# Multifunctional System Protection for Transmission Lines Based on Phasor Data

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***Abstract*—Transmission network control and protection can be enhanced using phasor data. In a first step multifunctional line protection with system protection function set and back up protection function set can be created. The Matlab model was developed using the experience from the operation of existing wide area system and expended with new function sets. The paper presents multifunctional protection system and different types of disturbance scenarios with which the model was evaluated and from which the conclusion were drawn. Obtained indices as a result of simulation process can be useful for further development and definition of criteria for the implementation of wide area protection algorithm.**

***Keywords—wide area monitoring protection and control; multifunctional system protection; back up line protection; Matlab modeling***

## I. INTRODUCTION

Protection and control system in modern transmission network is usually divided into three layers. Two basic functionalities are implemented in the II layer. Functionalities of the layers constitute the Wide area monitoring protection and control (WAMPAC) system [1], [2] with the Multifunctional line protection (MFLP) element, Fig. 1.

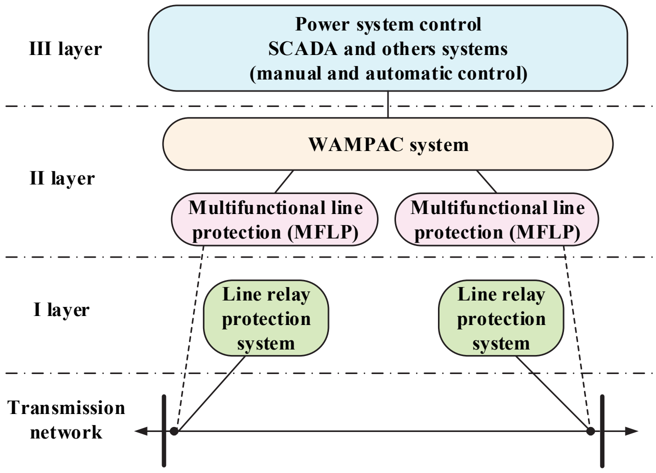

Fig. 1. Protection and control layers

WAMPAC system that is modeled in Matlab is based on a phasor data stream usually gathered at the main control center [3]. The presented concept for multifunctional lines protection is also based on phasor data measurements and was also modeled and designed in a Matlab simulation environment. The most common transmission system operations behavior and characteristic disturbances were simulated to verify the model and acquire new data to enhance and improve presently installed protection system.

Phasor data stream was obtained from the simulation environment through a measurement module in Matlab model. Positive sequence values of voltage and current were used for measurement and protection purposes. MFLP concept of the line protection is used on all 400 kV transmission lines.

## II. MULTIFUNCTIONAL LINE PROTECTION

System protection function and back up line protection function are the two main parts of MFLP concept, Fig 2.

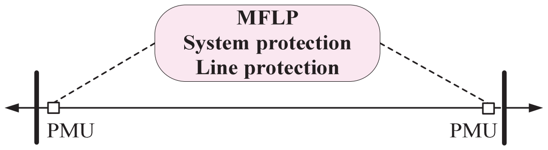

Fig. 2. MFLP concept with system and line protection

To be able to respond in a proper way to system wide transmission network disturbances (voltage, frequency and angle stability) system protection function must be created and parametrized carefully. Phasor data stream from different parts of a transmission network must be collected in control center. The collection of this data in real time enables realization of back up line function. Back up protection functions are important for both back up reasons and for system real time protection perspective. From the phasor data measurement additional alarming, monitoring, and protection criteria can be obtained (e.g. first defense line functions) in order to preserve transmission stability.

Basis for both groups of protection functions (system and back up line protection) are positive sequence components measurements from PMU devices. The PMU data represents sufficient foundation to handle symmetrical three phase system disturbances and line faults. In table I the list of realized protection and monitoring functions is given. It shows the protection functions in Matlab model for a purpose to monitor and prevent angle instability.

Knowledge and experience gathered from the operation of classical numerical line protection has enabled advancements now the phasor data technology is available. Line protection devices have well-proven and efficient protection functions. These protection functions have two different functionalities and protection philosophy which are incorporated in one piece of hardware. First function is to protect a line from fault (e.g. short circuit) and second is system to provide various system functions.

Using different system functions [4] in these protection devices has some obstacles. In general it is hard to achieve full system observability just from one point in the system. Regular line protection has available data measured only from one line end. Rarely the measurement data from other line end is available. Line differential protection exchanges the data between both ends but this is not the full data range. Because of that during system disturbance it is difficult to realize proper system protection function since all the required data is not available.

MFLP is tuned and oriented to track conditions in three operating stages of the transmission network for angle stability enhancement:

1. Normal operating condition with lines breaker switching in accordance with the day ahead plan. All critical system values are monitored.
2. Power swing condition in transmission network with the available measurements must be recognized. In that circumstances alarm is generated and in some cases breaker switching must be carried out to prevent more serious consequences.
3. Out of step conditions must also recognized in time and the transmission network should be separated with breaker switching operations to prevent more serious consequences.

The following system protection and backup protection functions can be realized using the available phasor data, listed in Table I.

Also with the tracking of all these values (Table I) monitoring function can be established and additional criteria for protection function can be added. Key performance indices are calculated and define for these values in order to be used as an input for protection device setting.

TABLE I. LIST OF FUNCTION

| **No.** | **Protection and Monitoring function** | |
|---|---|---|
| | ***System protection*** | ***Line back up protection*** |
| 1. | Phase angle protection | Over current protection |
| 2. | Rate of change of angle protection (ROCOA) | Over load protection |
| 3. | Angle acceleration | Line differential protection |
| 4. | Rate of change of resistance | Line impedance protection |
| 5. | Rate of change of reactance | Over and under voltage protection |
| 6. | Rate of change of impedance | Voltage and current monitoring |
| 7. | Rate of change of active power | |
| 8. | Rate of change reactive power | |
| 9. | Rate of change of current | |
| 10. | Rate of change of voltage | |

## III. TRANSMISSION NETWORK AND SYSTEM PROTECTION MODEL

In order to accomplish steps for moving from currently WAM system installed in control center towards full capability WAMPAC system, simulations environment was created in Matlab. Groundwork for modeling of the WAMOAC system is Croatian 400 kV network [5] and WAM system with PMU devices installed on all lines, Fig. 3.

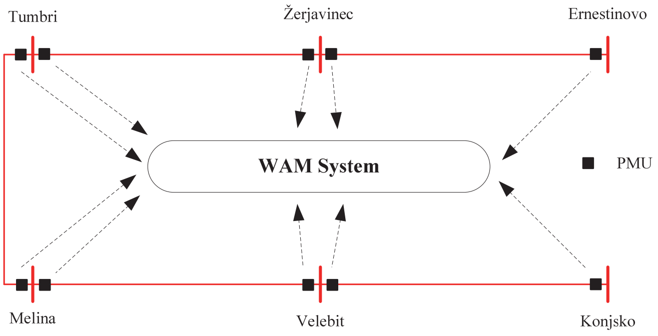

Fig. 3. Croatian 400 kV transmission network with WAM system

The result in of the conducted analysis of phasor data shows there is a great potential to for creating a protection model. This following requests needs to be fulfilled:

- Three phase transmission network model included;
- Intermediate power flow functionality model included;
- Time domain of the model needs to be in milliseconds;
- Line one phase fault model included;
- System disturbance model included;
- Protection function model included.

Matlab Simulink simulation environment is chosen and the mode shown on Fig. 4. is created. The Matlab tool allows a broad scalability in modeling. Also data generated during the simulations are wholesome and well-structured and therefore the analyses performed have good value.

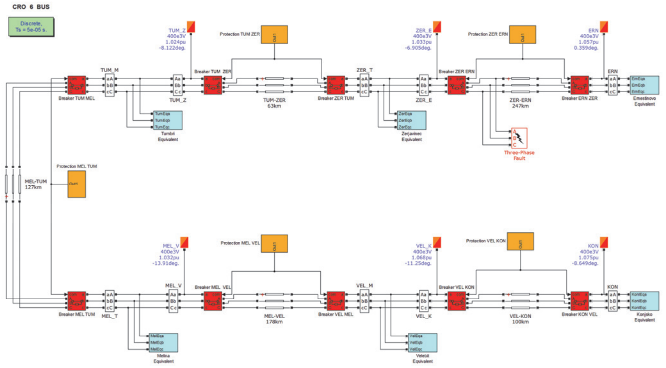

Fig. 4. 400 kV transmission network model with MFLP in Matlab environment

Model was verified and validated with archived data for regular switching operations and with data gathered from various disturbances occurring in the transmission network [6], [7], [8], [9].

All system and back up functions from Table I. were modeled for each 400 kV transmission line as is depicted on Fig 5.

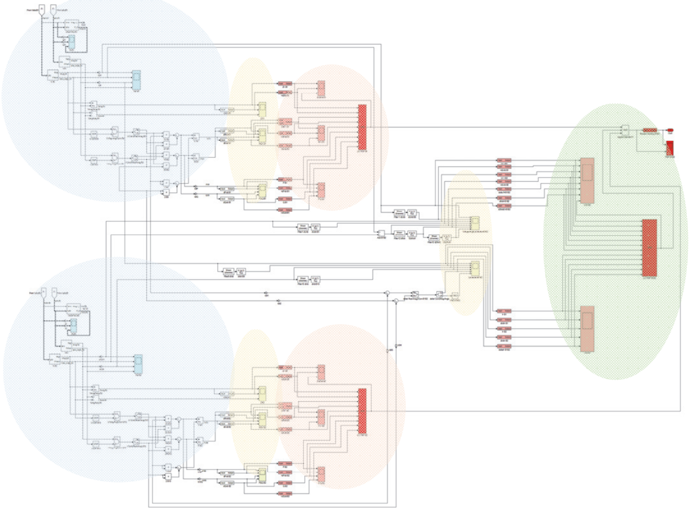

Fig. 5. MFLP model for 400 kV lines in Matlab environment

Model has four parts. Input part (blue colored circle on Fig 5.) collects measurement from line ends (U, I, P and Q) and extracts positive sequence measurements for voltage and current. From these derived measurements are created (Z, R, X, P and Q). Next part (yellow colored on Fig 5.) creates input for all protection and monitoring function listed in Table I. Light red parts on Fig 5. represents protection setting and triping criteria. Last part (green colored on Fig 5.) represents tripping matrices for line breaker switching. With the described model flexible environment for all kinds of protection simulation was created.

## IV. Protection response

System protection responses are focused on angle stability. Monitoring voltage angles between line ends is crucial for angle stability protection (Table I. No. 1, 2, 3). Power swing phenomena simulations were first step in the research process. Active power oscillations were initiated at one end of the transmission network (starting at 3rd and lasting till 8th second). Behavior for angle difference, ROCOA, and angle acceleration for 400 kV line Ernestinovo – Žerjavinec as one characteristic disturbance are presented in Fig. 6. Transmission network footprint during such system events can be seen from angle measurements such as presented on Fig 6.

Measurement in the vicinity of disturbance source recorded larger deviation in all measured system values. Damping effect through transmission network reduced deviations in electrical values. Simulations results were presented in two 400 kV substations. First substation (Ernestinovo) is the disturbance origin and second one (Konjsko) is relatively far off.

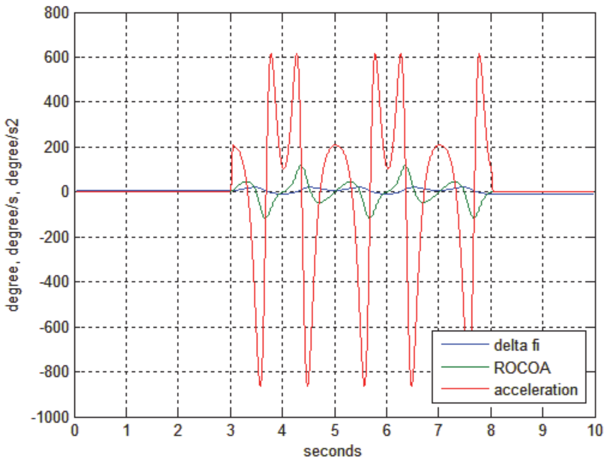

Fig. 6. Angle, ROCOA and angle acceleration behavior in 400 kV substation Ernestinovo, during active power oscilations with source in Ernestinovo substation

On fig. 6 the characteristic footprints for intensive power swing (angle perspective) near disturbance source are shown. In 400 kV substation Konjsko similar angle pattern can be noticed but it is substantially damped as depicted on Fig. 7.

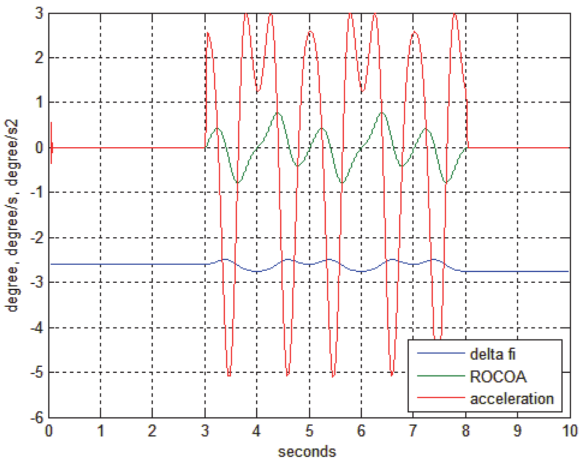

Fig. 7. Angle, ROCOA and angle acceleration behavior in 400 kV substation Konjsko, during active power oscilations with source in 400 kV Ernestinovo substation

Setting of the main angle protection function can be obtained using and analyzing simulation results. Additional criteria can be met if impedance values measurements are utilized. Conclusions from analyzing archived WAM data highlight those possibilities. Resistance and reactance behavior for the same active power oscillation disturbances in 400 kV substations Ernestinovo has significant deviation and rate of change for these values as depicted on Fig. 8.

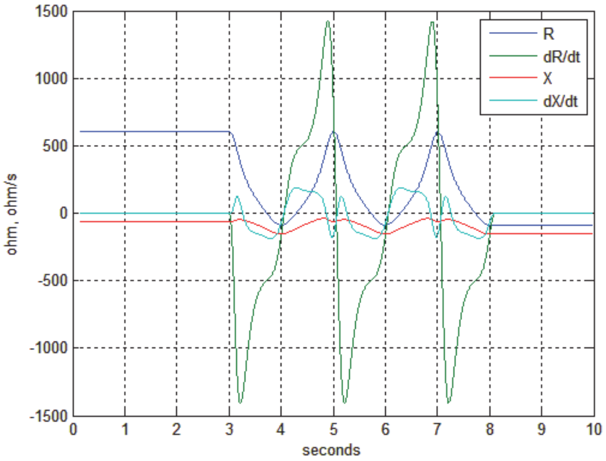

Fig. 8. Resistance, rate of change of resistance, reactance, and rate of change of reactance behavior in 400 kV substation Ernestinovo, during active power oscilations with source in 400 kV Ernestinovo substation

Similar pattern can be observed in 400 kV substation Konjsko located further from the disturbance source, Fig. 9.

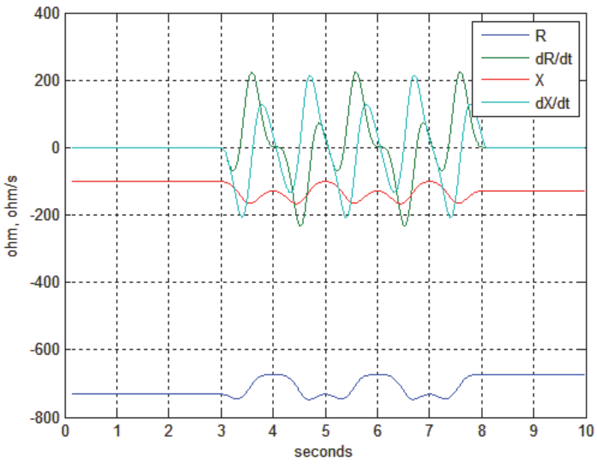

Fig. 9. Resistance, rate of change of resistance, reactance, and rate of change reactance behavior in 400 kV substation Konjsko, during active power oscilations with source in Ernestinovo substation

Additional criteria for protection purposes can be created with the values of reactance and resistance change. Triping criteria can be supplemented with the rate of change of resistance.

Power deviations tracking during disturbances are important for monitoring, alarming and protection purposes. Power changes for the same disturbance scenario in 400 kV Ernestinovo substation are presented on Fig. 10.

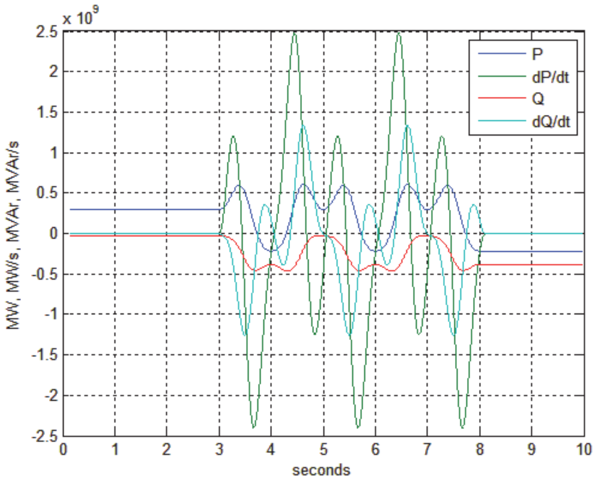

Fig. 10. Active power, rate of change of active power, reactive power, and rate of change reactive power behavior in 400 kV substation Ernestinovo, during active power oscilations with source in Ernestionovo substation

Deviations in power changes are damped in 400 kV Konjsko substation in the similar way, Fig. 11.

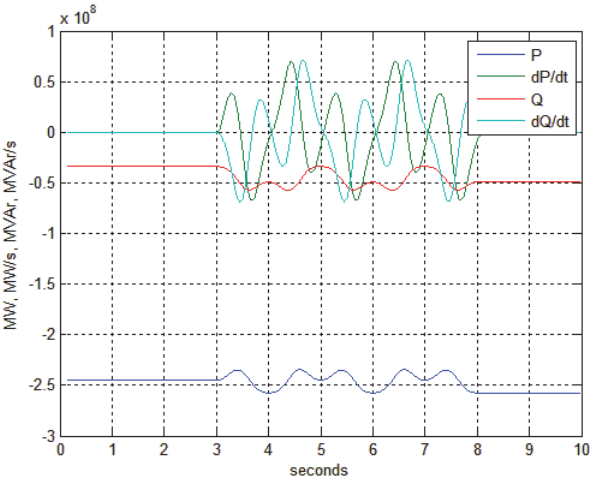

Fig. 11. Active power, rate of change of active power, reactive power, and rate of change reactive power behavior in 400 kV substation Konjsko, during active power oscilations with source in 400 kV Ernestionovo substation

Tracking the change and rate of change of electrical values and analyzing these values can lead to the definition of extra protection criteria. Applying additional criteria for protection purposes can aid the detection of breaker switching operations and disturbance.

Line protection function run properly in Matlab model for line fault simulations. Line differential protection is most interesting for clear selection and fault detection. The differential protection can detect various kinds of faults if the right measurement is available since the current patterns are unique for every type and location of fault (Fig. 12).

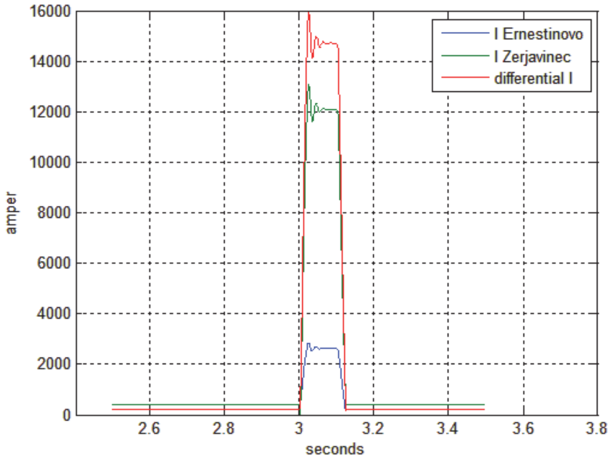

Fig. 12. Line current from Ernestinovon and Zerjavinec 400 kV substations, and differential current values on 400 kV line Tumbri – Zerjavinec, for a three phase short circuit at 400 kV substation Zerjavinec.

Current differential protection module has over current protection for both transmission line ends. Using the current and time settings obtained from the simulations can speed back-up current protection and overload protection. Rate of change for current values can provide additional tuning criteria.

## V. CONCLUSION

Complex process to design and build a Wide area monitoring, protection and control system has many phases. At the starting phase conceptual solution should is developed. During that phase many analyses and simulations should be obtained. Matlab model is a well proven simulations environment that platform offer possibilities to investigate many transmission network states and disturbances. Phasor data can be used for transmission line protection purposes in control centers. These kinds of multifunctional transmission line protection devices can have the scope and functionality of both the backup protection and system protection functions. Consequently Matlab model was developed for 400 kV transmission system and corresponding protection system. Recorded disturbances and other archived data were used to validate developed Matlab model.

In the next step, to get more realistic insight in transmission behavior during normal breaker switching operations and disturbances, calculation for key performance indices were calculated. These indices are categorized for these two basic conditions – normal breaker operations and for disturbances. Protection and monitoring function are set based on the calculated indices and the model can be tested with additional series of simulations.

## ACKNOWLEDGMENT

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