CURRENT AND VOLTAGE WAVEFORMS UPON THE CONDUCTOR RUPTURE IN ONE PHASE OF THE 110 KV RADIAL CONNECTION OF THE GENERATOR AT HPP DUBROVNIK TO THE POWER SYSTEM – SIMULATION AND MEASUREMENT

Mr. sc. Milan Stojsavljević, dipl. ing.
Mr. sc. Darko Nemec, dipl. ing.
Dr. sc. Muharem Mehmedović, dipl. ing.
Institut za elektroprivredu i energetiku d.d., Zagreb, Croatia

Zdeslav Čerina, dipl. ing.
Robert Kosor, dipl. ing.
Sergio Gazzari, dipl. ing.
Hrvatska elektroprivreda d.d., Croatia

ABSTRACT

This paper presents results of time-domain simulation of single-phase opening (the effect of the 110 kV phase conductor rupture) of the 110 kV transmission line Komolac – Trebinje (a part of radial connection of HPP Dubrovnik to the system) in realistic operating conditions. The simulation results comprise instantaneous and RMS values of phase currents, phase voltages and residual current in the 110 kV line bay Komolac at the HPP Dubrovnik switchyard and in the 110 kV transmission line bay Trebinje at the substation Komolac. Simulation results are compared with quantities recorded by the numerical line protection device REL511 installed at HPP Dubrovnik. Simulation includes electromechanical transients with excitation system and turbine governor being modelled. Rather good correspondence between simulation results and measurements in this particular case shows that such calculation results could be used as a basis for tuning and coordination of protection systems.

Keywords: electric power system, generator, radial connection, protection system, simulation

1. INTRODUCTION

Application of the protection devices based on the numerical technology and its foolhardy progress, profusion of the offered functions and possibilities of the numerical protection devices / relays and the power system management, have also given the techniques for the analysis of electric power plants and systems a new dimension. Owing to increased use of numerical protection devices with fault recording capabilities, it is now much easier to compare simulation results with measurements from the real power system for purpose of model validation. As the result, higher quality of modelling and deeper insight into system behaviour can be achieved.

A well-known and widely used class of program tools for time domain modelling of power systems in terms of instantaneous values of network variables is the family of so-called electromagnetic transient programs (EMTP). Besides detailed modelling of individual network elements, standard versions of such programs offer also the possibility for flexible modelling of measuring, control and protection devices in power plants and systems. In that way more realistic models can be built, provided that enough input data with sufficient level of detail are available. Standard simulation results are given in form of voltage and current waveforms in a specified interval. Usually, some post-processing of simulation results should be done for better and clearer presentation. This is easily achieved by exporting the results in a standard format (e.g. ASCII) to some general-purpose application for calculation and graphical presentation.

Modelling of a rather specific case of phase conductor rupture of the 110 kV transmission line in the particular part of the electric power system is addressed in this paper. The part of power system under investigation comprises 110 kV radial connection of one 120 MVA hydrogenerator (HPP Dubrovnik) to the electric power system realized through two 110 kV transmission line sections (110 kV TL HPP Dubrovnik – Komolac and Komolac – Trebinje) with local passive consumption supplied from the transformer 110/35 kV in substation Komolac at the end of the first section.and the second section of the 110 kV connection ends in the node with transformation 110/220 kV in substation Trebinje as the coupling point to the electrical power system.

The phase conductor rupture occurred at the very beginning of the second 110 kV section (substation Komolac), i.e. at so called "current bridge" at the connection point of the transmission line.

The simulation model comprised detailed dynamic representation of the generating unit with its control systems (excitation system and turbine governor). Simulation results were validated by comparison with the current and voltage waveform records made by the numerical protection device of the transmission line. This protection is installed at the beginning of the first section of the 110 kV radial connection (i.e. at HPP Dubrovnik).

Calculations of the current and voltage waveforms are made for the positions at the beginning of the both sections of 110 kV connection (HPP Dubrovnik and substation Komolac). Rather good accordance between simulation and measurements is achieved thanks to accuracy of input data (model parameters, initial steady state) and relatively simple transmission network configuration. Of course, further refinment of the model is still possible, particularly now when there is a new generating unit monitoring system installed at HPP Dubrovnik which is capable of recording instantaneous values of generator currents and voltages as well as currents and voltages in the 110 kV bay.

2. THE SIMULATION MODEL

The generator G1 at HPP Dubrovnik, situated in the southern part of the Croatian power system, is a 120 MVA unit connected to the 110 kV substation Komolac via 110 kV transmission line HPP Dubrovnik – Komolac (designation D164/1+D165). Note that the generating unit circuit breaker at HPP Dubrovnik serves at the same time as the line circuit breaker of the 110 kV TL Dubrovnik - Komolac. From the substation Komolac there are two 110 kV connections, one to the substation Ston and the other to the substation Trebinje. The 110 kV transmission line Komolac – Trebinje (designated as D138) is the interconnection line between electric power systems (EPS) of Croatia and Republika Srpska.

In the present configuration the electric power system of the Republika Srpska is in the II. UCTE synchronous zone, while the Croatian electric power system is in the first UCTE synchronous zone. That means that simultaneous operation of both before mentioned transmission lines is not allowed, which leaves the generator G1 of the HPP Dubrovnik working either on the Croatian EPS or on the EPS of Republika Srpska. In the configuration considered in this case the transmission line D138 Komolac – Trebinje was in operation, and D137 Komolac – Ston was disconnected.

In the year 2000, the new numerical transmission line protection REL511 ver. 1.2, manufactured by ABB was installed in the HPP Dubrovnik. That protection relay protects D164/1+165 HPP Dubrovnik – Komolac and among other functions has a fault recorder function.

A full three phase model of the local electric power system is used for calculations. The model, consisting of the generating unit G1 in HPP Dubrovnik with the excitation and turbine governing system, two 110 kV transmission lines: HPP Dubrovnik – Komolac and Komolac – Trebinje, power transformer 110/35 kV in the substation Komolac with local consumption represented with the constant impedance model and equivalent representation of the 220 kV electric power system connected via power transformer 110/220 kV, 150 MVA at the substation Trebinje, has been set up in LEC ATP program package and is presented schematically in the fig. 1. The transmission lines were modelled as pi-equivalents with lumped parameters.

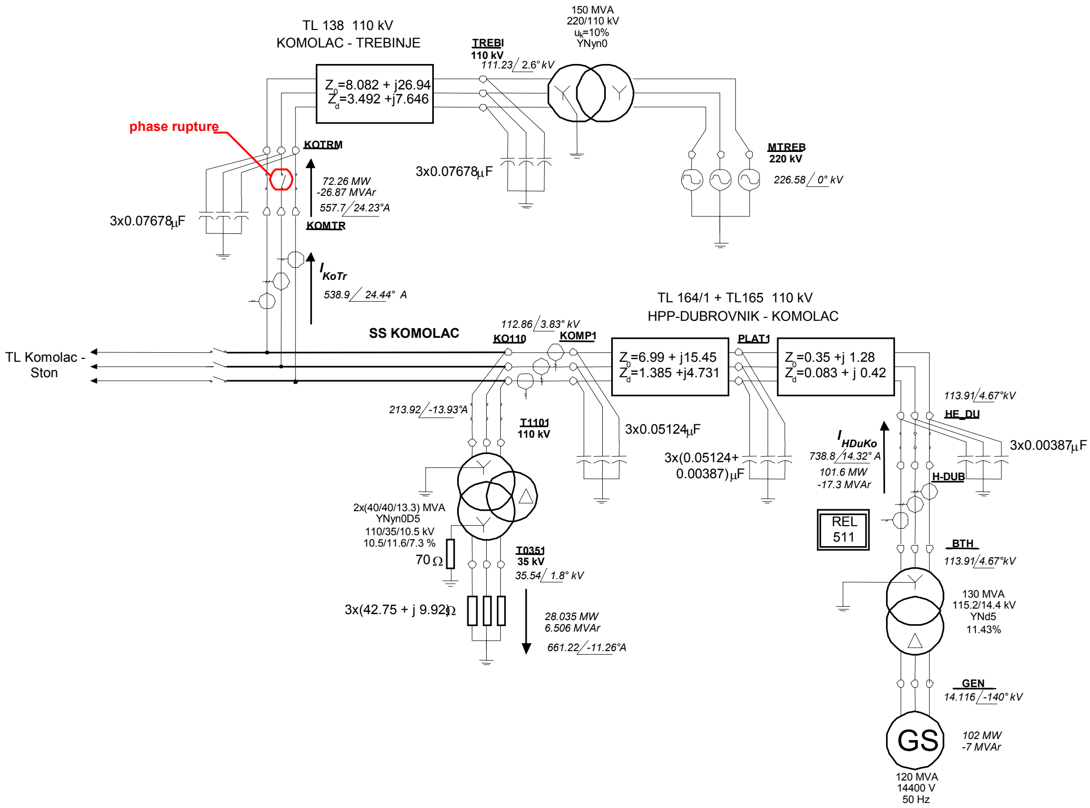

Figure 1 Simulation model used for the calculations of the current and voltage waveforms upon the single-phase conductor rupture of the 110 kV transmission line Komolac – Trebinje with calculation results of the initial (pre-fault) steady state

Location of current measurements on the 110 kV transmission lines HPP Dubrovnik – Komolac and Komolac – Trebinje used in the model, are clearly marked (I_{HDuKo}, I_{KoTr}, figure 1)

Initial steady state, based on the realistic operating conditions recorded before the mentioned fault (power flow 72 MW / -28 Mvar on the TL 138 Komolac – Trebinje, local load 28 MW / 6.5 Mvar at the substation Komolac) was modelled. Basic calculation results of the initial steady state made on the model are also shown in fig. 1 as phase RMS values of voltages and currents. All voltage and current phase angles in fig. 1 are referred to phase ’’A’’, that is ’’L1’’ (initial state is balanced). Active and reactive power flows are referred to the total three-phase power in the respective monitored branches.

3. RESULTS OF ANALYSIS

3.1 Course of fault

A realistic operating incident is modelled – the phase conductor L2 rupture in the substation Komolac at the very beginning of the 110 kV TL Komolac – Trebinje. Sudden phase unbalance caused the electromechanical swinging of the generator G1 at HPP Dubrovnik against the system. Distance protection LZ92 installed in the 110 kV line bay of the TL Komolac – Trebinje in the substation Komolac could not have operated upon such fault and there was no overcurrent earth fault protection.

It was the operation of the overcurrent earth fault protection function comprised by the protection device REL511 (with setting: 120 A, 4 seconds) that switched off the circuit breaker in the 110 kV line bay of the TL HPP Dubrovnik – Komolac. This happened approximately 4 seconds after the fault had occured, which is in compliance with the adjusted time delay of that protection function. By this action the generator at the HPP Dubrovnik was disconnected from the system but the Komolac substation and the 110 kV TL HPP Dubrovnik – Komolac were still connected to the power system through the two healthy phases of the 110 kV line Komolac – Trebinje.

The fault recorder function within the numerical protection REL 511 at HPP Dubrovnik was triggered by operation of the earth fault protection. Having total recording length of 4 seconds and the prefault interval set to 500 milliseconds it could not have recorded the entire phenomenon from the inception of the fault to the opening of the circuit breaker.

3.2 Comparison of simulation results and measurements

The results are presented in form of the phase currents and voltages waveforms and residual current (I_N=$3I_0$) waveforms (instantaeous values) along the time axis in an interval approximately 100 ms before and 100 ms after the switching off of the circuit breaker in the line bay of the HPP Dubrovnik switchyard. Instantaneous values of currents and voltages in the line bay at HPP Dubrovnik switchyard obtained from simulation are shown in fig. 2 simultaneously with the same quantities recorded by the numerical protection REL 511, thus allowing direct comparison between simulation and measurement. Pretty good accordance of simulation results with actual measurements can be observed. The currents and voltages on the line Komolac – Trebinje could not have been compared in the same way since there was no recording device at the Komolac substation.

Vector diagram showing amplitude and phase relations of the measured and calculated currents and voltages immediately before the switching off of the circuit breaker in the line bay of the HPP Dubrovnik switchyard (i.e. generating unit circuit breaker) is shown in fig. 3.

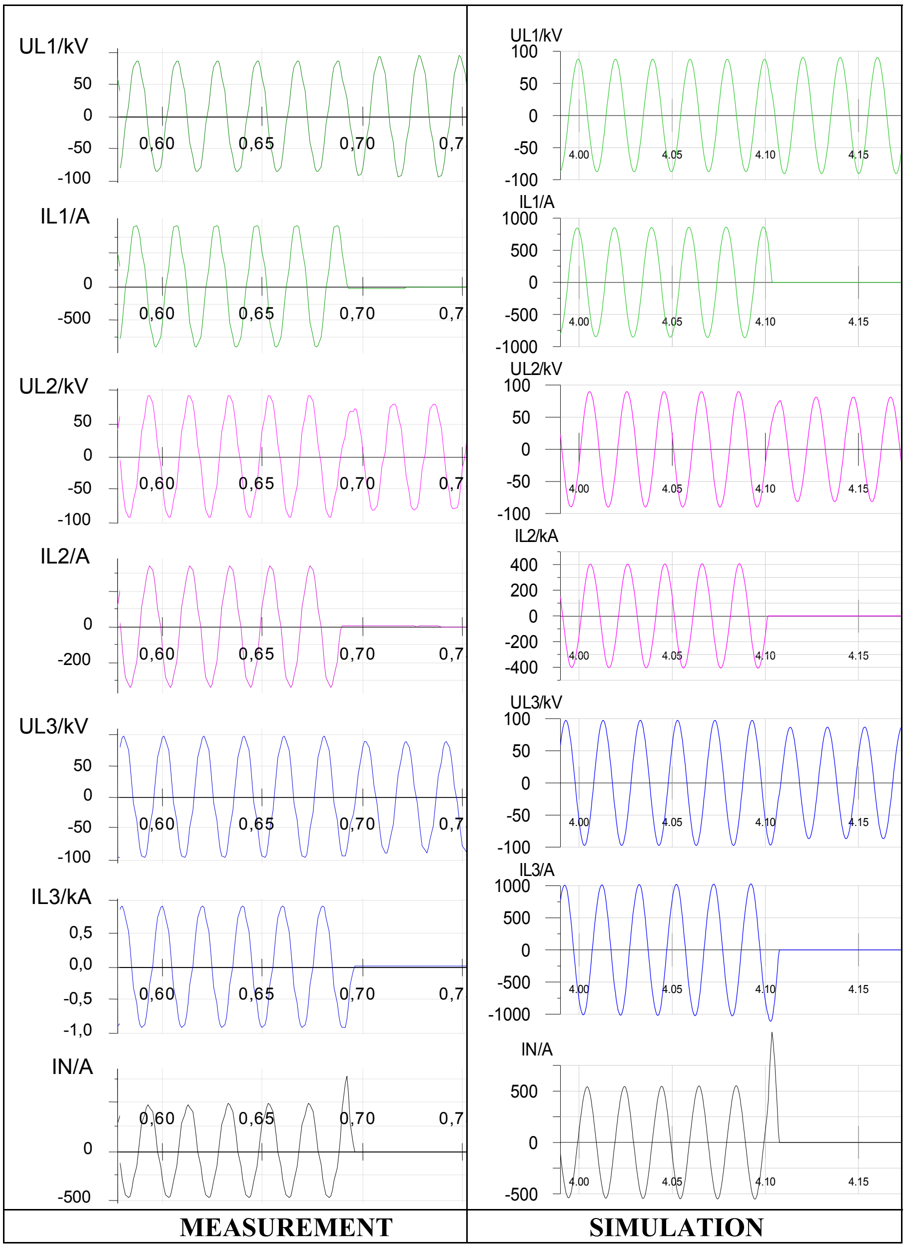

Figure 2 Instantaneous values of voltages and currents on the TL HPP Dubrovnik – Komolac (line bay in the HPP Dubrovnik switchyard) with open phase L2 on the TL Komolac – Trebinje, zoomed approximately 100 ms before and after opening of the circuit breaker in the line bay of the TL HPP Dubrovnik – Komolac in the HPP Dubrovnik switchyard

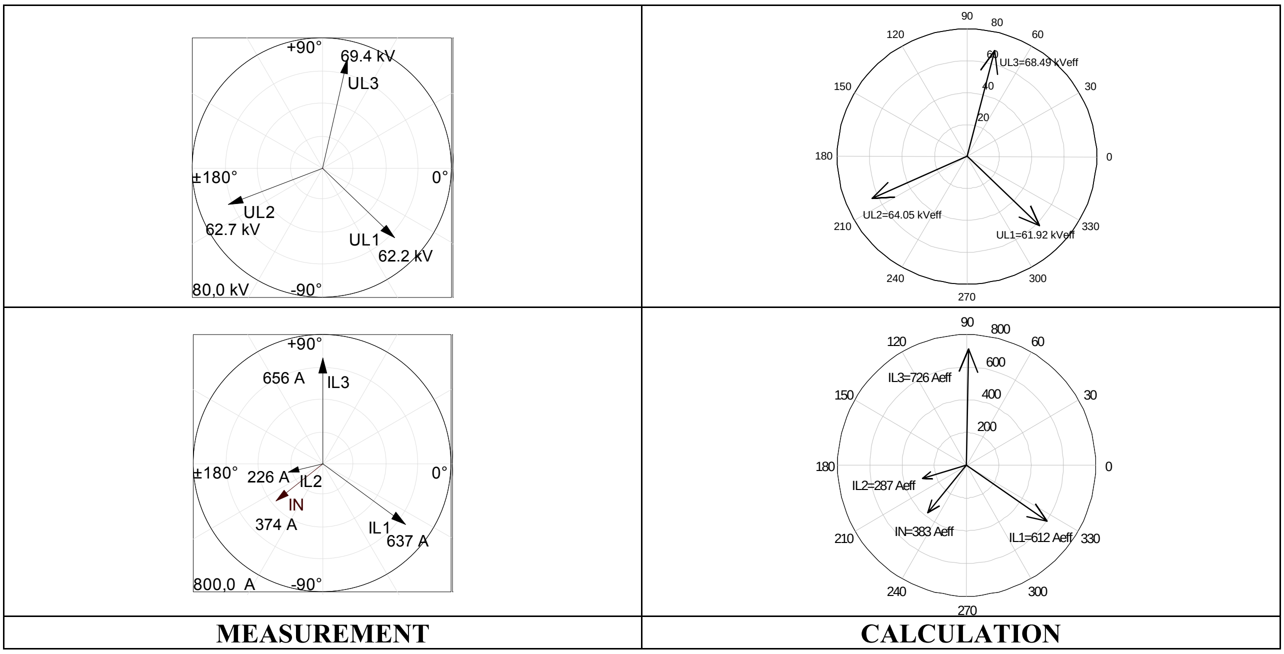

Figure 3 Vector representation of line currents and voltages in the 110 kV TL HPP Dubrovnik – Komolac immediately before switching off the circuit breaker at HPP Dubrovnik

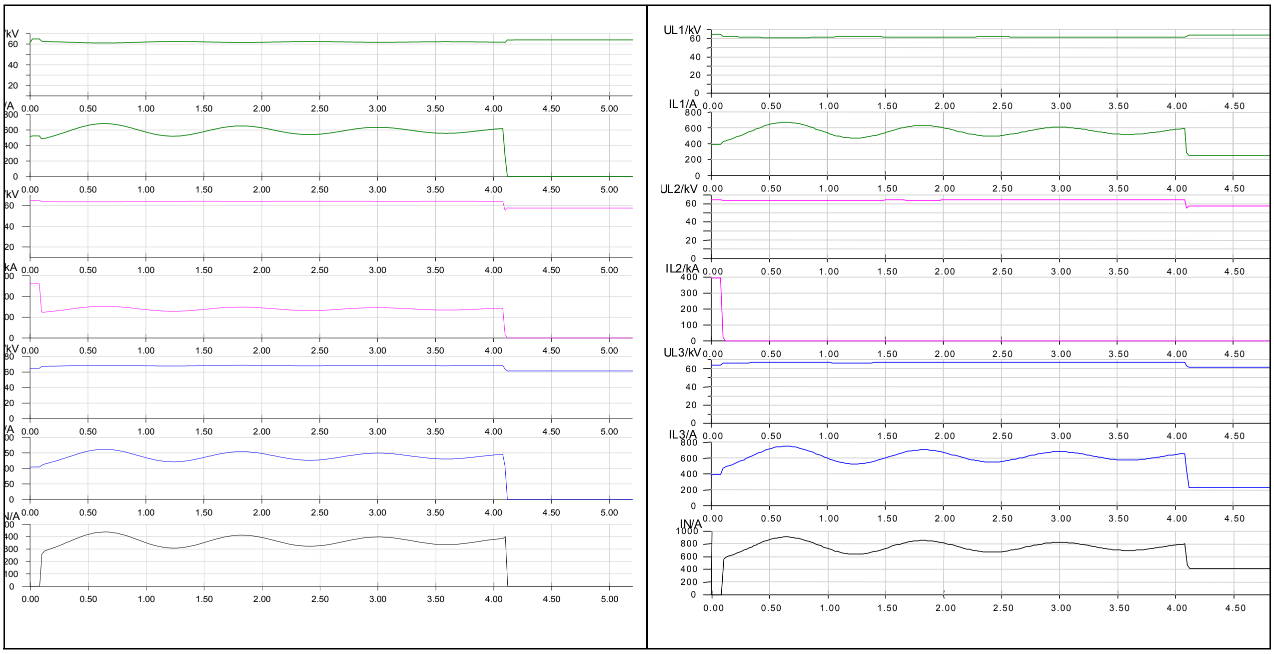

Figure 4 Simulated time responses of currents and voltages (RMS values) on the 110 kV TL HPP Dubrovnik - Klomolac (left) and on the 110 kV TL Komolac-Trebinje (right)

The whole course of the phenomenon, as obtained from simulation, is shown in fig. 4 in form of time responses of RMS values of voltages and currents in the 110 kV line bay at HPP Dubrovnik and on the 110 kV TL Komolac- Trebinje (in 110 kV line bay at Komolac substation). Local mode oscillations (swings) of the generating unit G1 at HPP Dubrovnik can be readily observed in all phase currents and in the residual current at both locations. Oscillation frequency is approximately 0.84 Hz and maximum peak to peak value of the oscillatory component in RMS residual current I_N on the TL HPP Dubrovnik – Komolac amounts to 70 A while mean value of the total I_N is about 350 A, well above the threshold of the overcurrent ground fault function in REL511 (120 A). At the same time, the maximum amplitude of the damped oscillatory component of the same frequency (0.84 Hz) in the residual current I_N on the 110 kV TL Komolac – Trebinje is approximately 130 A.

After switching off of the circuit breaker in the HPP Dubrovnik switchyard the oscillatory component in all three currents vanishes because it had been caused by the electromechanical swinging of the generating unit G1 in the HPP Dubrovnik in relation to electric power system, and the residual current I_N as a vector sum of the currents in the healthy phases amounts to approximately 400 A. From the I_N current response it can be read off that the share of the HPP Dubrovnik generator in that current without oscillatory component is approximately 360 A. Obviously, the unsymmetry on the transmission line Komolac – Trebinje was still present after opening the circuit breaker at HPP Dubrovnik.

Considering that the calculation results are very sensitive to the input data, relatively good amplitude and phase correspondence of the measurements and simulation results is achieved. The poorest matching of measured values and simulation results can be observed in the current in the L2 phase where the measured value is 22% lower than the value obtained from the simulation.

Measured currents in the other two phases have equal values (their mutual difference is approximately 3%) while in the simulation the current in the L1 phase is about 18% lower than the L3 current. The residual current I_N in the simulation is lower by 2.4%.

Obviously, the earth fault overcurrent protection was necessary to protect the 110 kV TL Komolac – Trebinje against such faults. As a temporary solution until installation of a dedicated protection device, it was decided to use the existing time overcurrent protection with definite time characteristic which had been already installed at TS Komolac in the role of line overcurrent protection. Residual current measurement is obtained from suitably connected current transformers and fed to the measuring circuit of the relay in phase L2. The relay setting is 120 A with time delay of 2.5 seconds which is coordinated with the earth fault overcurrent protection of the 110 kV transmission line HPP Dubrovnik – Komolac (120 A, 4 seconds).

4. CONCLUSION

An attempt to simulate a non-typical fault by means of a rather simple model set up in the EMTP program is presented in the paper. Simulated time domain responses of characteristic variables are compared to measurements of the same quantities from the real system, obtained from numerical protection devices with fault recorder function. Valuable experience regarding some aspects of modelling is gained from the here presented case.

Rather good correspondence between simulation and measurement is encouraging in the sense that such simulation models could be used in the process of protection coordination and tuning as well as in the post mortem analysis of various disturbances. It is shown that modelling of electromechanical transients could also have impact on the results, especially when it is necessary to observe periods which are long enough to allow such transients to develop (i.e. several seconds or longer). In the paper it is clearly illustrated by the time diagrams of voltage and current envelopes (RMS values) during fault. Powerful simulation tools such as EMTP programs enable modelling of machine rotor dynamics as well as excitation systems and turbine governors along with dynamics of network elements and with currently available computer processing power it is feasible to use such complex models for practical engineering analyses. Modelling accuracy will remain dependent on available system and equipment data and validation of simulation results against measurements will become even more important step in establishing credible models. Wider use of numerical protection devices with fault recorder capabilities at various points in the power system will make possible further improvement. Closer cooperation between protection engineers and power system analysts will be necessary in order to exploit those new possibilities and achieve more realistic simulation models which would then serve as a reliable basis for protection system analysis and tuning.

BIBLIOGRAPHY

[1] Dommel, H. EMTP Reference Manual (Theory Book), BPA 1986

[2] Alternative Transient Program Rule Book, Leuven EMTP Center, 1987

[3] Test protocols of the numerical protection REL511 of the 110 kV line HPP Dubrovnik – Komolac, June, 12^{th} 2000, HEP, Transmission area Split, Relay protection department

[4] Tuned and calculated settings of the distance protection LZ92 of the 110 kV transmission line Komolac – Trebinje, HEP, Transmission area Split, Relay protection department

[5] Test report of the excitation control system of the generator G1 in HPP Dubrovnik, Energy Institute Zagreb, september 1997