COMPARATIVE RESEARCH INTO SWITCHING OVERVOLTAGES IN THE CASE OF SWITCHING BY SF6 CIRCUIT BREAKER IN THE 400 kV NETWORK OF CROATIA

Srećko Bojić, Ante Sekso
Energy Institute
Ulica grada Vukovara 37

Ivo Uglešić
Faculty of Electrical Engineering
and Computing, University of Zagreb

41000 ZAGREB, CROATIA

SUMMARY

This paper presents a summarized overview of the results of researches into switching overvoltages on a new transmission line with reduced dimensions in the 400 kV network of Croatia.

The researches have been based on a comparative analysis of the results of the measurements performed in the live network and the results of computer simulations performed on a model in the case of switching the unloaded 400 kV transmission line by a SF_6 circuit breaker.

KEY WORDS

Switching overvoltage, switching, transmission line, circuit breaker

1. INTRODUCTION

Over the last two decades in Croatia, a number of facilities of the 400 kV rated voltage network have been put into service, specifically: five substations, then four lines between these stations, and five lines toward the neighboring countries created in the region of the former Yugoslavia.

Since the war of aggression on Croatia, the northern and southern so-called main 400 kV lines have been cut off, and the only line currently in operation is the one between the capital of Zagreb and the city of Rijeka as well as the connections with Slovenia, and through the latter with the UCPTE network (with Italy and Austria). It is planned to construct soon a new substation near Zagreb and through it a line for connection to the 400 kV network of Hungary, whereby a significant European interconnection East-West will be implemented though the territory of Croatia. Due to its geographical shape, the Croatian 400 kV network is in terms of topology a radial one with the possibility of closing it into a loop through the territory of Bosnia-Herzegovina being uncertain.

Characteristic of the Croatian 400 kV network are uncompensated and relatively long lines. All this indicates that significant overvoltages may occur during various switching operations under normal and off-design conditions. The studying therefore of overvoltages has been paid special attention to since initial formation of the 400 kV network in Croatia [1-3] and combining in most cases measuring-technical and computer-based approach. On the basis of about ten such projects significant experiences have been gained and a large data base developed from the real network. When a new 400 kV Meline-Tumbri line was put into service, it was assessed that the entire switching overvoltages computation and measurement process had to be re-conducted owing to the numerous particularities as detailed below.

2. MEASUREMENTS OF OVERVOLTAGES ON THE MELINA-TUMBRI LINE

Earlier studies of overvoltages in the Croatian 400 kV network were resumed upon the construction of the Melina-Tumbri line which was put into service in 1992.

There are several basic and strong reasons for resuming such and similar researches in the real network, namely:

In terms of the design, the constructed line has reduced size towers as compared to other 400 kV lines in Croatia, and it was put into service equipped with only one ground wire due to a delay in equipping it with the other ground wire with a built-in fiber optic cable, which resulted in change and asymmetry in the typical parameters of the line.

The line is switched by a SF_6 circuit breaker at one end, which represents the beginning of application of this type of circuit breakers in the line fields of the 400 kV network.

2.1 Research Approach and Description of Testing System

Research into overvoltage occurrences in today's weakened 400 kV network has been planned to be divided into several sub-projects, these being in addition to overvoltage in the case of switching the unloaded line by a SF_6 circuit breaker, a research into overvoltage in the case of switching an unloaded autotransformer and overvoltage in the case of single-phase fault clearing [4].

Extremely adverse conditions in the electric power system of Croatia did not allow the carrying out of all the researches planned, so for now they have been limited to testing overvoltage occurrences in the case of switching the 400 kV Melina-Tumbri unloaded line by a SF_6 circuit breaker.

The basic measuring configuration for testing purposes is shown in Figure 1.

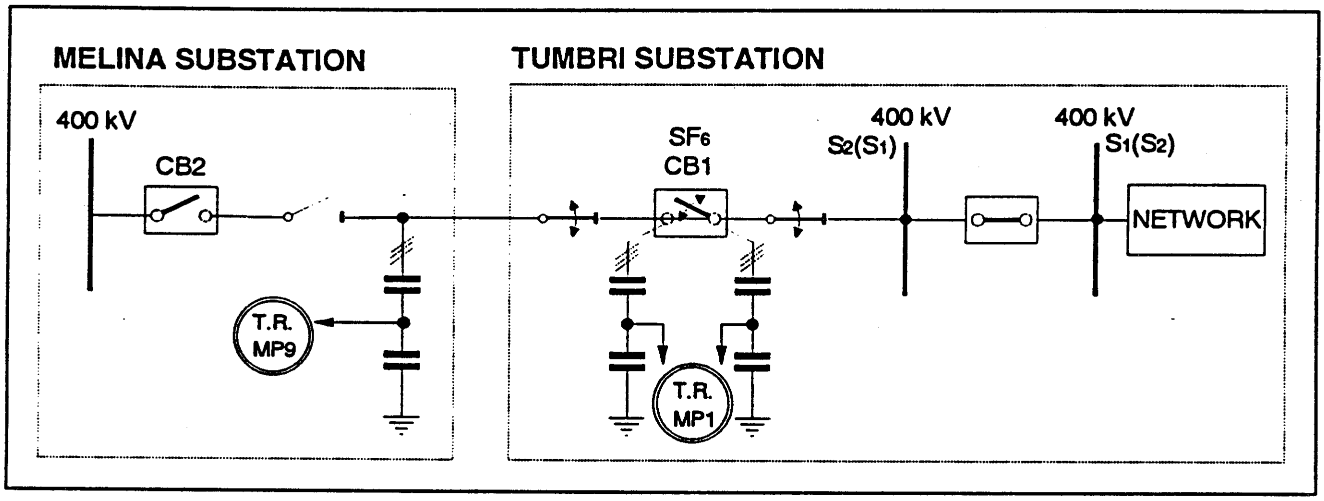

Figure 1. The basic measuring configuration for testing

This configuration includes measuring of switching overvoltages at both ends of the Melina-Tumbri line in the case of the SF_6 circuit breaker switching as well as measuring of transient recovery voltage on the SF_6 circuit breaker.

The particular nature of this study assignment, especially with respect to the measuring of transient recovery voltage on the SF_6 circuit breaker and the number of measuring points on the 400 kV voltage level, required special preparations in measuring equipment.

For such or similar scope of testing at this voltage level, almost invariably, the main barrier in the planning and implementation of testing is an insufficient number of appropriate HV test dividers.

The applied measuring systems, as primary parts for appropriate preparation of the measuring signal and appropriate frequency response, used the low damped capacitive high voltage dividers developed by the Energy Institute. Special attention in developing the HV dividers was paid to their combined capacity earthwise. For instance, the dividers for measurements on the SF_6 circuit breaker were designed to have very low capacity values (approx. 160 pF) earthwise in order to improve frequency response. Further reduction in dividers' capacity would lead to a region of higher influence of parasite capacity between individual equipment components in a plant, which would introduce a degree of uncertainty in the measuring.

The instrumentation part (secondary part) of the measuring system, for registration of measurement value, used multi-channel transient recorders, multi-channel high-resolution oscilloscopes and other computerized measuring systems (DAS).

3. RESEARCH RESULTS

The full-scale testing of the network for the given test configuration was planned to cover 10-15 switching cycles in the unloaded transmission line.

However, because of timing constraints in the implementation of testing due to unfavourable power situation in Croatia and adverse weather conditions, tests were carried out on only nine switching cycles, which imposes certain limitations in further processing and interpretation of the results.

The unloaded line Melina-Tumbri of 128 km in length is switched on from the 400 kV Tumbri substation through the SF6 circuit breaker as shown in Figure 2.

The network connected to the Tumbri substation consists of one the 48 km long 400 kV transmission line Tumbri-Krško, and of the 110 kV network. In this way the unloaded transmission line is switched on through the "weak network", which is of an inductive character. For computations with the non-transposed asymmetric line Tumbri-Melina, K.C.Lee's model was chosen [5].

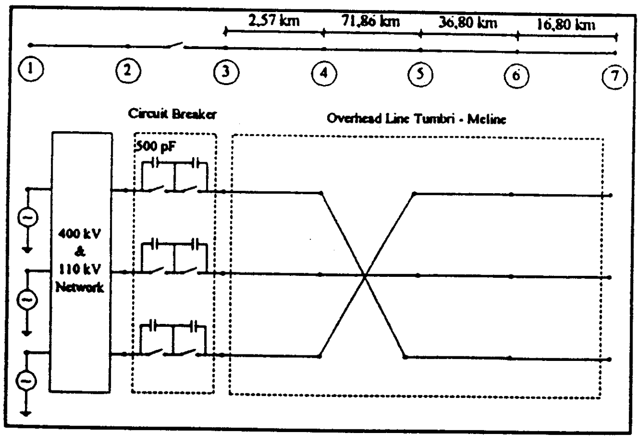

Figure 2. Electrical network for computations

The equivalent network in computations was determined by network reduction procedure. The principal characteristics of conductor material and ground wires as well as geometric values of reduced-size towers were used to compute parameters of the transmission line for each section separately. In the last section (6-7) the sizes are increased. The transmission line has two conductors in a bundle, i.e. 3x2x490/110(65) Al/steel and a ground wire 120/70 AlMgl/Steel. The distance between the conductors in a bundle is 400 mm. The sizes of the supporting tower are shown in Figure 3. The parameters of the line were computed by LINE CONSTANTS program [5] for frequencies corresponding to the dominant frequency in transient occurrence.

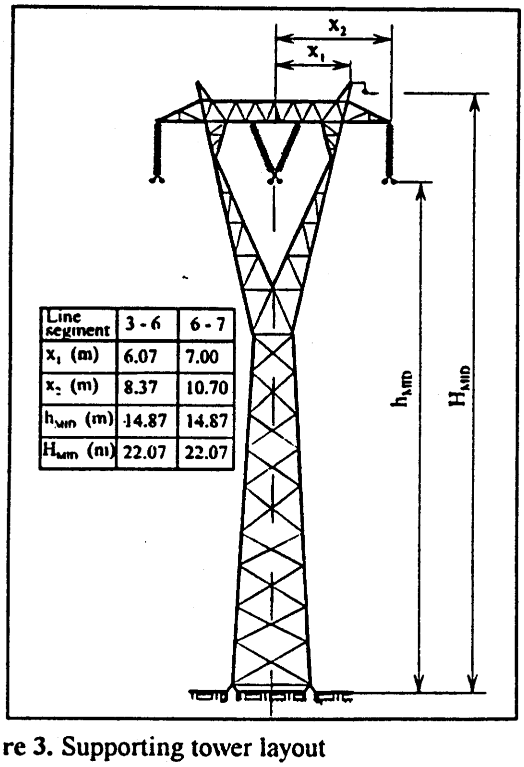

Figure 3. Supporting tower layout

The highest overvoltages at switching on the unloaded line occur at the open end, and their value depends on the moment the circuit breaker poles switch on.
The characteristic values for overvoltage groups measured at individual measuring points of the line are given in Table I.

Table I

SWITCHING	LINE START		LINE END	
	k_{max}	k_{avg}	k_{max}	k_{avg}
On	1.42	1.,19	2.18	1.53
Off	1.18	0.95	1.20	0.96

The computation adopted statistical approach, i.e. using STATISTIC switch [5]. The standard deviation of the switch closing time was ± 2 ms. The mean value of the computed overvoltages at the line end in all phases was 1.86 and the maximum overvoltage computed was 2.45. These values are slightly higher than those measured (mean value 1.53 and maximum value 2.18). There were however 40 calculations and only 9 experiments, which makes comparison more difficult.

From the results shown it is evident that all characteristic values of overvoltage groups considered are within the expected and permitted values.

The typical oscillogram of the normal switch off at the end of the test line is given in Fig.4.

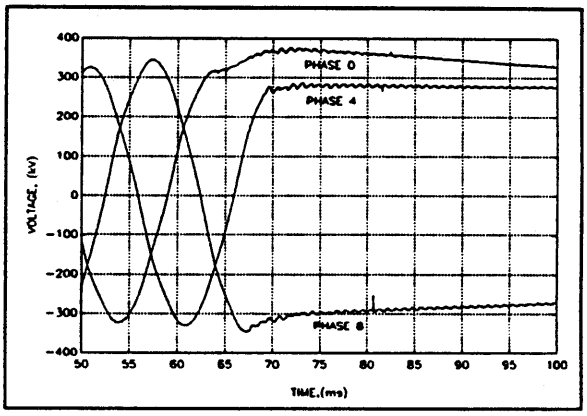

Figure 4. Voltage at the end of line (switch off)

The unloaded transmission line represents a capacitive load for the network. After the contacts of the circuit breaker are opened, a current is being interrupted approximately during the current cross through zero, at which point phase voltage reach its maximum (in the medium phase the switching off occurred a little before the voltage maximum). The capacitive voltage transformers on the line Tumbri-Melina disable quick discharg of the transmission line. The first current switched off is in the phase 0, and the last in the phase 4. After the current in the phase 0 is switched off, the currents in the phases 4 and 8 continue their crossing for some time. Due to the capacitive intercoupling they increase the voltage at the phase 0 which is being added to the voltage already existing in this phase, so that the total voltage remaining on the circuit breaker's pole at the side of the unloaded line exceeds the maximum operating voltage by the factor of 1.15. Very slight oscillations can be observed on the oscillogram arising from Ferranty effect, which manifests here faintly due to the line being short.

The maximum recovery voltage measured on the circuit breaker is 2.14; Fig.5.

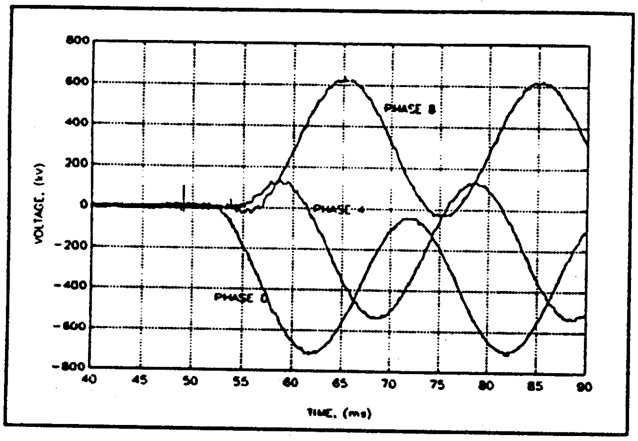

Figure 5. Transient recovery voltage

What is particularly characteristic of the tests conducted is the oscillatory phenomenon recorded during the switching off of the line by the end of the testing with the oscillogram shown in Fig.6.

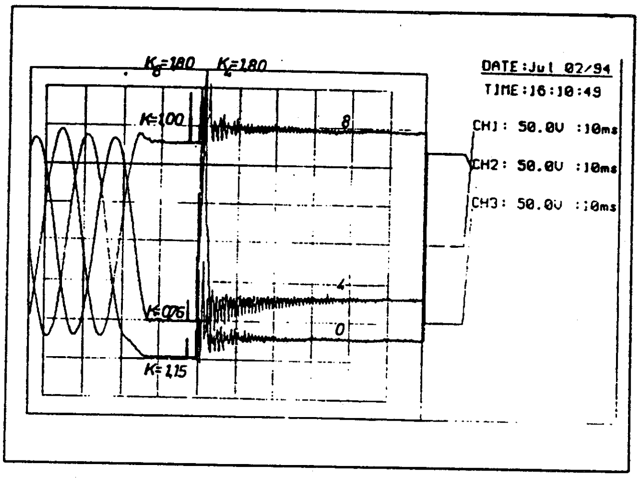

Figure 6. Switch off (voltage measured at the start of line)

The transient phenomenon of typical frequency oscillations of about 1200 Hz, of a specific time of occurrence (about 10 ms after the circuit breaker switches off) as well as high overvoltage factors recorded, especially at the end of the unloaded line, point to the restrike effect.

Unfortunately, during the switching off the oscillogram of the current failed, which would otherwise additionally have clarified the phenomenon that occurred.

A subsequent simulation of the restrike conducted on a model in the phase "4", assuming that HF component of the current is switched off at its second cross through zero, produced an oscillogram of the voltage conditions on the line that correspond to the conditions recorded on the live network (Fig.7).

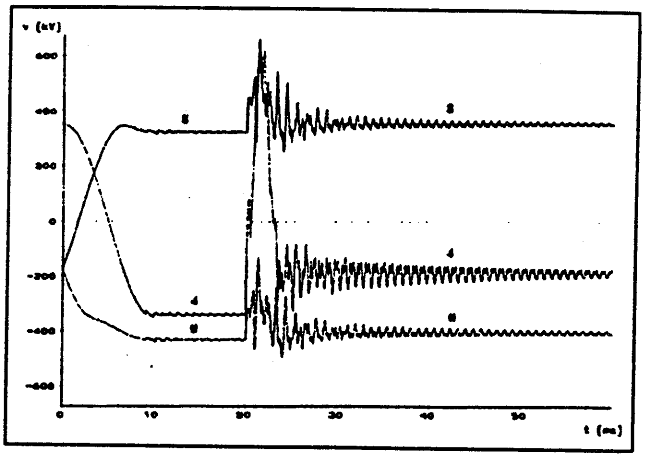

Figure 7. Simulation of the restrike on the model

The 1200 Hz frequency corresponds to the superposition of two natural oscillation frequencies of the line, which is about 600 Hz. Natural frequency oscillations first cause occurrence of arc whose extinction a few milliseconds thereafter causes again oscillations at the same frequency. The model for computation has taken into consideration the arc resistance of the circuit breaker. On this occasion a separate model of the 400 kV line Tumbri-Krško was used, and additionally, the damping resistances in the model were somewhat increased as compared to the computed values.

The simple test circuits used in a laboratory for circuit breaker testing do not simulate adequately operating conditions, therefore restrike phenomena are possible on the circuit breaker during the switching off of the capacitive currents in operation [6]. During restrikes, very high overvoltages may occur, especially if HF current is switched off during its first cross through zero.

The simulation of such a case established that during the extinction of the impulse current after its first cross through zero, the remaining phase voltage on the circuit breaker pole at the side of the unloaded line exceeds 1200 kV which may lead to a new failure and destruction of the circuit breaker.

4. CONCLUSIONS

The comparative researches conducted into switching voltages in the case of switching the unloaded line by a SF_6 circuit breaker in the 400 kV network test configuration show that the overvoltage factors are within the expected limits and do not exceed the values specified for the equipment insulated on a standard basis for the 420 kV voltage level.

The overvoltage conditions recorded during testing with the typical oscillations, moment of occurrence and considerably higher overvoltage factors, given the absence of the current oscillogram, were additionally clarified by computer simulation of the restrike on the circuit breaker.

Considering that the recorded event was not expected, it indicates the possibility of its occurrence in the real operating conditions which requires adequate supervision and/or periodic review of the state of equipment and devices, and additional preventive and protective measures where necessary.

5. ACKNOWLEDGMENTS

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