Interference in the Substation Jose up 400/115 kV

Gustavo Carrasco

***Abstract*- In the Jose substation the presence of transient electromagnetic interference was detected in control and instrumentation cables. This interference arises during the operation of a 400 kV disconnect switch affecting the remote measurement temperature transducer and the tap changer voltage regulator (MK30) of Autotransformer #3 (AT3), located in control house #2, which is used for data acquisition (DAH-2), and is near the disconnect switch. In this study have presented the results obtained by simulations carried out with the Alternative Transients Program (ATP) about the interferences in weak currents in control and instrumentation cables due to transient or permanent electromagnetic fields that cause false trips to the equipment.[1]**

Keywords: ATP, cables control, disconnect switch, electromagnetic noise, Induction, Interference.

I. INTRODUCTION

The interferences in control and measurement cables are related to transient or permanent electromagnetic fields which might causes damages to the equipments as well as the generation of false trips or alarm. These electromagnetic interferences come from the high voltage circuits and the machines connected to the low voltage circuit, which generates interferences of low and high frequency from 50 Hz up to 10 kHz and 100 kHz to 10 MHz respectively. The last range is denominated parasite interference; where the shielding is not always effective to protect the circuits affected by this interference [1].

At substation Jose the presence of electromagnetic interference by high frequency transients has been determined in control and measurement cables, particularly in those which are spread along in canalization tray from the DAH-2 to the AT3 and in parallel to the 400kV line.

This interference begins during switching of 400kV disconnect switch X924 affecting the remote temperature transducer measurement and the voltage regulator of the tap changer (MK30) for AT3, both located inside the DAH-2, near to these disconnect switch.

This study was done by the inconveniences in the substation due to electromagnetic interference that causes a wrong operation in the equipment. The study contains the results analysis for different sensibilities done with ATP simulation of the induce voltage in cable that feeding the voltage regulator of the tap changer as function of the height separation between high and low voltages circuit; horizontal displacement of the cable in relation to the axis of high voltage circuit; variation of the cable shielding thickness, variation of the cable shielding resistance to earth and evaluation of the frequency response of the circuit. Additionally it includes the frequency response analysis for a filter proposed by the tap changer manufacturer to mitigate the electromagnetic interference in the voltage regulator of the tap changer and its behavior during high frequency transients induced in the low voltage circuit cable by the switching of the 400 kV disconnect switch X924.

II. SYSTEM DESCRIPTION

The 400kV switch yard of the substation Jose is a breaker and half configuration with a double bus bar in 115 kV. The substation single line diagram is shown in fig 1. Figure 2 show a picture with the location of the disconnector switch, the DAH-2 and the tray for the cables of control and measurement used in this study.

Is important to indicate that these control and measurements cables affected by this electromagnetic interference are sharing the same route with of the high voltage line section and they are located at 3.5 m of a distance from the axis of high voltage (Phase B), which has a distance between phases and height of 7 m.

To determine the current levels and the induced voltage by opening and closing of the disconnect switch X924, were evaluated a line section from the disconnect switch near to house #2 for data acquisition (DAH-2) until the bus # 2 up 400 kV where is located the AT3, and from the disconnect switch until the exit of line in bar #1. Those distances are 85 and 15 m respectively.

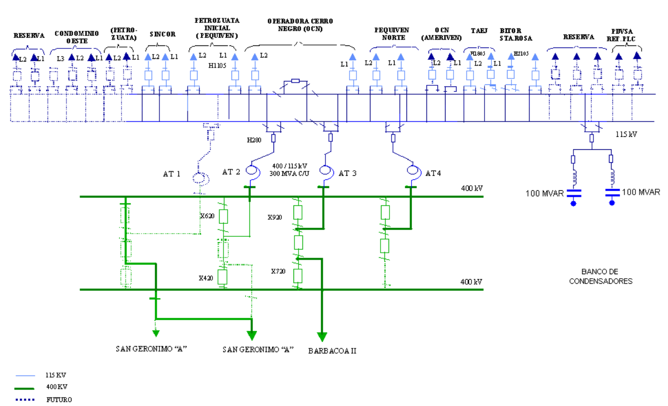

Fig. 1. Single line diagram of the substation José 400/115 Kv

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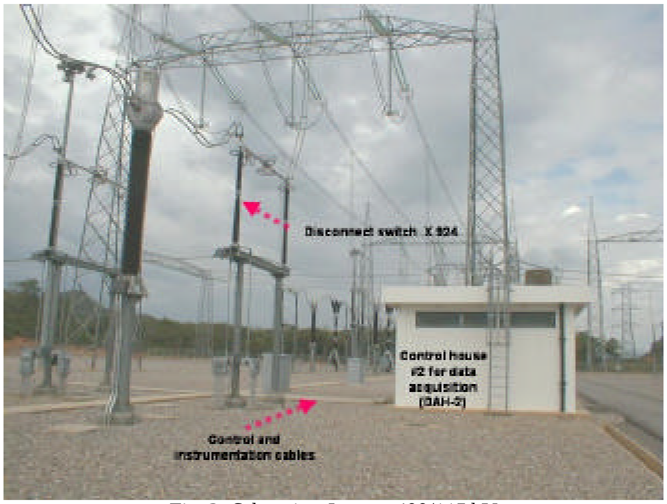

Fig. 2. Substation Jose up 400/115 kV

III. METHODOLOGY AND CONSIDERATIONS

The methodology used is described below:

A. *Electromagnetic induction in cables to feeding the voltage regulator of the tap changer*

To evaluate the switching impact of the disconnect switch X924 from the switchyard up 400 kV of the substation Jose in the magnitudes of induced voltage in cable's system of control and measurement, its equivalent models was represented by the ATP including the electromagnetic noise caused by the electric arc that arises during the opening of this disconnect switch as well as the affected circuit of low voltage. Different cases were made to analyze the sensibilities, such as the variation of the distance between high and low voltage line sections, horizontal displacement of the cable with regard to the high voltage line section, the thickness of the cable and variation of the cable shielding resistance to ground. Figure 3 show the simulated circuit in ATPdraw.

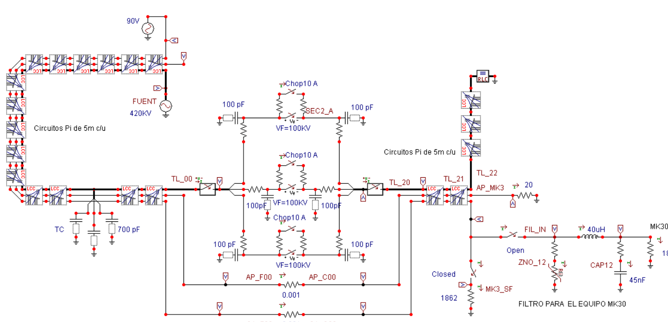

Fig. 3. Substation Jose up 400/115 kV simulated in the ATPdraw

B. *Analysis of the filter frequency response*

The filter proposed by the manufacturer to be associated to the voltage regulator of the tap changer of the transformer #3 (AT3) of the substation Jose to 400 kV was simulated with the ATP to analyze its frequency response.

To evaluate the behavior of the filter as a function of the frequency was applied to the input of the filter a constant voltage of one volts peak and varied in certain range the frequency, at the same time it was measuring the output voltage of the filter in function of the frequency. This procedure is used to determine the frequency range where the filter amplifies the input voltage, the gain and the resonance frequency.

C. *Filter behavior during electromagnetic interferences.*

Through ATP simulations was evaluated the filter behavior during electromagnetic interferences of high frequency induced by the high voltage circuit toward the cable that feed the voltage regulator of the tap changer during the switching of the disconnect switch X924 up 400kV. Different cases were evaluated with and without the filter to compare its results and to verify their impact in the interferences mitigation.

IV. APPROACHES AND USED MODELS.

Next, are described the used approaches to represent the bus bar section up 400 kV and the low voltage cable in the same route:

1. To the section of high voltage line was employed a mutually couple "PI" circuit model and its resistance, inductance and capacitance were calculated a frequency of 5 MHz. In high voltage was considered a distance between phases and phase height to earth of 7m and for the cable, the earth level was located 3.5m from the axis of the configuration of high voltage.

– The low voltage cable model that feeds the voltage regulator of the tap changer is included inside the "PI" circuit of the high voltage line section. The cable was represented by a solid conductor inside a tubular conductor which thickness represents the cable shielding. This tubular conductor has a thickness of 1mm.

– The disconnect switch was represented as an ideal switch controlled by voltage that closes its contacts when is exceeding the disruptive discharge voltage (Flashover voltage) and additionally was assigned an arc time of deionization equal to zero (Tde=0), which indicates to the switch the time that should remain closed when the current has a value of zero. By this way the multiple reignition of the electric arc was represented and is generated the currents and voltage of high frequencies.

– The filter was represented according to the data given by the manufacturer.

– This study assumed for the voltage regulator of the transformer tap changer that is feeding by an AC voltage source of 90 volts peak and for high voltage side of the system a voltage of 420 kV rms or 1.05 per unit of the nominal voltage (400 kV rms).

– The reference case for this study was considered as a cable with a shield of 1 mm of thickness and both ends of the cable connected to a ground with a resistor of 20 Ω. With the purpose to determine the induced voltage in the cable it was evaluated a case with the shield to ground for the cable end where is connected the voltage regulator of the tap changer.

V. EVALUATED CASES

To determine the levels of induced voltage or electromagnetic noise of high frequency in the cable and equipments, we proceeded to simulate with ATP and the suitable models, the opening of the disconnect switch that is locating close to the DAH-2 for cases without filter and with the cable's shield in one or both ends to ground.

A. Cases without filter:

1. Variation of the vertical distance between the high voltage line section where the noise source is located (disconnect switch X924) and the cable or low voltage circuit.
2. Horizontal displacement of the cable with regard to the axis of the high voltage circuit using the central phase and phase B as reference.
3. Variation of the shield's thickness of the cable (tubular conductor).
4. Variation of the cable shield resistance to ground and frequency response of the complete circuit.

B. Cases with filter:

1. Evaluation of the frequency response of the filter that is associated to the voltage regulator of the tap changer. This case does not involve switching of the disconnector switch.
2. Evaluation of the filter behavior that is associated to the voltage regulator of the tap changer and verification of their effectiveness in the mitigation of the level of electromagnetic noise of high frequency in the cable and equipments.

VI. RESULTS ANALYSIS

Next is carried out the results analysis of the simulations to evaluate the level of electromagnetic interference of high frequency in measurements and control cables during the opening of the disconnect switch X924 according the previous mentioned cases.

A. Variation of the high voltage circuit height

In Table 1 is shown the results of the induced voltages inside the feeding circuit of the voltage regulator of the tap changer or arrival point in function of the height of the high voltage circuit by the opening of the disconnect switch X924.

In this table it is observed that the induction decreases when increases the high voltage circuit height. The values in columns 5 and 6 of Table 1 are for overvoltages in high voltage circuit and the percentage of the induced voltage in the cable that is feeding the voltage regulator of the tap changer (low voltage circuit) due the opening of the disconnector switch. As can be appreciated the percentage of induction is low but it is enough to cause interferences that affect the normal operation of the measurements equipments. Also, can be observed for cases with the shield to ground for the cable in the end where is connected the voltage regulator of the tap changer that the induction is smaller in comparison with cases in which the shield in both ends are grounding.

TABLE 1
INDUCED VOLTAGE AS FUNCTION OF THE HEIGHT

	Grounded in both ends (GBEs)					Grounded in one end (GOE)	
1	2	3	4	5	6	7	8
h(mts)	VInd, Vp	VInd(pu)	HV(V)	HV(pu)	Induction%	Vind(V)	Differs%
6	369	4.10	388000	1.19	0.087%	337.5	-8.54
7	324	3.60	398000	1.22	0.076%	303	-6.48
9	273	3.03	399000	1.22	0.059%	235	-13.92
10	251	2.79	400000	1.22	0.055%	220	-12.35
15	200	2.22	395000	1.21	0.041%	162	-19.00
20	182	2.02	390000	1.19	0.037%	145	-20.33

1- (h)- Height; 2-Voltage pick induced; 4 (HV) - Voltage in the side of high for switching of X924; 6 - % of Induction of the circuit of high voltage to the cable.

It is important to mentioning that this sensibility was only carried out with theoretical ends according to the objective of evaluating the behavior of the induction in function of the height among the low and high voltage circuits to validate the model to be used in ATP. Besides, to simplify the model it was changed the high voltage circuit height instead of the depth of the control cable location. Variation of the horizontal displacement of the cable with regard to the phase B of the high voltage circuit

B. Variation of the horizontal displacement of the cable with regard to the phase B of the high voltage circuit

In Table 2 is shown the results of the induced voltage inside the feeding circuit of the voltage regulator of the tap changer as a function of the horizontal displacement with reference with the central phase (B) of the high voltage circuit. In this table it can be observed that the smallest induction was obtained when the cable was exactly under the central phase and this condition remain constant until the half point among the two phases (B and A). Then, it begins to increase until reaching its maximum value that it is located exactly under the extreme phase (phase A) and from there it decreases as it goes away of the line section.

TABLE 2
INDUCED VOLTAGE AS FUNCTION OF THE HORI ZONTAL DISPLACEMENT

	Grounded in both ends (GBEs)			Grounded in one end (GOE)	
1	2	3	4	5	6
Dh(mts)	Vind(V)	Vind(pu)	Induction%	Vind(V)	Differs%
0	322	3.58	0.074%	292.4	-9.19
3.5	324	3.60	0.077%	303.0	-6.48
5	372	4.13	0.093%	367.3	-1.28
7	407	4.52	0.097%	383.4	-5.80
10	355	3.94	0.089%	350.0	-1.41
20	143	1.59	0.034%	135.0	-5.59
30	100	1.11	0.022%	86.4	-13.60
50	90	1.00	0.019%	75.0	-16.67

1 (Dh) - Horizontal Displacement of the cable; 2 - Voltage pick induced; 6 - % of Induction of the circuit of high voltage to the cable.

In Table 2 is shown the results of the induced voltages inside the feeding circuit of the voltage regulator of the tap changer for cases with the cable's shield in one or both ends to ground, where it can be appreciated that the induced voltage is lightly higher (6.48%) when both ends are grounding.

In column 4 of Table 2 is included the percentage of induced voltage from the high voltage circuit to the cable that is feeding the voltage regulator of the tap changer where it can be appreciated that this value is low (0.077%) with regard to the overvoltage in the high voltage circuit (1.22 pu), however it is enough to cause interferences that affect the normal operation of the measurements equipments.

C. Variation of the cable thickness

In Table 3 is shown the induced voltages in the cable in function of the variation of the shield thickness when is switching of the disconnect switch X924. In this Table, it can be observed that the induction decreases when shield's thickness increases, highlighting the importance of selecting a thickness for the shield of the cables appropriated to decrease or to avoid the induced voltage on it.

TABLE 3
INDUCED VOLTAGE AS FUNCTION OF THE SHIELD THICKNESS OF THE CABLE

1	2	3	4	5	6
D (cm)	C(mm)	GAEs/Vind(Vp)	Induction %	GOE/Vind(Vp)	Differs%
1.04	0.2	480	0.121%	389	-18.96
1.1	0.5	486	0.122%	410	-15.64
1.12	0.6	497	0.125%	409	-17.71
1.13	0.65	496	0.125%	408	-17.74
1.14	0.7	486	0.122%	404	-16.87
1.15	0.75	463	0.116%	394	-14.90
1.2	1	324	0.081%	303	-6.48
1.22	1.1	251	0.063%	253	0.80
1.23	1.15	213	0.054%	208	-2.35
1.25	1.25	175	0.044%	134	-23.43

1(D)–External diameter of the cable; 2(C) - Thick of the shield of the cable; 3 - Voltage pick induced; 4 - % of Induction of the circuit of high voltage to the cable.

D. Induced voltage in the cable as function of the shield resistance to ground

Before proceeding with the results analysis of this chapter, it is important to mention that it was evaluated the behavior of the high voltage circuit with the low voltage circuit with the subroutines Cable Constants and Line Constants, because it does not exist in the ATP a subroutine that allows the combination of cables with transmission line to obtain an appropriate model. For the test carried out, it shows that the PI line constant's model has an agreement behavior with the prospective results.

In Table 4 was included the results of the induced voltage in the cable as function of the shield resistance to ground in when is opening the disconnect switch X924. In this Table, is shown that the smallest induction was obtained for a resistance of 30 Ω approximately and higher values of resistances; then the induced voltage increases in a stable way as was waiting, however an atypical behavior was observed for smaller values of 30 Ω.

TABLE 4
INDUCED VOLTAGE AS FUNCTION OF THE CABLE SHIELD RESISTANCE TO GROUND

Ra(W)	Vind/GBEs(Vp)	Vind/GOE(Vp)
1	537	475
5	480	429
10	418	378
15	368	332
20	324	303
30	280	263
50	282	256
75	308	303
100	390	385
1000	824	826
2000	877	865
5000	924	906

To evaluate in a precise way these phenomena, was carried out for the circuit a frequency response analysis with 3 different values of resistances (0, 30 and 1,500 Ω), determining the existence of multiple areas of resonances in the circuit under study that changed in function of the values of the resistors, as show in the Figure 4. In this case to evaluate the behavior of the circuit as a function of the frequency was applied to the high voltage side a constant voltage of one volts peak and varied in certain range the frequency, at the same time it was measuring the output voltage of the cable in function of the frequency.

In Figure 5 is shown inside a rectangular area the frequency of the interference in the induced voltage that oscillates among 3 to 5 MHz with a resonance frequency of 4.3 MHz where the smallest gain was obtained for a resistance of 30 Ω followed by 0 Ω and finally 1500 Ω. This confirms in the frequency domain the atypical behavior of the induced voltage as function of the cable shield resistance to ground as was observed in the time domain.

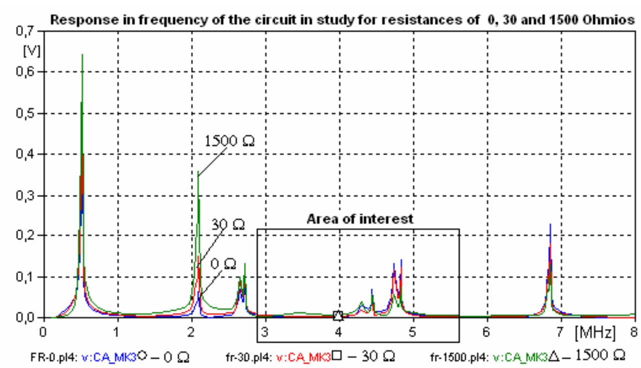

Fig. 4. Frequency response for the cable's shield resistances to ground with resistances of 0, 30 and 1500 Ω

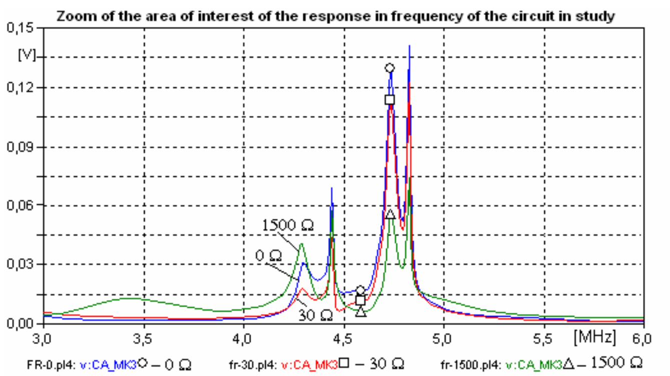

Fig. 5. Zoom of rectangular area of interest in the figure 4

The previous findings suggest that this atypical behavior, could be attributed to the model used, additionally was carried out a test where was eliminated the mutual capacitances between the cable and the high voltage conductors but leaving the capacitances of the cable shield. Then was verified that this atypical behavior disappears but increase the induced voltage in the cable; however, the behavior of the induced voltage in the cable as function of the shield thickness is incoherent and it was taken the decision to maintain the selected model.

E. Frequency response of the filter associated to the voltage regulator of the tap changer

In Figure 6 is shown the frequency response of the filter and can be appreciated a resonance frequency of 116 kHz which coincides with the theoretical calculations for an L = 40μH and C = 47 nF. The following behaviors were observed from the frequency response of the filter:

1. Approximately in the range of 60 Hz up to 20 kHz is not appreciable distortion of amplitude and phase.
2. A distortion was observed in the range of frequency of 20 to 160 KHz; particularly to 116 kHz where a resonance exists with a change of phase and amplifying the input voltage.
3. From 160 KHz to higher frequencies, non amplitude distortion and only phase change was observed. Then the filter will operate correctly to mitigate interferences in this range of frequency.

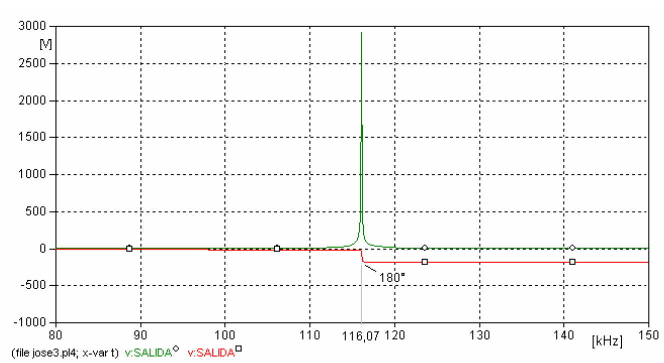

Fig. 6. Frequency response of the filter

F. Filter behavior in presence of the electromagnetic interference of high frequency

In Figures 7 and 8 is shown the behavior of the induced voltage wave in the cable that feed the voltage regulator of the tap changer for cases with and without filter. In this Figure, it can be appreciated that the filter eliminates the induced interferences of high frequency, which reach a voltage level of 326 Volts peak with a frequency of 4.25 MHz.

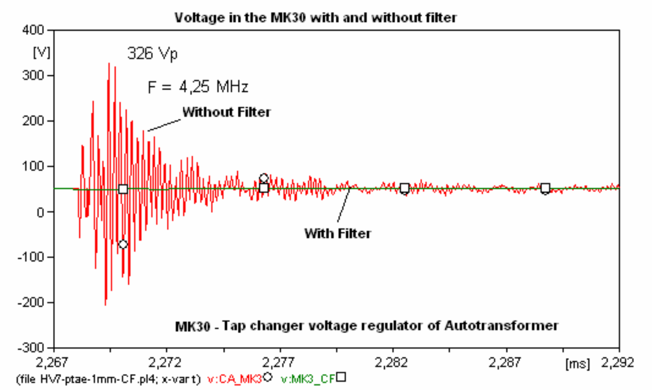

Fig. 7. Input voltages at the voltage regulator of the tap changer with and without filter

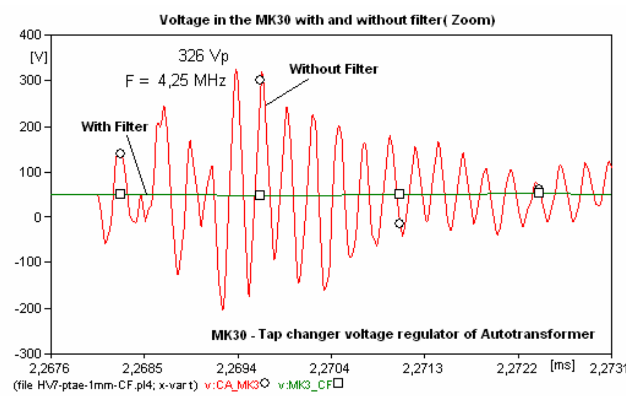

Fig.8. Zoom of the input voltages at the voltage regulator of the tap changer with and without filter

VII. CONCLUSIONS AND RECOMMENDATIONS

The conclusions and recommendation of this study are the following:

1. It has been proved that to decrease the induced voltage level is needed to increase the vertical separation between the high voltage circuit and the cable of low voltage. However, to increase the vertical separation is not a right solution because it could be required a separation non standard to be able to have a significant effect, that is complex technically and not be an economic solution.

2. A variation in the induced voltage level was observed when increase the horizontal displacement between the cable and with reference with the central phase (B) of the high voltage circuit. The smallest induction was obtained when the

cable was exactly under the central phase and this condition remain constant until the half point among the two phases (B and A). Then, it begins to increase until reaching its maximum value that it is located exactly under the extreme phase (phase A) and from there it decreases as it goes away of the line section.

3. It has been determined the behavior of the induced voltage as a function of the cable shield's thickness which indicates an approximate way the convenient thickness that cables should have, with the purpose of contributing to limit the induction phenomena for future substations, however is important to keep in mind that the shield is not always effective for interferences of high frequency.

4. From the simulations it has been obtained that the induced voltage is smaller in 7% approximately when the cable shield is grounding in the end where is located the voltage regulator of the tap changer in comparison with the case in which both ends of the cable shields are grounding with resistors of 20Ω. These percentage changes varying the basic conditions, however with one end grounded it continues giving smaller values.

5. The smallest induced voltage was obtained with a grounded resistor for the cable shield of 30Ω approximately and for higher values the induced voltage increases; however an atypical behavior was observed for smaller values than 30Ω and that can be due to the line model used or maybe need to be improved. Nevertheless the results are partly satisfactory in the sense that in this model of the circuit a resonance frequency of 4.3 MHz was obtained and the frequency of the electromagnetic interference was 4.25 MHz, being presented the smaller amplification gain for a resistance of 30Ω in comparison with resistances of 0 Ω and higher than 30Ω , that confirm by this way the attributable atypical behavior to the used model.

6. The associated filter to the voltage regulator of the tap changer, it was determined a resonance frequency of 116.07 kHz; however the induced interference frequency is in order of 3 to 5 MHz and for this resonance frequency does not imply risk or impediment to use the filter.

7. Through the simulations the satisfactory behavior of the filter can be appreciated before the electromagnetic transient interferences of high frequency. The filter has an attenuation tendency after the 160 kHz and its use is recommendable because it not represents trouble by its input voltage amplification and for the frequency of the interference phenomena in study (3 to 5 MHz).

VIII. REFERENCES

[1] Nota Técnica N°2, Contrato Edelca 329-100 S/E's Palital, Jose y El Furrial, Cogelex Alsthom, marzo 1998. (In Spanish)

[2] W. C. Kotheimer, "Substation Transients and Solid State Controls", Northwest Electric Light and Power Association, April 1974.

[3] W. C. Kotheimer, Control Circuit Transients, GE Power Management, GER-3061.

[4] W. C. Kotheimer, Theory of Shielding and Grounding of Control Cables to Reduce Surges, Pennsylvania Electric Association Fall Meeting, October 1973.

IX. BIOGRAPHY

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