36th CIGRE Serbia Conference 2023
Flexibility of the Power System
May 22–26, 2023 Zlatibor

Implementation of DLR System Results in Real-Time Network Applications

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Abstract — For several years now, two DLR (Dynamic Line Rating) systems have been operating within the Electric Grid of Serbia, successfully calculating the dynamic limits of transmission lines equipped with sensors. One system is OTLM, developed by a Slovenian manufacturer, and the other is Ampacimon, developed by a Belgian manufacturer. Both systems calculate the real-time limits of transmission lines and send this data to two SCADA/EMS systems at the National Dispatch Center (NDC). Currently, the data is displayed on SCADA screens and is only for informational purposes, i.e., it is not used in further calculations. This year, as part of the international R2D2 project, EMS has decided to use these limits for N-1 contingency analyses in real time. It was decided that the results of the dynamic limit calculations from the DLR systems would be integrated into network applications on the GE SCADA/EMS system in real time. This paper presents the implementation of this application and its use in real-time operations.

Keywords — DLR, Limits, Network Applications, SCADA, N-1 Analysis

1 INTRODUCTION

DLR (Dynamic Line Rating) represents a method for determining the permissible load of overhead transmission line (OHTL) conductors based on their thermodynamic characteristics and current weather conditions (measured directly on the conductor). Experience with the application of the DLR method has shown that line capacity can be increased when meteorological conditions along the route are taken into account. In this way, the Transmission System Operator (TSO) is allowed, when conditions permit, to increase the load on the transmission line during a specific time period.

With the proper application of the DLR method, it is possible — with a certain level of accuracy — to calculate the maximum duration of a given conductor load without overheating the conductor or compromising safe energy transmission criteria. The system is designed to

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operate in real time, meaning it uses the latest available measurements, not older than 5 minutes.

The core component of the DLR system implemented at Serbian TSO – EMS is the DLR sensor from the company Ampacimon, shown in Figure 1.

Figure 1 – DLR sensor installed on EMS transmission lines

2 DESCRIPTION OF THE DLR SYSTEM IMPLEMENTED IN EMS

The existing DLR system implemented at EMS consists of:

1. A system for local measurement of meteorological parameters, the effective current load value on the transmission line in the critical span, and the vibration frequency of the conductor in the critical span of the transmission line.
2. A system for data acquisition from local DLR sensors, meteorological data providers, and data transmission to a central DLR server located at the EMS premises.
3. Software for processing the collected data and archiving it.
4. A system for transmitting data from the central DLR server—after calculating the dynamic allowable continuous current load limits of the transmission line—to the SCADA server/interface as the end user point at EMS.

The implemented DLR sensors locally measure the current effective load current of the transmission line in the critical span using an integrated Rogowski coil, the conductor temperature, the effective wind speed and direction, and the vibration frequency of the transmission line conductor. The effective wind speed is the wind speed perpendicular to the direction of the transmission line conductor, which predominantly influences the cooling of the conductor integrated into the DLR system.

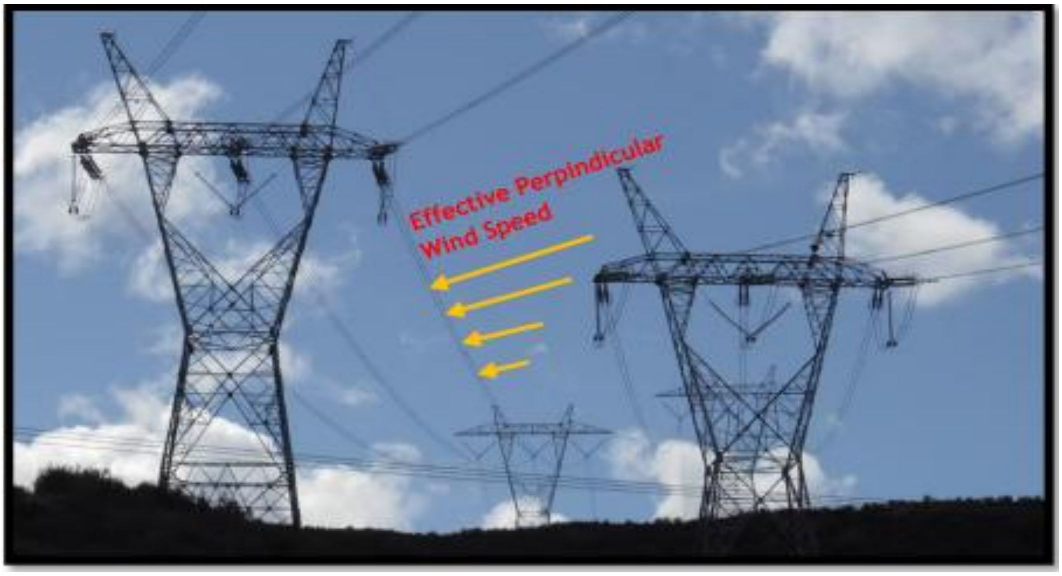


Figure 2 – Effective wind speed and direction on the transmission line

The effective wind speed is the wind speed perpendicular to the direction of the transmission line conductor, which predominantly influences the cooling of the transmission line conductor integrated into the DLR system (Figure 2). The meteorological data provider supplies, from the location of the DLR sensors, data on current values of ambient temperature, solar radiation, and wind speed, as well as historical data on these parameters for the given location. The DLR system has the capability to exchange data with systems providing meteorological data. In this particular case, the meteorological data provider is the IBM Weather Service Database (TWC) (2).

The data acquisition system from local DLR sensors uses a mobile communication network for data transmission. Measured data is transmitted via modem and the internet, along with meteorological data obtained from the meteorological data provider, to the central DLR server at EMS AD for acquisition, processing, and storage.

The data processing software, licensed with ADR Operate, ADR Trend, ADR Horizon, and ADR Ice (3), calculates the conductor sag in the critical span, the average conductor temperature, and the local effective wind speed values using directly measured parameters from the local DLR sensors in the field. By applying locally measured parameters from the DLR sensors, parameters indirectly obtained through software calculations, and parameters received from the meteorological data provider, the DLR system outputs the dynamic allowable continuous current load limit of the transmission line.

The system has the capability to detect the presence of ice and to display the longitudinal weight of ice after ice detection on critical spans of transmission lines with installed DLR sensors (ADR Ice). The system can calculate and display limits of the dynamic effective value of the allowable current load for critical spans of the transmission line, as well as make predictions for periods up to 48 hours.

The architecture of the DLR system operation implemented at EMS is shown in Figure 3.

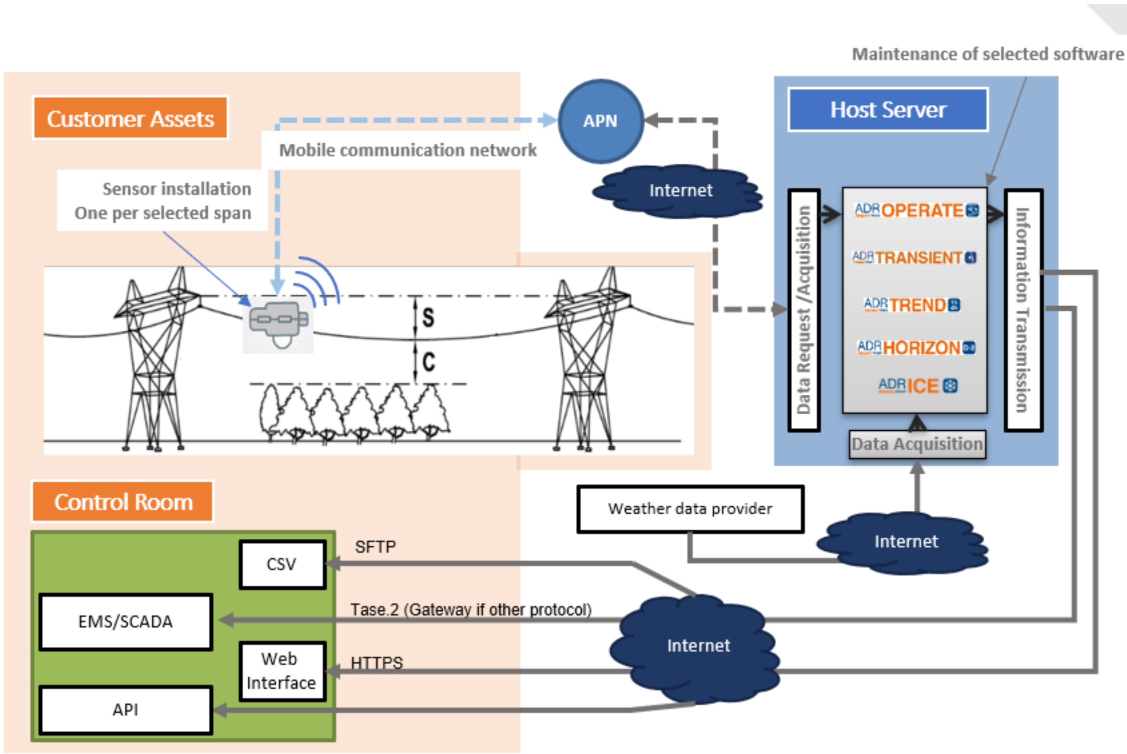


Figure 3 – Architecture of the implemented DLR system operation

3 OBJECTIVE AND DESCRIPTION OF THE SYSTEM IMPLEMENTATION IN REAL-TIME NETWORK APPLICATIONS

3.1. IMPLEMENTATION OBJECTIVE

This paper will consider three 110 kV transmission lines equipped with DLR sensors from the Belgian company Ampacimon. The mentioned transmission lines are 147/2 TS Bor 2 – TS Negotin, 151/4 TS Pančevo 2 – PRP Alibunar, and 151/5 PRP Alibunar – TS Alibunar. Transmission line 147/2 is particularly important as it is part of the group of lines through which the production from the Đerdap 2 hydro power plant is fed into the grid (Figure 4). Đerdap 2 HPP is usually not subject to tertiary regulation because its production largely depends on the inflow, i.e., the production of Đerdap 1 HPP. Therefore, almost all the energy produced by Đerdap 2 must be fed into the grid. Critical cases occur during high production regimes of Đerdap 2 (230–270 MW), when the N-1 security criterion is compromised. The most critical is precisely transmission line 147/2, which has weaker transmission characteristics than the other two lines, 1166/1 and 1204.

The remaining two transmission lines, 151/4 and 151/5, operate within the "South Banat loop," which connects two wind farms, Alibunar WF and Košava WF (Figure 5), so it is necessary to maximize the utilization of the transmission network.

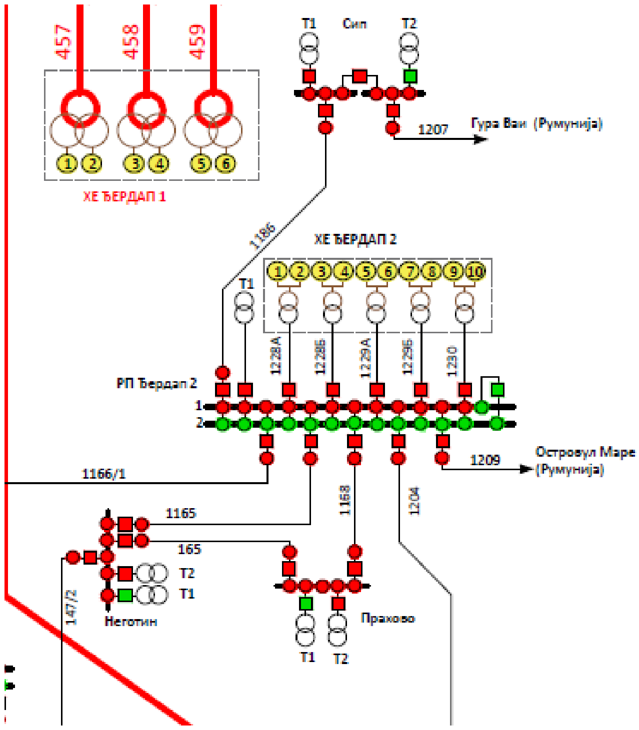


Figure 4 – Network around the Đerdap 2 Hydroelectric Power Plant

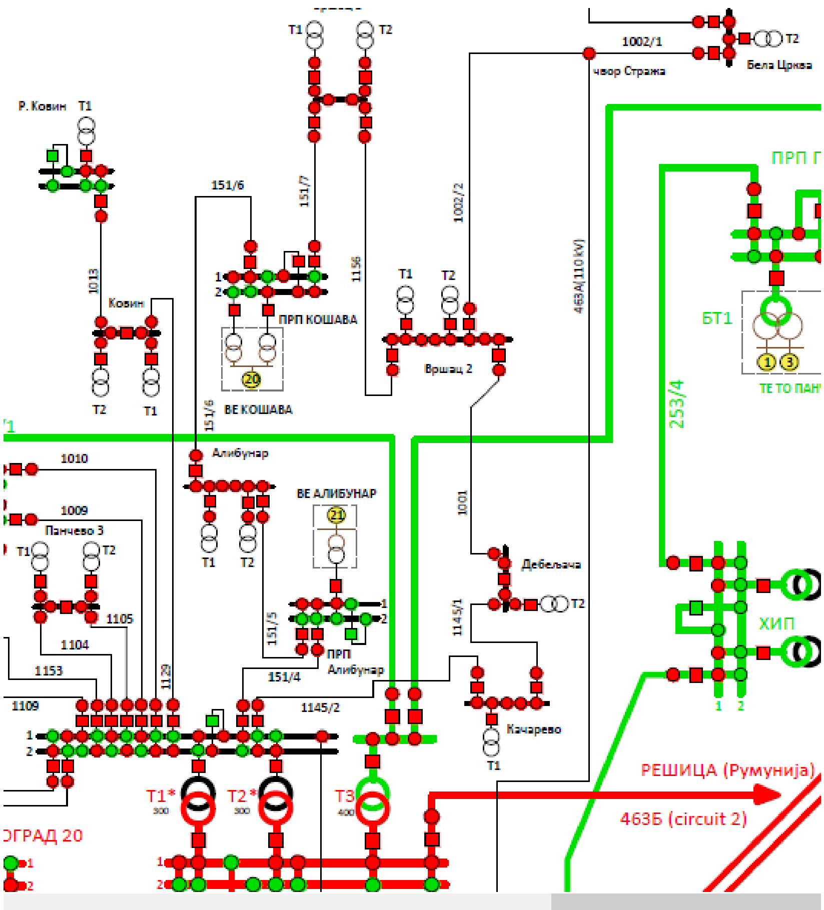


Figure 5 – South Banat Loop

The implementation aims to maximize the transmission capacity of the mentioned transmission lines at all times. Data measured by the DLR sensors on these transmission lines are collected on the DLR server, which sends this data to the GE SCADA system at the NDC (Figure 6). However, the dynamic limit values arriving at the SCADA system are for informational purposes only, while the SCADA limits for these transmission lines, as well as the limits used in network applications for real-time security analyses, are seasonal values (summer or winter). Therefore, it is necessary to develop an application that will enable the automatic updating of dynamic current limit data received from the DLR server into the SCADA limits of the given transmission lines, which will then be used in real-time security analyses.

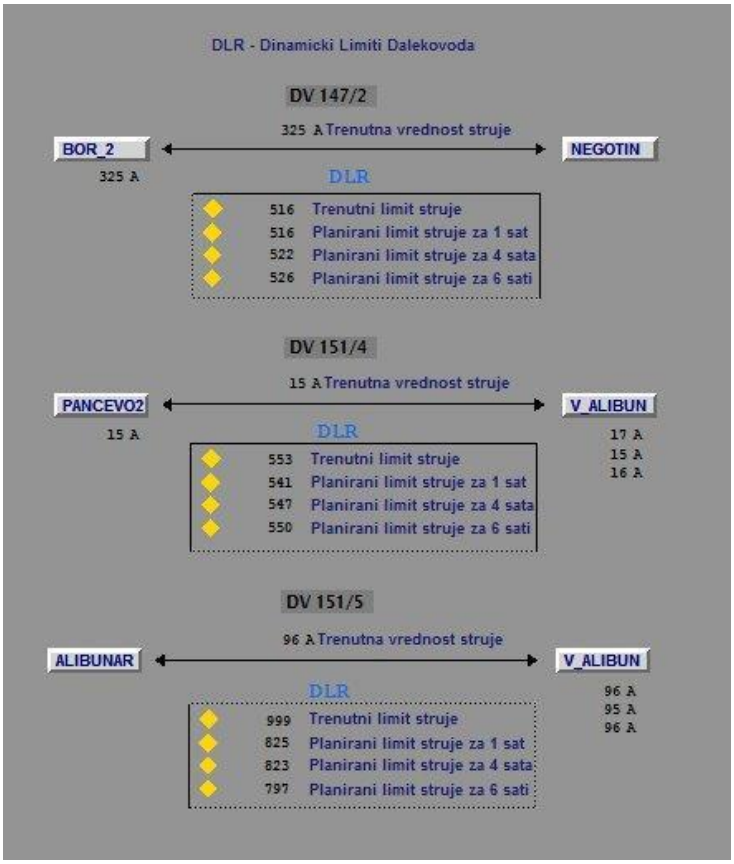


Figure 6 – Data from the DLR server in the GE SCADA system

3.2. DESCRIPTION OF THE IMPLEMENTATION

The idea is to develop an application that reads the limits arriving in the SCADA system as analog values and enters them as SCADA limits for the selected transmission lines. After that, the limits would be automatically updated in network applications and subsequently used in network calculations.

To ensure safe and stable operation of the application — i.e., to keep the limits on the mentioned transmission lines current and accurate at all times — we had to consider the accuracy of the data coming from the DLR system. Besides limits, the DLR system also sends a quality indicator for each calculated limit individually. In the figure above (Figure 6), below each transmission line, the current limits, forecasted limits, and validity status of the calculation are displayed. Using the validity status of the DLR calculation, we can control whether the data received from the DLR system is valid. Another signal indicating data quality is the SCADA measurement validity flag, which allows us to verify whether data is arriving from the DLR system, thereby enabling us to eliminate the impact of communication problems between SCADA and the DLR server. It is crucial that valid and accurate limits are available in SCADA at all times.

If either of these two pieces of information is invalid, the application will attempt to retrieve data from a CSV file generated by the DLR system. This approach bridges communication problems between SCADA and the DLR system. The CSV file also contains information about the validity of the forecasted limit calculations, based on which the application decides whether to consider that data. If none of these methods provide valid limit data, the static (seasonal) limit stored in the application database is used.

The application will reside on both SCADA/EMS servers and run every 5 minutes, which matches the data update interval from the DLR server. Upon startup, the application retrieves data from the SCADA system, loads data from the CSV file (downloaded from the DLR server), and analyzes it, i.e., checks its validity. If any data obtained from the SCADA system fails the validity check, the application then verifies the CSV file data and, if its quality is satisfactory, uses it for that transmission line. The application contains static limit data for each selected transmission line, which is used when valid DLR data is unavailable for that line. Data from the DLR system may be invalid if there is an issue with communication between the DLR server and sensors or if a sensor malfunction occurs.

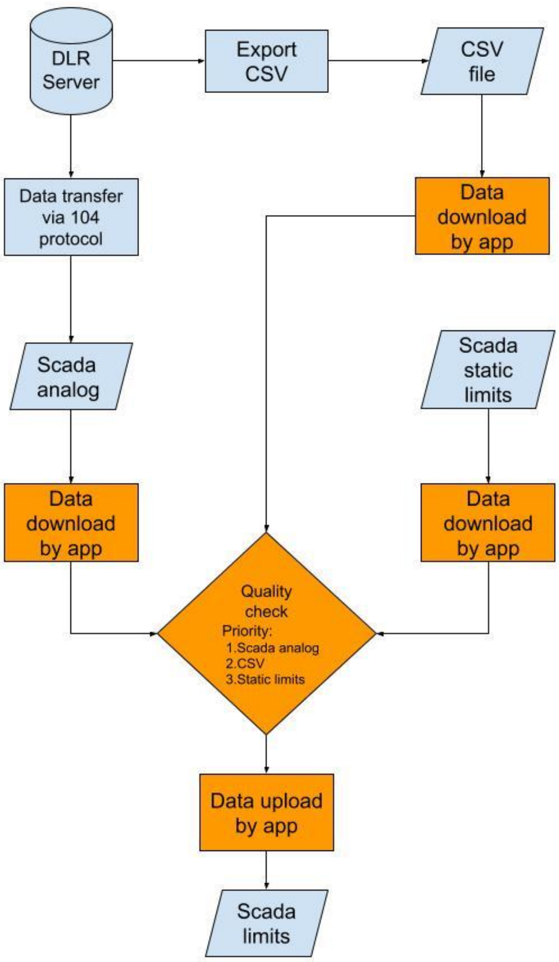


Figure 7 – Data flow diagram through the application

Figure 7 shows the data flow diagram through the application. Data is periodically sent from the DLR server to the SCADA system via the IEC 60870-5-104 protocol, and CSV files are exported. The diagram also shows static limits entered manually by the user. The application collects data from all three sources, analyzes it (validity check), and then writes the selected values into the current limits for the corresponding transmission lines in the SCADA system.

Two commands from the Habitat environment, hdbexport and hdbimport, are used to read and write values on the GE SCADA system.

The hdbexport command exports binary data from the Hdb database into an ASCII-formatted file. The format of the exported ASCII file can be configured using various command options. Hdbexport is designed for two-way operation with hdbimport. The default operation of hdbexport creates a complete ASCII export file of the database that hdbimport can import to reproduce the same database content.

The hdbimport command imports data into the Hdb database from one or more ASCII-formatted files. The hdbimport and hdbexport commands are complementary functions in that data exported by hdbexport can be imported using hdbimport.

The application uses the hdbexport command to retrieve data from the SCADA database, then creates the corresponding file and uses the hdbimport command to read the created file and write it into the appropriate SCADA limits. Here, an analog record is written into a limit record. The figure below shows the hierarchy of SCADA records in the Habitat database for analog values.

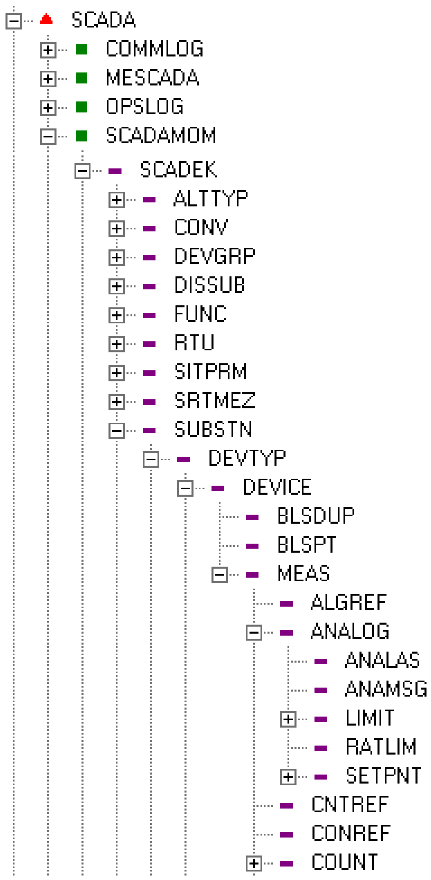


Figure 8 – Data organization in the GE SCADA system

In Figure 8, it can be seen that the limit is hierarchically below the analog value, meaning that in this case, we cannot use the file obtained by export directly for import; instead, we need to modify it. The modification of the obtained data differs as follows: one analog value (data from the DLR) can be linked to one or more currents (sometimes for a transmission line we get only the current of one phase, and sometimes currents of all three phases), currents exist at both ends of the transmission line, and finally, one limit obtained from the DLR system must be written into two types of limits: alarm and warning. At EMS, the rule has been adopted that the limit obtained from the DLR is split into two limits according to the following rule:

$$\text{Alarm} = \text{DLR limit} \cdot 1.1$$
$$\text{Warning} = \text{DLR limit} \cdot 0.95$$

From the options mentioned above, the question arises of how the application can know which transmission lines receive forecasted limits from the DLR applications, to which currents, and how many of those limits will be entered, etc. For this reason, the application contains a configuration file that must include: SCADA codes of transmission lines equipped with DLR sensors, all currents and their SCADA identifiers, SCADA names of limit types (warning/alarm), and coefficients by which the limit is multiplied to obtain the warning and alarm values.

Finally, once the limits are written into the appropriate SCADA fields, they become available to all network applications. In the GE SCADA/EMS system, the SCADA limits are automatically copied into the NETMOM database in RTNET (Estimator), and from there forwarded to the RTCA (Outage Analysis), VVD (Voltage/Var Dispatching), and RMTNET (Outage Analysis for several hours ahead) applications where they are used in calculations.

4 ANALYSIS OF THE OBTAINED DATA

It is difficult to present the analysis of the obtained data in a real environment because one would have to wait for a moment in the system when the mentioned transmission lines are overloaded beyond the static limits, but still below the forecasted dynamic limits. Since this makes little sense and there is no time to wait for such a moment, we conducted the analysis in a study mode using the GE DTS system, where the overload of one of the mentioned transmission lines, 147/2, was simulated.

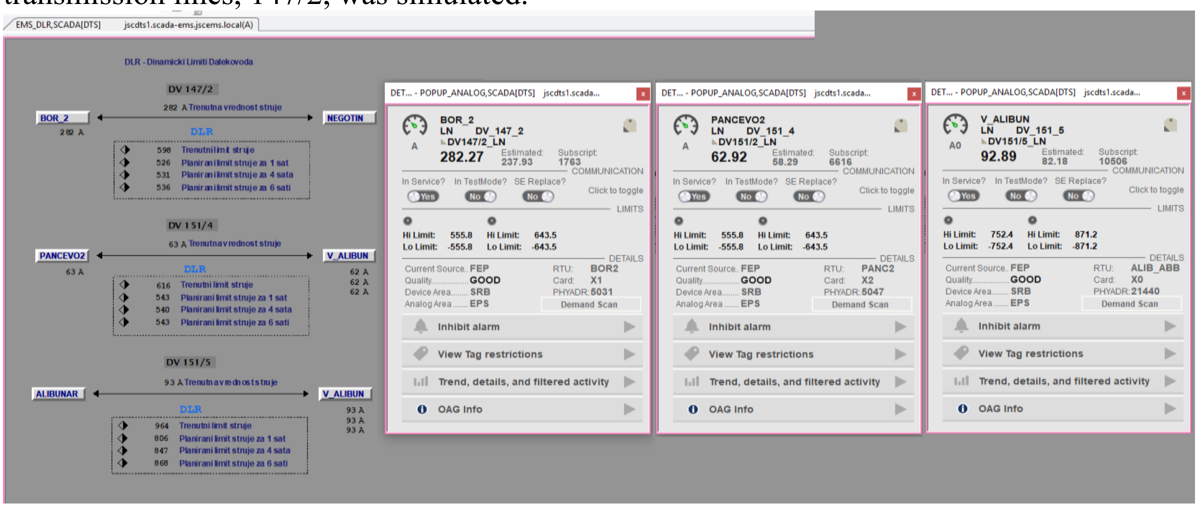


Figure 9 – Initial state of SCADA limits

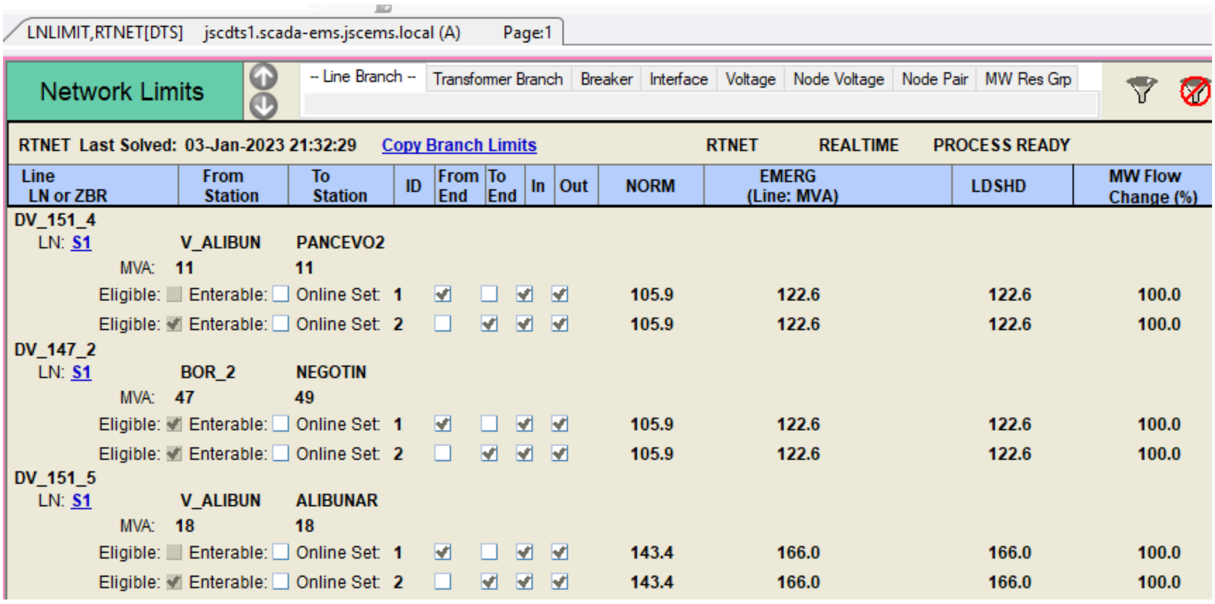


Figure 10 – Initial state of limits in the network application

The above figures show the initial states of the limits in the SCADA system and the RTNET application for the selected transmission lines. Each transmission line has static limits. In Figure 9, on the left side, the current limits can be seen, as well as the forecasted limits for the upcoming hours. It can be noticed that the limits from the DLR system are higher than the static ones. In the next figure (Figure 10), the limits in the estimator (RTNET) before importing the DLR limits are shown. The NORM column contains the warning limits, and the EMERG column contains the alarm limits, both expressed in MVA.

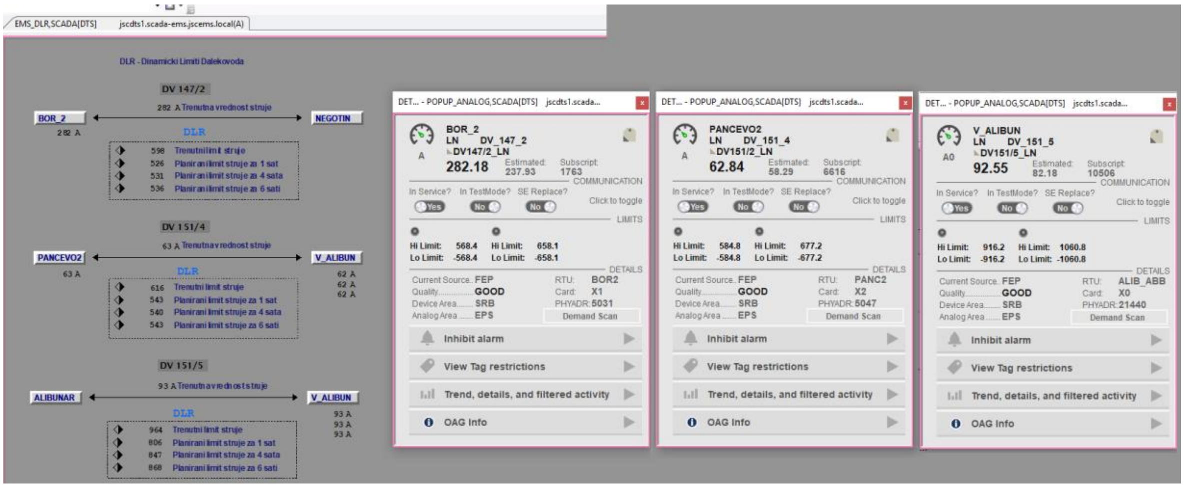
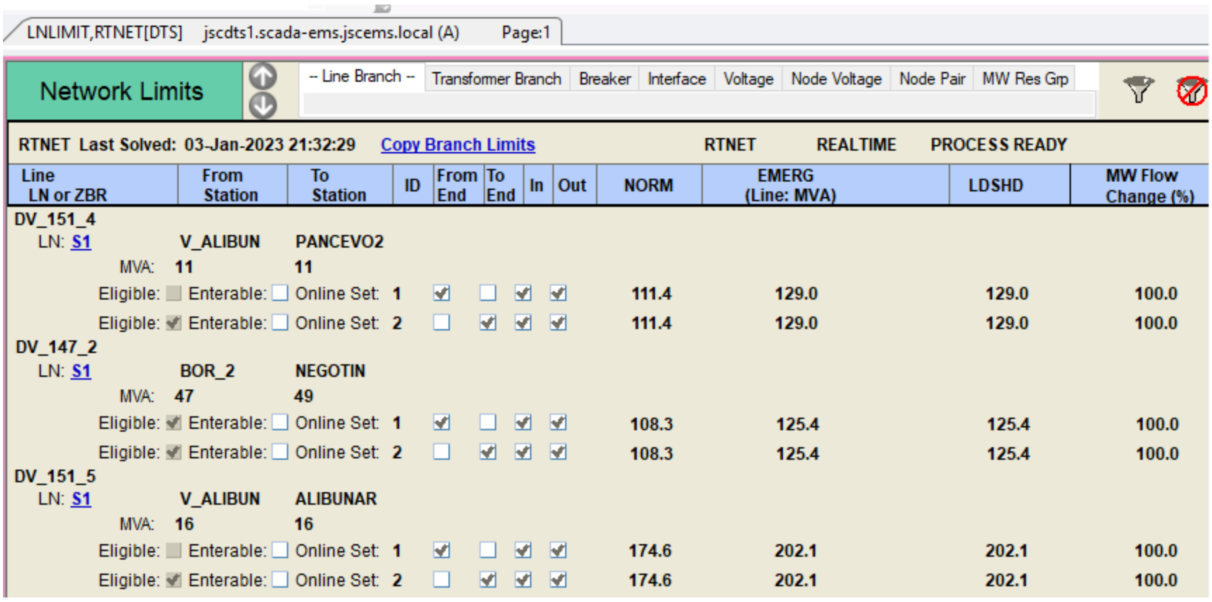


Figure 11 – SCADA limits after importing DLR limits



Slika 12 Limiti u *RTNET*-u nakon importovanih DLR limita

Figures 11 and 12 show the limits in the SCADA and RTNET applications after importing the DLR limits. The limits on the mentioned transmission lines are higher than at the beginning, indicating that the imported limits from the DLR system have increased the capacity of the transmission lines and are now used in other network applications and calculations.

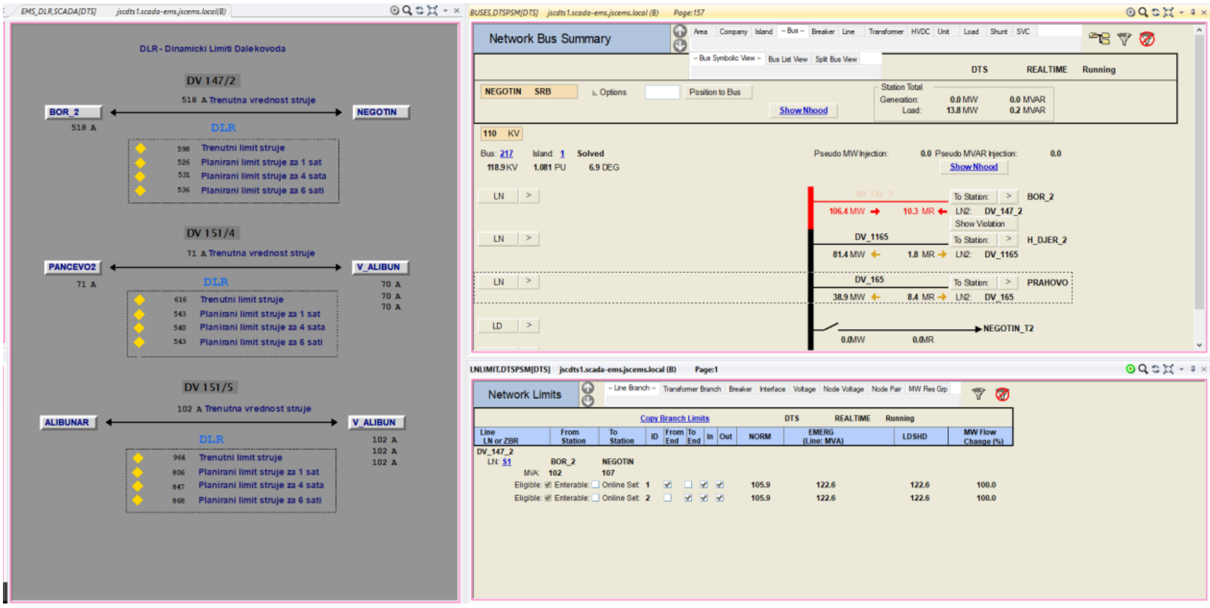


Figure 13 – Moment of transmission line overload with static limits

In study mode, by disconnecting the 110 kV transmission line no. 1204 and increasing production at the Đerdap 2 hydro power plant, we overloaded the 147/2 transmission line slightly above the warning limit obtained from the SCADA static current limit. These simulated conditions correspond to a high water level regime on the Danube when Đerdap 2 HPP has high production due to inflow. In that regime, the N-1 security criterion is threatened, meaning that the 147/2 transmission line is overloaded in case of failure of one of the remaining two transmission lines. Therefore, we simulated the failure of one of those two lines, specifically transmission line 1204, which caused the overload of transmission line 147/2. At that moment, the limits obtained from the DLR system for that line were higher than the static limits. In the study application, the mentioned line was overloaded, i.e., the current was above the warning limit (Figure 13). After that, we started the application that copied the analog values obtained from the DLR system into the SCADA limits, after which they were automatically transferred to the network applications.

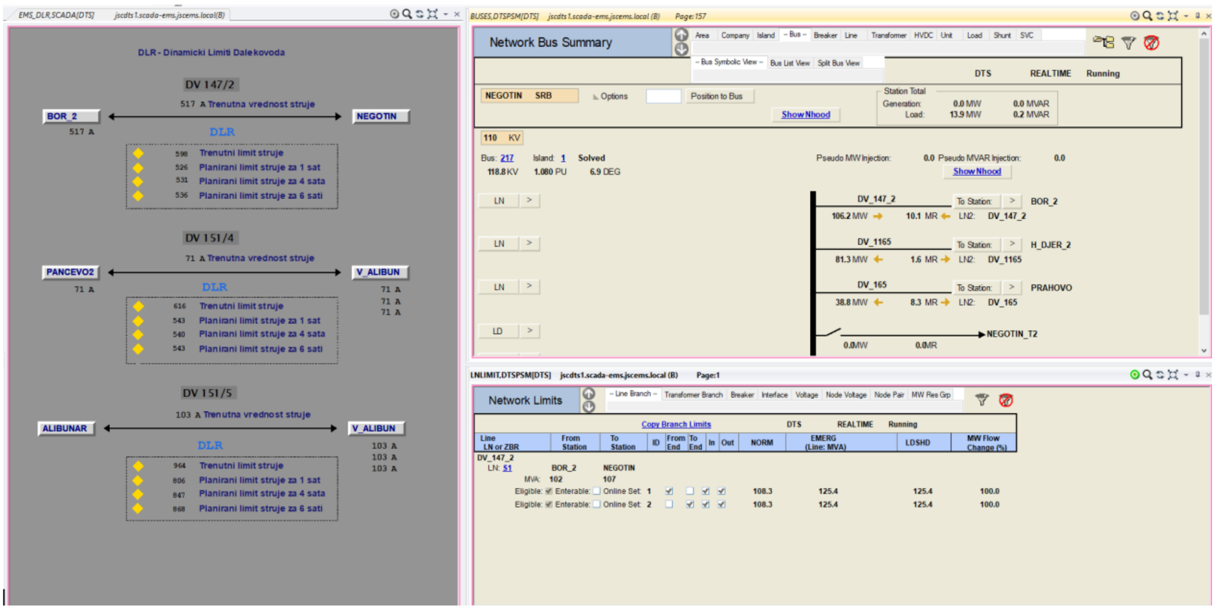


Figure 14 – Moment after DLR limits have been taken into account

After the new limits were applied, the overload disappeared, meaning the transmission line capacity increased (Figure 14).

In the case of potential overloads on any of the transmission lines through which the production of the Đerdap 2 hydro power plant is fed into the grid, two dispatcher actions are possible. The first involves an agreement between the Serbian and Romanian operators, according to which—if the neighboring network conditions allow—it is possible to transfer one block, i.e., two generators of Đerdap 2, to operate radially on the Romanian system via the 110 kV interconnection line no. 1209 Đerdap 2 – Ostravul Mare. This way, up to 50 MW could be evacuated from the system.

The second option is redispatching the power plant, i.e., issuing an order to reduce production due to system endangerment. Activating tertiary reserves due to redispatching is very costly. However, this simulation shows that, in most cases, this will not even be necessary. By using dynamic limits, we practically utilize the maximum transmission capacity of the transmission lines at any given moment.

5 CONCLUSION

This paper presents a use case related to the integration of the DLR system into real-time network applications, as part of the international R2D2 project. The current implementation concerns three specified transmission lines that, within the pilot project, have DLR sensors installed by the Belgian manufacturer Ampacimon. The significance of the implementation is demonstrated through simulation on the Dispatcher Training Simulator (DTS), using the example of transmission line 147/2. The ultimate goal of the use case is to utilize DLR limits within the SCADA/EMS system, i.e., in the regular operational management processes.

The main effort is to ensure that the implementation is scalable, so that DLR limits of new transmission lines can be easily integrated if new DLR sensors are installed. An increasing number of DLR sensors will be necessary, especially due to the integration of renewable energy sources, all aimed at the optimal utilization of the network's transmission capacity. From this perspective, wind energy is the most important. As already noted in this paper, wind is the most significant factor in cooling conductors, thereby increasing their transmission capacity. Under windy conditions, when more energy from wind farms needs to be fed into the network, using DLR limits will make this possible because the windy conditions increase the transmission capacity of the lines through which this energy is transmitted.

This is one of the main reasons why DLR sensors in the pilot project have been installed on transmission lines 151/4 and 151/5, as these lines connect the Alibunar wind farm to the transmission system. Considering that these lines operate within the "South Banat loop," which can be regarded as one of the critical points of the 110 kV network, using dynamic limits would greatly optimize this part of the network, especially since the loop includes another wind park, Košava Wind Farm, in addition to Alibunar.

6 REFERENCES

1. https://www.ampacimon.com/en/adr-sense
2. https://www.ibm.com/products/weather-company-data-packages
3. https://www.ampacimon.com/en/adr-software-suite
4. https://www.ge.com/digital/applications/transmission/advanced-energy-management-system-aems

Acknowledgment

This document has been prepared based on work conducted within a project funded with the support of the European Union. The content of this document is the sole responsibility of the authors and under no circumstances can it be considered to reflect the views of the European Union.