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Overhead Transmission Line Monitoring System in Croatian Power Grid

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SUMMARY

Putting the transmission network in the service of the electricity market causes a large energy flow in certain transmission directions. The key technical question is how much time will transmission network tolerate this situation without any damage. In this case, the actual thermal loading of the conductor in normal and emergency state for re-dispatching energy is a very helpful information for the system operator. This information can be obtained through thermal monitoring system installed overhead power lines (OHLs).

In this paper 110 kV OHL Crikvenica – Vrataruša in the Croatian power system was analyzed. The line was created after the interpolation of a wind farm (WF) Vrataruša of 42 MW in the existing OHL Crikvenica – Senj at the beginning of 2010. The operation of WF Vrataruša at full power, in some cases, may require a change in network topology. This is done by sectioning of busbars in substations or by redispatching production of hydro power plants (HPPs) in neighboring area. As this situation is not present throughout the year but occurs only in certain periods, the problem of safe energy evacuation was attempted to be solved by using the Overhead Transmission Line Monitoring (OTLM) system.

This paper describes the experience with OTLM devices within the pilot project on the 110 kV OHL Crikvenica - Vrataruša, along with viewpoints from grid dispatcher and relay protection specialist.

KEYWORDS

Thermal monitoring, overhead power line, ampacity optimization, OTLM, smart grid, static rating, dynamic rating

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INTRODUCTION

By the implementation of the third energy package and the deregulation of the energy market it was attempted to establish a common market of electrical energy in the European Union while maintaining high standards of service and security of supply to the end customer. The electricity flow follows its market price, especially now when there is a great deal of renewable energy sources which are replacing conventional power sources running on coal or gas due to the European 20:20:20 policy.

The nature of renewable sources, like the wind, can cause dynamical load changes in transmission routes which can lead to overload on certain lines, while others remain under designed load. At the same time it has to be taken into consideration that the majority of HV transmission lines in Croatian transmission system were built during sustained growth period in 1960s, 70s and 80s that ex-Yugoslav countries experienced. Over the years, these lines have undergone some minor overhauls like substitution of suspension equipment, insulators and installation of OPGW but, in most cases, their transmission capacity remained the same as in original designs.

The transmission capacity of OHL is determined by two key factors, the first is the maximum permanently permitted conductor temperature which is set at 80°C for ACSR [1] and the second is minimal allowed safety clearance from the conductor to the ground or object beneath which is defined by the safety standards [2] and depends from the type of an object and voltage level of the OHL. The first factor affects the plastic deformation of the conductor that is why, after a certain number of thermal cycles, it can lead to the rupture or slippage of the conductor from terminal clamps. The second factor has a considerable influence on the safety of the people and the environment from voltage flashovers.

Both factors can be affected by a number of physical quantities which can change instantly. Solar radiation, air temperature, speed and wind direction has direct impact on heating and cooling of the conductor. Considering that these physical quantities are very difficult to predict or even estimate, in use are very conservative methods for determining the maximum allowable transmission capacity of the OHL.

In practice, the designers of power lines use deterministic model where the predefined worst case scenario of + 40°C ambient temperature, with little or no wind, is used to determine the ampacity of the power line. This method is safe, but in appreciation of the growing demand for power flow raises the question whether it is efficient enough.

To meet the requests delegated to the grid by the volatile market and power sources the transmission network has to be enhanced. Seeing that the reconstruction of existing, as well as the building of new resources is a long and costly process, so alternative solution had to be found. By using the emerging smart grid technologies we can gain advanced understanding of network condition. This allows a safe correction of the OHL ampacity and gaining much-needed additional transmission capacity.

In this case, the actual thermal loading of the conductor in normal and emergency state for re-dispatching energy is a very helpful information for the system operator. This information can be obtained through thermal monitoring system installed on OHLs.

OVERHEAD POWER LINE THERMAL MONITORING SYSTEM

The thermal monitoring of OHL in a transmission grid is possible with various technologies on different power levels. The choice depends on the requests given by the transmission system operators. The sag and the conductor temperature are two key parameters which define the ampacity of the OHL. The conductor temperature is defined by thermodynamic equilibrium where the heat input equals heat losses. The conductor is heated by the solar radiation and by the heating effect of flowing current (I^2R). Equation (1) shows the relationship between current and conductor temperature.

$$q_s - q_c - q_r = mC_p \frac{dT_c}{dt} - I^2 R(T_c) \quad (1)$$

The following symbols represent:

q_s	=	energy gained through solar radiation [W/m]
q_c	=	convection losses [W/m]
q_r	=	radiation losses [W/m]
mC_p	=	maximal thermal conductor capacity [W/m°C]
I	=	conductor current [A]
T_c	=	conductor temperature [°C]
$R(T_c)$	=	resistivity of the conductor at given temperature T_c [Ω/m]

The conductor temperature can be measured in one spot or continuously all over the length of the line. The spot method is cheaper but the device has to be carefully placed on the OHL. It should be mounted on the bottom conductor, on the part of the line that passes through area where the landscape changes sharply and line is shielded from wind by various natural or manmade barriers. On a complex terrain, the number of measurement points should be greater than the one in flat woodless areas. The continuous method, with for example optical phase conductor (OPPC), is considerably more expensive but there is no need to evaluate the geometry of the terrain, since it generates approximately one measurement spot every 2 meters of the line length.

Depending on the parameters that can be measured there are different levels of load control and line monitoring:

1. Static rating is the basic method. It is represented by overcurrent protection devices at substations with preset values according to the OHL design documentation. For example, on 110 kV line, with typical 240/40 mm^2 conductor, the switch-off current is set at 40 % above the nominal current of installed current transformer and the tripping of the circuit breaker is activated after 5 s.
2. Dynamic rating is more advanced than static rating. Beside the temperature of the conductor, we have to gather the weather parameters along the OHL line by installing weather stations. The data is then collected by an appropriate software which calculates the permitted load based on a modified equation (1). Dynamic capacity achieved in such way is higher than static one and extremely weather dependent because the climatological parameters can change instantly.
3. The system for managing transmission network load boundaries is the highest level of monitoring which includes all the features of dynamic rating along with load forecasting in both normal and emergency (n-1) state of the grid.

The study [4] has shown that in 90–95 % of the time the OHL line is loaded within its operational parameters (Figure 1.) and only 5 % of the time is overloaded so the real question is whether it is economically feasible to do the reconstruction of the line if we need more capacity only 5 % of the time.

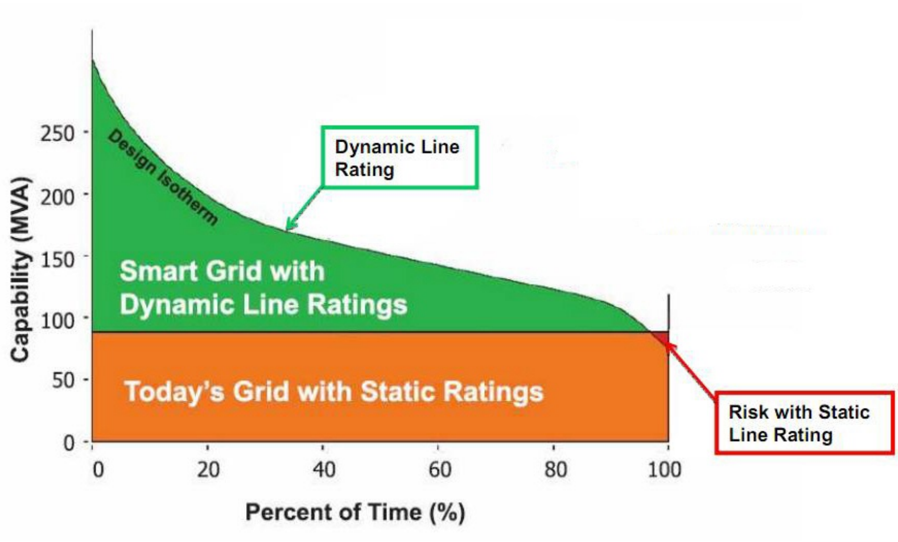

Figure 1. The relationship between static and dinamic line rating

THE 110 kV OVERHEAD POWER LINE CRIKVENICA – VRATARUŠA

When transmission substation (TSS) Crikvenica was connected to the grid back in 1974., the initial OHL from the direction of HPP Vinodol and HPP Senj was separated in two electrically independent entities, the OHL 110 kV HPP Vinodol – TSS Crikvenica and the OHL 110 kV TSS Crikvenica – HPP Senj. By interpolation of the WF Vrataruša into existing OHL 110 kV TSS Crikvenica – HPP Senj, two new lines have been formed, the OHL 110 kV TSS Crikvenica – WF Vrataruša and the OHL 110 kV WF Vrataruša – HPP Senj.

The OHL 110 kV TSS Crikvenica – WF Vrataruša was designed and built with steel lattice towers with “fir” and “danube” top geometry (lead-in TSS Crikvenica). The used conductors are of ACSR type with cross section of 240/40 mm^2 (till tower no.65) and 250/55 mm^2 (from tower no.65 till WF Vrataruša). The OHL is equipped with OPGW on top of the towers. The insulators are glass cap and pin type, IEC marking U120BS. The designed transmission capacity of the OHL is 123 MVA or 645 A.

WF Vrataruša started its test run at the beginning of 2010 and delivered its first significant amount of power into Croatian transmission grid. The wind farm consists of 14 wind generators Vestas V 90-3.0MW with overall installed power of 42 MW and up till now is the biggest WF connected to the Croatian transmission grid. Since this WF is located between HPP Vinodol and HPP Senj, it inevitably affects their operation (Figure 2.).

The network analysis has shown [3] that most of its power, WF Vrataruša delivers trough transmission line Vrataruša – Crikvenica – Vinodol. The net power output of HPP Senj is 210 MW and net power output of HPP Vinodol is 90 MW. The HPP Vinodol operates in secondary regulation with operation range between 0 to 90 MW which can be achieved in seconds. During a hydrologically favorable period, like the first three months of 2010., this direction is heavily burdened by energy delivered from HPPs from Dalmatian region to Slovenia and Italy even without additional power added from WF.

Since wind power accounts as the renewable energy source, the placement of its energy is a priority in the transmission network and operation of WF Vrataruša at full power may require a change in network topology. This is realized by sectioning of busbars in substations or by redispatching production of HPPs in neighboring area. As that this situation is not present throughout the year but occurs only in certain periods of time when there are simultaneously present favorable hydrological and wind conditions in the region, it was attempted to solve the problem of safe transport of power by existing power line by using the OTLM system.

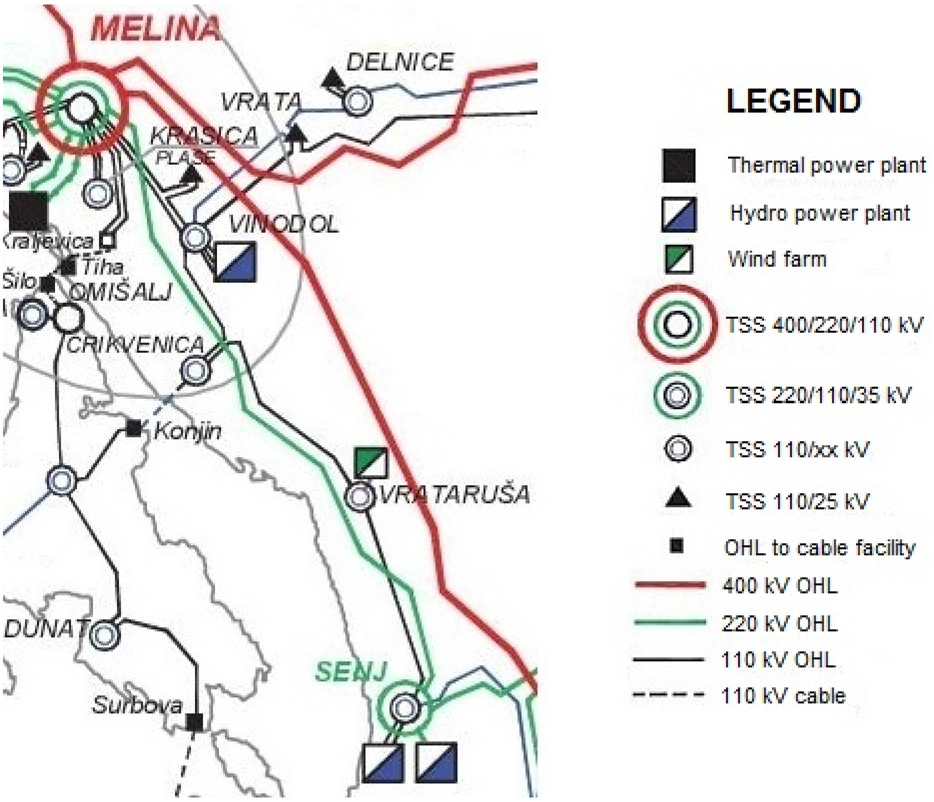

Figure 2. The transmission grid layout around WF Vrataruša

THE OVERHEAD TRANSMISSION LINE MONITORING SYSTEM (OTLM)

The full implementation of system for dynamic thermal rating of overhead power lines requires substantial financial resources so it has been decided to approach to this project in several stages. In the first stage, the equipment for the contact temperature and current measurement of the conductor will be acquired. Later, the system will be upgraded with weather stations and appropriate software to achieve the feature of dynamic load rating.

Figure 3. The OTLM device

Obtained system consists of OTLM devices (Figure 3.) along with the software in form of web application on a database server (Figure 4.). The device comprises several sensors from which the most important one is the contact thermometer which measures the actual conductor temperature at sensor fixing points on the OHL phase conductor. The current transformer and the supplying unit provide the power for operation without any additional external source. Measurements of ambient temperature, humidity, current and angle of inclination of the conductor are also provided. Housing is made of fire resistant composite material to meet the heavy ambient conditions.

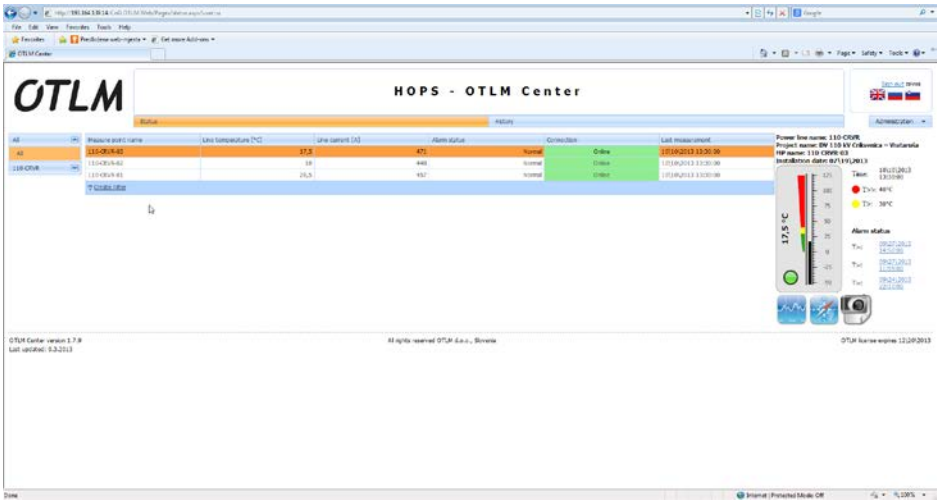

Figure 4. The OTLM center

The data from the unit is transmitted to selected server via GSM network, internet and standard IEC protocols (Figure 5.) for further analysis. Local and remote access to the device for parameter setting, firmware upgrade etc. is also enabled. The device is equipped with a GPS signal receiver so the temperature and current measurements are annotated by precise time stamp.

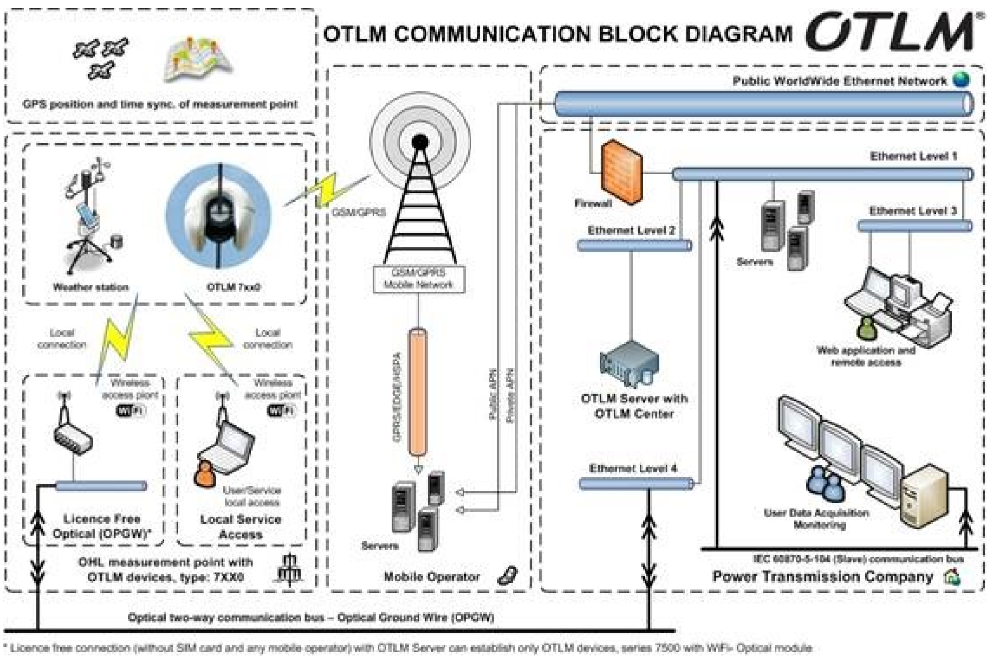

Figure 5. The OTLM communication block diagram

On OHL 110 kV TSS Crikvenica – WF Vrataruša three measurement points (MP) have been selected based on power line geometry, terrain complexity, tower accessibility and it was attempted to cover the entire length of the line. The first point was in the Vinodol valley (span between towers no. 25-26), the second one was at span between towers no. 67-68 and the third was at span between towers no. 96-97 just before the WF Vrataruša (Figure 6.). The installation was carried out by qualified linesmen from Croatian grid operator on July 19th 2013.

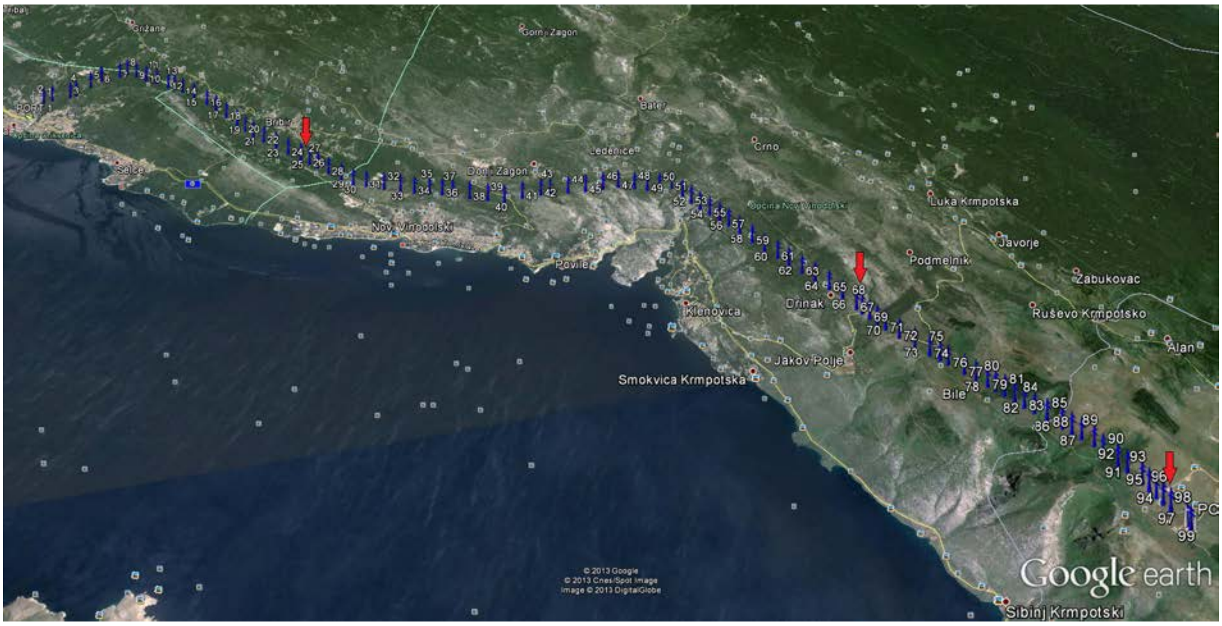

Figure 6. OHL 110kV TSS Crikvenica – WF Vrataruša

Some interesting conclusions were made after the first three weeks of data gathering. Out of three measurement points, the highest conductor temperatures were noticed on MP 1 in the Vinodol valley so that area represents the bottleneck for energy transfer on this OHL.

The system is set to generate two alarms. The first (yellow) is set at conductor temperature of + 30°C and the second (red) at conductor temperature of + 40°C. During almost four years of how long the system has been deployed, the amount of alarms generated can be seen on Figure 7. The white color represents the state when OHL functions within designed parameters.

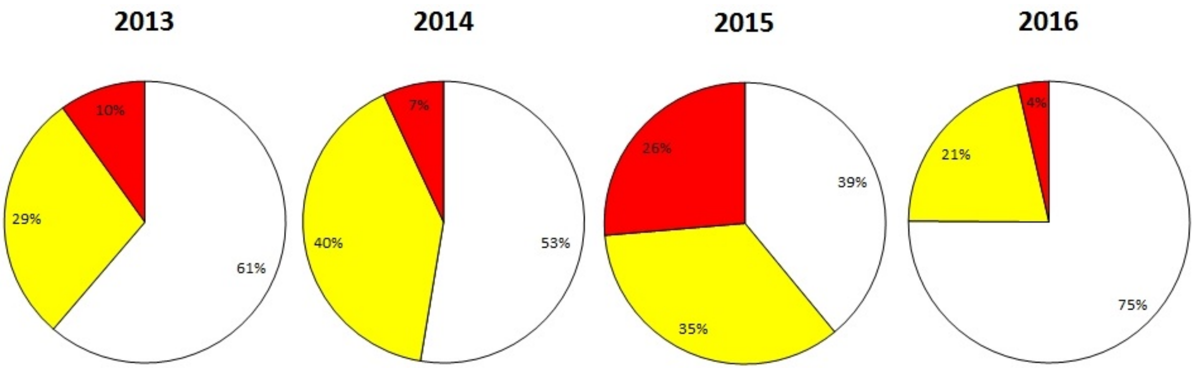

Figure 7. The alarm distribution during the years

Based on the data presented on the graphs, it can be seen that the most critical year was 2015. During the year 2015., there were 106 days during which the red alarm went off and the highest recorded temperature was of + 66,1°C on the 3rd of June while the line current was 492 A (Figure 8).

Considering that the line was originally designed for 645 A and the mounting sag table goes up to + 40°C, we don’t have to come close to designed line ampacity to have issues with safety clearances. Based on these new insights, in the department for maintenance of OHLs, it was decided that the route of this line should be carefully monitored along with regular execution of vegetation management activities. There is also a strong possibility that a Light Detection and Ranging (LIDAR) survey will be conducted to determine accurately the critical spans.

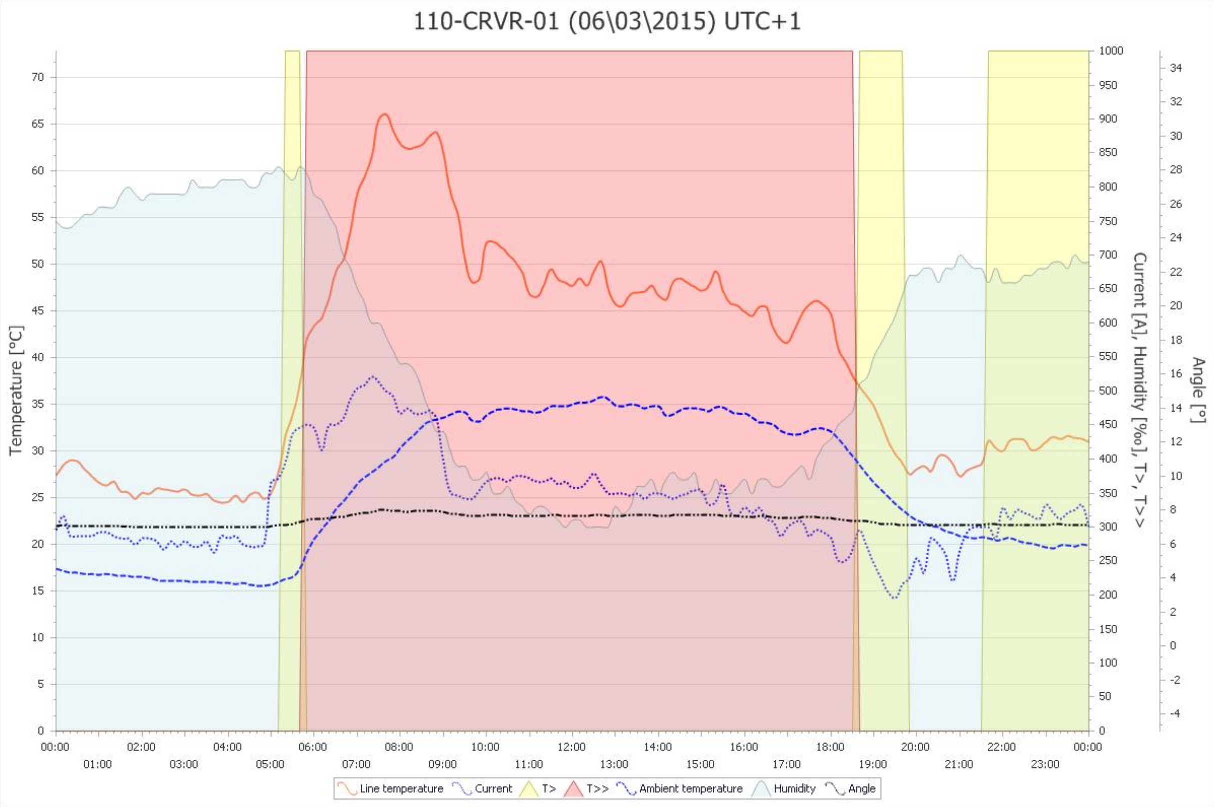

Figure 8. The data received from OTLM device on the 3rd June 2015.

CONCLUSION

Although the system is not complete but only the first stage has been installed, even at this level, it can be seen that the advantages which this tool adds to asset management are numerous.

First of all, this system allows us to maximize the transmission capacity while maintaining the presumption of safety both for the structural elements of the transmission line and the distance from the live parts to the ground. Furthermore, the fact is that the lines in Croatia were designed in accordance with the regulations and the designers left a reserve in respect to economical operation of the OHL in its lifetime. Thus, the designed lines can rarely cross the designed capacity, which can happen only in exceptional conditions, high environment temperature and unfavorable ambience. It is exactly on this edge that the grid dispatcher needs a system which enables him to be in the safe zone along with the necessary amount of transferred energy as well as with the surroundings of OHL.

The fact that the main function of the OHL is power transfer, an activity that its income side has in to the amount of energy transferred must not be forgotten, as well as the fact that more transferred energy means more money for the grid operator.

This pilot project has proved that with the application of new technologies, existing resources can be used more efficiently. In the future, we will hopefully upgrade this project to full dynamic system rating level and expand it with new lines within SYNCHRO.GRID project.

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