ANALYSIS OF OVERVOLTAGE CONTROL ON HALF WAVE LENGTH AMAZON TRANSMISSION SYSTEM

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ABSTRACT

This paper presents the results obtained from EMTP simulations carried out to investigate the overvoltage problems caused by short circuits, load rejection and energization in a half wave length transmission system.

A study was also developed to verify the possibility of deriving a load from any point along the line.

As a consequence of very high overvoltages calculated, it was necessary to analyse and compare methods of controlling these overvoltages: spark gaps, shunt reactors, shunt resistors and metal oxide varistors.

keyword: Overvoltages - Long Distance - Transmission System - Half Wavelength

1. INTRODUCTION

The Brazilian Power System consists of two interconnected systems, Southeast/West-Central/South and North/Northeast.

As power resources near the major load centers become exhausted, it will be necessary to exploit the energy resources located in the Northern region (Amazon basin), where there is great hydroelectric potential. On the other hand, major power markets are in the Southern sector of the Southeastern region and at the coastal side of the Northeastern region.

Therefore a great challenge will be faced in the future, namely the transmission for long distances of large amounts of energy.

The motivation for this study is related to the investigation of half wave length transmission system (HWLTS) as one of the hypothesis to transmit energy from Amazon power plants to Southeast region of Brazil, due to the fact that the transmission distance is about 2500 km, which corresponds to half wave length ($\lambda/2$) in the Brazilian frequency system (60 Hz). (1)

The greatest advantage of this alternative relies on the fact that the half wave length line has the same, performance of a short line with respect to voltage drop and stability. As a consequence there is no need for intermediate substations and for reactive power compensation.

On the other hand, there are many points that recommend a careful study of this kind of transmission before its application.

Preliminary studies (2), based upon simplified models, indicated that in this kind of transmission system (HWLTS) very high overvoltages appear when short circuits in critical points along the line occur.

The aim of this paper is to present the analysis of several methods applied in order to limit the overvoltages caused mainly by short circuits. After this, it was verified whether the selected solution could be used also to reduce the overvoltages derived from load rejection and energization.

This paper summarizes the results of EMTP simulations of an energized open line configuration (Figure 1 - circuit breaker opened), in which are applied three phase faults near line ends. The occurrence of short circuit in these critical points determine resonant circuits, resulting in very high overvoltages. It was studied the following ways of controlling these overvoltages:

- spark gaps
- shunt reactors
- shunt resistors
- ZnO arresters

For load rejection cases, the circuit breaker was initially closed.

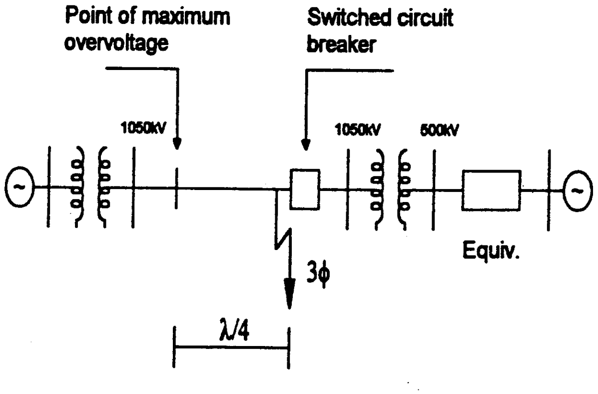

Figure 1

Finally, the problem of tapping the line was studied, analysing also the compensation requirements.

2. CHARACTERIZATION OF THE MAIN PROBLEM

In a half wave length transmission system (HWLTS), the line generates and absorbs the same amount of reactive power in all normal operating conditions and the Ferranti effect does not exist. On the other hand, when a short circuit occurs resonant circuits may appear, leading to extremely high overvoltages.

With the purpose of verifying the overvoltage level along the transmission system, including the sending end bus and the open line end where there are transformers and switching devices, faults were applied along the line.

The critical locations were the km 2239 from the sending end and its symmetric point in relation to the center of the line.

The middle point of the HWLTS and the one located 1/4 of wave length apart from the fault are the critical points where the highest overvoltages occur.

This situation requires an immediate action in the sense of changing the network topology, through the insertion of passive or active elements in the most adequate location.

The following methods of controlling and limiting the overvoltages were evaluated:

a. spark gaps with a flashover voltage of 2.0 p.u., located at:

   - the middle of the line;
   - the sending end;
   - the sending end and the middle of the line;
   - the sending end and λ/4 apart from the fault point.

b. shunt reactors at the middle of the line varying in the range of 1/32 XLT to 1/2 XLT, where XLT is the line reactance.

c. shunt resistors at the middle of the line varying in the range of 250 to 900 Ω.

d. ZnO arresters located at:

   - the middle of the line;
   - every 100 km along the line;
   - every 100 km along the central 1500 km of the line and every 50 km along the central 400 km.

The insertion of the resistors and reactors was made by the flashover of a spark gap adjusted to 2.0 p.u.

The saturation of the sending end transformers was also represented in these simulations.

3. SIMULATION RESULTS

Table 1 presents a summary of the main results derived from the simulations of three phase short circuits applied in the critical point (km 2239) carried out for each condition previously mentioned. The magnitude of the overvoltages and its respective time of occurrence are listed.

The values for the basic configuration were obtained without taking into account the transformer saturation.

The duration of EMTP simulations was 100 ms, to represent the action of the primary protection of the line.

Results in table 1 indicate that the influence of the sending end transformer saturation is in the direction of decreasing the amplitude of overvoltages. Despite being a small reduction, this saturation avoids the continuous growth of the voltage.

Since saturation is not sufficient to keep the voltage bellow a reasonable level, the insertion of spark gaps, located in distinct points along the line, was tried. Nevertheless, this was not a good solution, since magnitudes of 3.4 p.u. occurred.

In order to reduce the overvoltages, it was analysed the efficiency of the insertion of reactors in the middle of the line, by the flashover of a spark gap adjusted to 2.0 p.u. as suggested in (3).

A reactor (130 mH) with an equivalent impedance of 1/16 of the line reactance showed the best results, presenting maximum overvoltages around 2.6 p.u.. However, this is not a good solution because the overvoltages in terminal devices are not acceptable and the reactor power is also very high.

Another attempt to limit the overvoltages was the installation of shunt resistors at the middle of the line inserted also by spark gaps with the same adjustment.

The best results were obtained with a resistance of 450 Ω, but even under this condition the overvoltages along the line are high and the power dissipated by the resistor is very high.

Nevertheless, the values derived from the insertion of resistors showed that the direction for solving the problem could be the installation of metal oxide varistors, with the characteristics shown in Annex I.

Initially, the ZnO arresters were located only in the middle of the line, but the results were not satisfactory.

TABLE 1

OVERVOLTAGE (P.U.) AND ITS TIME OF OCCURRENCE			
CASE	AT THE SENDING END	AT THE POINT OF MAXIMUM OVERVOLTAGE	AT THE MIDDLE OF THE LINE
• Basic Configuration.	3.05 (100 ms)	8.74 (100 ms)	
• Basic Configuration with simulation of the sending end transformer saturation.	2.59 (89 ms)	7.59 (100 ms)	
• Spark gap at the sending end.	2.14 (53 ms)	5.80 (99 ms)	5.88 (100 ms)
• Spark gap at the middle of the line.	3.41 (24 ms)	2.44 (23 ms)	2.03 (20 ms)
• Spark gap at the sending end and at the middle of the line.	3.86 (26 ms)	2.91 (29 ms)	2.22 (22 ms) 2.04 (23 ms)
• Spark gap at the middle of the line and at the maximum voltage location.	3.41 (24 ms) 3.20 (70 ms)	2.14 (29 ms) 4.65 (65 ms)	3.80 (57 ms)
• Shunt Reactor of 1/ 2 XLT.	2.45 (48 ms)	3.59 (48 ms)	2.91 (43 ms)
• Shunt Reactor of 1/4 XLT.	2.55 (74 ms)	3.04 (32 ms)	2.18 (39 ms)
• Shunt Reactor of 1/8 XLT.	2.65 (58 ms)	2.61 (31 ms)	2.01 (20 ms)
• Shunt Reactor of 1/16 XLT.	2.54 (31 ms)	2.46 (30 ms)	2.01 (20 ms)
• Shunt Reactor of 1/32 XLT.	1.64 (23 ms)	3.16 (98 ms)	3.00 (106 ms)
• Shunt Resistor of 900 Ω.	1.64 (23 ms)	2.74 (98 ms)	2.61 (73 ms)
• Shunt Resistor of 750 Ω.	1.64 (23 ms)	2.48 (21 ms)	2.04 (25 ms)
• Shunt Resistor of 450 Ω.	1.66 (26 ms)	2.49 (21 ms)	2.02 (20 ms)
• Shunt Resistor of 250 Ω.	1.61 (23 ms)	2.72 (26 ms)	1.84 (37 ms)
• ZnO arrester in the middle of the line.	1.09 (28 ms)	1.68 (66 ms)*	1.71 (74 ms)
• ZnO arrester every 100 km along the line.			
• ZnO arrester every 100 km along the central 1500 km and every 50 km along the central 400 km.	1.26 (28 ms)	1.66 (34 ms)*	1.68 (55 ms)

***In these cases the maximum overvoltages occur at the middle of the line.**

Then, the arresters were distributed every 100 km along the line. In this case, the overvoltages were limited to 1.71 p.u. and the energy absorbed by the arresters, until 100 ms, is listed in Table 2.

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It was observed that the absorption of energy of the arresters located in the region up to 500 km from sending and receiving end was despicable, while for that ones placed around the central part of the line, it was very high.

Based on this fact, a first optimization of arrester distribution was tried, by removing the arresters near the extremities and disposing them every 50 km along the central 400 km of the line. This arrangement presented the best results as shown in the last line of Table 1. The higher current recorded in this case was 610 A, which is below the arrester specification.

In Table 3 the energy dissipation of the main arresters for this condition is listed, where a better energy distribution, compared to the previous case, can be seen.

Considering the last optimized arrester distribution, an additional investigation was carried out, evaluating the overvoltages and the energy absorption as a consequence of single and three phase short circuits along the line and due to load rejection.

A summary of the values derived from the three phase faults are presented in Table 4, in which voltages are indicated only for the critical points former defined.

For all single phase faults, the obtained overvoltages from EMTP simulations were below 1.3 p.u. and the energy dissipated by the arresters was below 1.0 MJ.

Results listed in Table 4 show that the most severe stresses in terms of energy are restricted to faults located in very well defined points of the transmission line.

TABLE 2

SURGE ARRESTERS LOCATION	ENERGY (MJ)
km 700	14.4
km 800	17.6
km 900	19.9
km 1000	20.8
km 1100	19.2
km 1200	17.4
km 1300	13.7
km 1400	7.3

TABLE 3

SURGE ARRESTERS LOCATION	ENERGY (MJ)
Sending end	< 0.1
km 900	14.0
km 950	14.3
km 1000	14.7
km 1050	15.4
km 1100	15.9
km 1150	14.6
km 1227	5.5
km 1300	12.2

TABLE 4

MEASURE POINT (km)	CASE A		CASE B		CASE C	
	VOLTAGE (p.u.)	Energy (MJ)	VOLTAGE (p.u.)	Energy (MJ)	VOLTAGE (p.u.)	Energy (MJ)
SENDING	1.26	< 0.1	1.44	< 0.1	1.44	0.1
END		6.3		1.7		0.3
600		14.0		6.1		*
900		14.3		6.7		
950		14.7		7.3		
1000	1.66	15.4	1.64	8.0	1.06	
1050		15.9		8.7		
1100		14.6		7.1		
1150		5.5	1.67	0.9		
1227		12.2		9..1		
1300						

MEASURE POINT (km)	CASE D		CASE E		CASE F		CASE G	
	VOLTAGE (p.u.)	Energy (MJ)	VOLTAGE (p.u.)	Energy (MJ)	VOLTAGE (p.u.)	Energy (MJ)	VOLTAGE (p.u.)	Energy (MJ)
SENDING	1.04	*	1.10	*	1.33	*	1.56	*
END								
600								
900								
950								
1000	0.44		0.00		0.62		0.90	
1050								
1100								
1150	0.00		0.22		0.77		0.95	
1227								
1300								

Where:

*Values smaller than 0.1 MJ
CASE A: three phase short circuit in km 2239.
CASE B: three phase short circuit in km 2454.7.
CASE C: three phase short circuit in km 1500.
CASE D: three phase short circuit in km 1227.
CASE E: three phase short circuit in km 1050.
CASE F: three phase short circuit in km 500.
CASE G: three phase short circuit in km 100.

Since the opening of the line can not be avoided when a three phase fault happens, another way of reducing the number of arresters was tried. The location of the arresters was changed, moving them from the region around the middle of the line and putting them every 100 km in the first and final 600 km of the line, thus protecting the terminal devices against overvoltages. This solution was inadequate because the energy absorbed by the arresters (higher than 50 MJ) exceeded their capacity. The energization of the line did not cause problems, since the energy dissipated by the arresters was lower than 1.0 MJ. The maximum registered overvoltage was equal to 1.8 p.u., which was immediately reduced in the following cycles and occurred near the open line end at 0.013 s after closing the pole breakers.

However, when the line is switched on with its central point short circuited, as suggest in reference (3), the overvoltage is reduced to 1.55 p.u., near the sending terminal. This fact indicates that energization of a half wave transmission line is not a critical operation.

Keeping the same arrester distribution, load rejection simulations were performed. The results showed high amplitudes of overvoltage (around 2.0 p.u..) but low arrester energy consumption near the receiving end of the line. Then, in order to reduce these values surge arresters were also placed in the region up to 500 km from sending and receiving ends. Hence, the overvoltage turned to 1.58 p.u. and the energy absorption was despicable.

4. ANALYSIS OF TAPPING A HWLTS

One of the most important question about the feasibility of the HWLTS is related to the possibility of it being tapped. Analysing the problem, two basic aspects are involved:

- Voltage control, due to the addition of a line section;
- Stability among the several power sources.

The first aspect can be solved by the total compensation of the line section connected to the original line.

The second aspect implies that the synchronism among generations must be guaranteed. This fact leads to the conclusion that tapping of the main line is limited to its first and last 600 km ($\lambda/8$).

The connection of a line section results in an electrical shortening of the main line, which brings about the necessity of increasing it.

Short circuits and load rejection were simulated in this new system and no significant differences were observed in the results.

5. CONCLUSIONS

The main conclusions of the studies are:

a) The installation of spark gaps was not a good solution since the overvoltages are higher than 3.0 p.u., besides the fact that the line must be opened to extinguish the arc.

b) The insertion of shunt reactors as an alternative showed a better performance to limiting overvoltages (magnitudes lower than 2.65 p.u.). However, the reactor capacity was considered very high (in relation to an inductance of 130 mH) and this solution was disregarded.

c) The option of installing shunt resistors in the middle of the line, in terms of overvoltage amplitudes, is compatible with the previous case (reactors), but the problem of a high power consumption (related to a resistance of 450 Ω) still remained, and this solution was also put aside.

d) Related to the insertion of ZnO arresters, the following conclusions could be verified:

   • with the ZnO arresters located only at the middle of the line, the overvoltages are very high and the energy absorbed exceed its capability.

   • The first effort to optimize the arrester distribution (every 100 km plus every 50 km in the 400 km around the middle of the line) limited the overvoltage magnitude to 1.68 p.u. and the energy absorption was lesser than its capability.

e) The last result indicates that deeper studies must be carried out in the sense of optimizing the location of arresters which consequently leads to a reduction of this quantity.

f) It is possible to derive a tap from a HWLTS but an economical analysis must be done in order to assure its feasibility.

It should be emphasized that, for the sake of simplicity, the analysis was performed without simulation of corona losses, which would certainly reduce both the overvoltage and the arrester energy.

6. REFERENCES

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ANNEX I : DATA

- TRANSMISSION LINE

$R1 = 0.009420$	Ω/km
$L1 = 0.848874$	mH/km
$C1 = 0.013576$	uF/km
$Ro = 0.31109$	Ω/km
$Lo = 3.8019$	mH/km
$Co = 0.00737$	uF/km

With these parameters the half wave length is equal to 2454.7 km.

- SENDING END TRANSFORMER

$Rtr = 0.4761904$ Ω
$Ltr = 63.1567$ mH
$Rm = 1.75381$ Ω
$Lm = 232.5989$ mH

- SURGE ARRESTERS

Rated Voltage: 800 kV
Maximum Continuous Operating Voltage: 640 kV
Current at Maximum Steady State Operating Voltage: 4 mA rms
Rated Frequency: 60 Hz
Lightning Impulse Withstand Level: 2400 kV peak
Switching Impulse Withstand Level: 1800 kV peak
Power Frequency Withstand Voltage: 1050 kV rms
Current and Energy Values: 8 kA/21.3 MJ
Maximum Residual Voltages:

	DISCHARGE WAVE 8/20 us		DISCHARGE WAVE	
			45/90 us	1000 us
I (kA)	(kV)	I (A)	(kV)	(kV)
1	1442	100	1315	1301
2	1488	200	1340	1324
5	1561	500	1377	1360
10	1620	1000	1409	1386
20	1697	2000	1447	1421
40	1810	3000	1476	1448