Smart grid concept based on-line monitoring and overhead lines dynamic rating

PhD Thesis – Abstract
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Globally, energy companies are currently concerned with increasing energy efficiency, accelerating renewable energy production and developing Smart Grid technologies [ENTSO2012c].

The idea of the smart grid - Smart Grid can be a consequence of technological developments that will give increased flexibility to the electricity grid and increase the quality of consumer power supply, helping to meet the goals set by the Lisbon Street, from 2007 to 2007. which analyzes resources and energy [EURO2009], [EPRI 2009], [ENTSO2012a].

Smart grids are smart grids that can intelligently integrate the behavior and actions of all users connected to these networks - producers, carriers, distributors and consumers of energy, as well as those who produce and consume simultaneously, with providing efficient, sustainable, economical and secure electricity [ENTSO2013a].

The Smart Grid can modernize the current electricity grid to meet the demands of 21st century society [DOE2009], [ENISA2012], [ENTSO2013b], [EPRI2013]. The transition to the networks of the future is achieved through an integrated and innovative approach in technical, commercial and regulatory terms. The introduction of smart grids in the Romanian energy system aims to achieve the following objectives [Guv2017]:

- elimination or reduction of damage to high voltage equipment and / or installations;
- elimination of the causes and factors that lead to the destruction of high voltage equipment and / or installations;
- increasing the service life of all active components in power stations, to their limits and even beyond;
- increasing the reliability / availability and safety of the energy system;
- reduction of maintenance costs;
- increasing the speed and efficiency in the use and management of technical information;
- improving the efficiency of the operation of the electric transmission network;
- ensuring the security of networks, quality control systems in power supply using a greater number of sensors, including real-time data exchanges with European transmission system operators (Transmission System Operator - TSO);
- increasing the capacity of the network to allow the integration of users with new requirements;
- implementation of means to improve the monitoring of electricity networks;
- increasing the use of Information Technology and Telecommunications to secure operations and increase network flexibility;
- reduction of electricity losses;
- increase the efficiency of existing assets and investments.

In this context, the topic of the doctoral thesis is part of the current concerns in the field of electricity transmission, in order to deepen the concept of smart-grid and its implementation in the electricity transmission system in Romania, by online monitoring and dynamic charging of overhead power lines (OHL).

The doctoral thesis extends to 168 pages, being structured on 8 chapters, preface and an extensive bibliographic list (128 titles). It contains a number of 81 figures with 29 tables.

Chapter 1 is introductory. The first part includes the framing and justification of the topic of the doctoral thesis, in the context of the existing concerns worldwide and in Romania. Today, power systems are being challenged by technological advances, the implementation of renewable energy sources, and the evolution of telecommunications and power electronics. According to the International Energy Agency, electricity consumption in Europe will increase at an annual rate of 1.4% by 2030, and the power installed in renewable energy sources will double from 13% today to 26% in 2030. There is a growth rate of consumption, which requires increased availability and security in the production, transmission and distribution of electricity [Gian2016].

The second part makes a brief presentation of the content of each chapter of the thesis. The last part of the chapter highlights both the way of capitalizing on the research carried out in the doctoral thesis (papers published in specialized journals or presented in international conferences), and the usefulness of the results obtained for the Romanian transmission and system operator. Finally, the perspectives opened by this doctoral thesis on the possible directions for the continuation and extension of investigations are underlined.

Chapter 2 highlights the concept of Smart Grid, the causes and needs that led to the implementation of such a concept in developed countries of the world and the factors that support the implementation of smart technologies in our country. The first part of Chapter 2 discusses the extensive damage in the US and Canada, as well as the policy of these states to support the modernization of electricity transmission and distribution systems, in order to maintain a reliable and secure electricity infrastructure. Therefore, the concept of Smart Grids was first launched in the US following the 2003 major breakdown (Table 2.1.1), and in Europe, in 2005, under the European Technology Platform for Future Power Grids, the 7th Framework Program of the European Union. European Commission.

The Smart Grid is an *"electricity network that can effectively integrate the behavior and actions of all connected users - producers, consumers who produce and consume simultaneously - in order to ensure a sustainable, cost-effective energy system. with low losses and high levels of quality, security and safety in the power supply "*.

Table 2.1.1. Blackouts due to problems in the electricity transmission system

No.	Location affected by blackout	Data	Affected population	Losses [USD]	Main causes
1.	USA & Canada [TF2004]	August 14, 2003	55 million of inh.	1-2 billions	a) Insufficient knowledge of the energy transmission system
					b) Ignorance of the conditions of deterioration of the energy transmission system
					c) Improper grooming / cutting of trees in the aisle of power lines
					d) Inadequate support for real-time diagnosis of the condition of transport system components
2.	USA & Mexico [Huff2011]	September 8-9, 2011	5 million of inh.	118 billions	A minor maintenance work on a 500 kV circuit breaker that accidentally cut off the 500 kV OHL between Hassayampa and Yuma power stations

The Smart Grid is characterized by:

1) increased use of information technology and digital control to improve the reliability, security, and efficiency of the electricity grid;
2) dynamic optimization of the operation and resources of the electricity network, in the conditions of a full cyber security;
3) implementation and integration of distributed and generation sources, including renewable ones;
4) development and incorporation of demand response, demand-side resources and energy efficiency resources;
5) implementation of intelligent technologies (real-time, automatic, interactive, which optimizes the physical operation of consumer devices and devices) measurement, communications on the operation and state of the network, to automate distribution;
6) implementation and integration of advanced technologies for electricity storage and flattening of the load curve, including electric vehicles, hybrid vehicles;
7) providing consumers with real-time information and control options;
8) identifying and reducing unreasonable or unnecessary obstacles to the adoption of Smart Grid technologies, practices and services.

Figure 2.1.2 shows the Smart Grid framework concept proposed by the US National Institute of Standards and Technology (NIST) [NIST2012]).

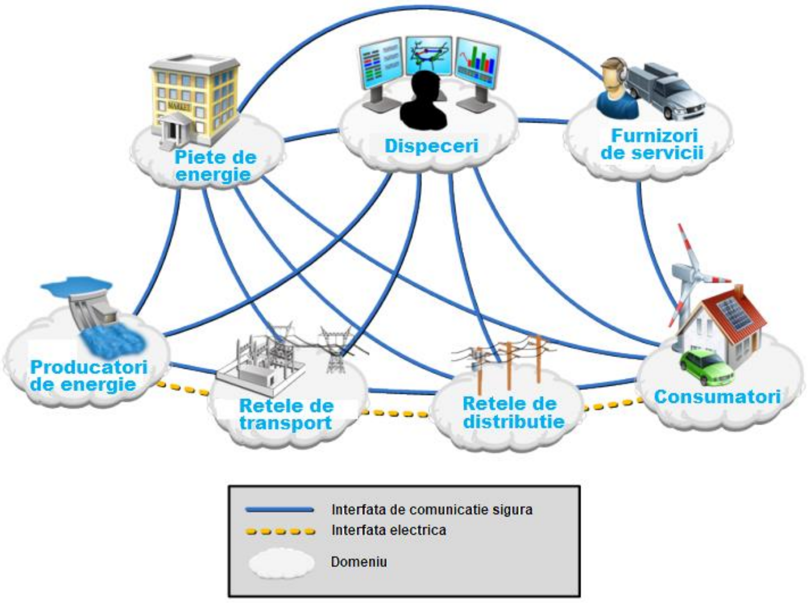


Fig. 2.1.2. Smart Grid framework concept, NIST proposal

The infrastructure of a Smart Grid system comprises 3 intelligent subsystems:

- the energy subsystem which includes the generation, transmission, distribution, supply and consumption of electricity;
- the IT subsystem which includes the activity of monitoring, advanced / intelligent measurement and network management;
- the communications subsystem that allows communication between networks (physical or wireless conductors), devices and applications established for their interoperability.

The second part of the chapter presents the factors that support the introduction of the concept of smart grid, starting from the need to modernize the power grids, given the major challenges they will face in the future. Smart Grid features were highlighted in the context of online monitoring of power lines and stations, Smart Grid domains and the actors involved, as well as the benefits of such networks, from the following perspectives: secure and continuous power supply, reliability and electricity quality, energy efficiency, improving environmental factors and reducing the overall operating costs of the network through the use of advanced technologies.

Main objectives for the introduction of Smart Grid in the Romanian energy system:

- the elimination or significant reduction of damage to equipment and / or high voltage installations that may affect other equipment and cause interruptions in the cascade;
- the elimination of the causes and factors that lead to the destruction of high voltage equipment and / or installations, which can affect buildings, people and the environment, can cause power outages on large areas and significant economic losses;
- increasing the service life of all active components in electricity transmission and distribution systems to their limits and even beyond;
- increasing the reliability / availability and safety of the energy system;
- knowing as soon as possible where and when a problem occurred;
- reduction of maintenance costs;
- increase the speed and efficiency in the use and management of technical information even if the staff is less qualified or reduced in number;
- increasing security in the supply of consumers;
- increasing the capacity of the network;
- implementation of means to improve monitoring and electricity networks.

The benefits of making smart grids:

- continuous supply of electricity and safety of electricity networks;
- fewer and much shorter interruptions, self-healing energy systems, through the use of digital information and automatic and autonomous control systems;
- Smart Grid networks are much more efficient, ensuring total energy consumption, peak consumption and lower energy losses;
- many of the operating costs are reduced or avoided;

Chapter 3 highlights the need for online monitoring of high voltage overhead power lines as part of the implementation of Smart Grid. The technical-applied researches carried out so far are presented, which took into account, on the one hand, the deficiencies and defects that appear in the operation of power lines due to various causes, which are often not discovered immediately, but after thorough investigations. and long-term, on the other hand, congestion in transport systems that are sporadic and difficult to predict, congestion that must be overcome with minimal effect, where network development is difficult to achieve.

The main field of technical-application research was intelligent networks for real-time monitoring and control of the transfer of energy flow from producers to final consumers (Figure 3.1.1), with specific reference to the online monitoring of high-power overhead lines. voltage at current technical requirements.

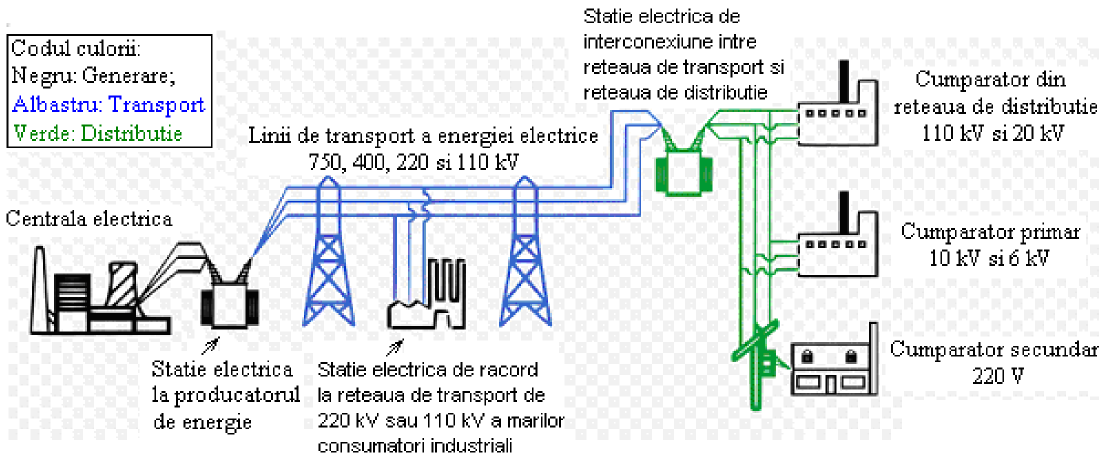


Fig. 3.1.1. Schematic diagram of the transfer of electricity from producers to consumers

The need for online monitoring of the OHL is motivated by the following aspects:

- deficiencies and defects that occur in the operation of power lines due to various causes;
- congestion in transport systems is sporadic and difficult to predict;
- structural congestion must be overcome with minimal effect, where network development is difficult to achieve;
- the existing transmission system is not adequate to dispatch new time-varying sources of energy generation, wind and photovoltaic.

Online monitoring must take into account the specific features of the electricity sector [Barth2008], [CIGRE2010], [Cloet2011], [Dai2013], [Doug2014]:

1) online monitoring systems must be able to integrate both old and new primary voltage power lines and equipment;
2) the incidents and defects produced at the primary high voltage power lines and equipment imply a period of time necessary to pass from the initiation phase to the emergency / incident phase, they can be detected / notified at an early stage by online monitoring;
3) failures can occur in cascade, causing power outages on large areas and significant economic losses;
4) power outages can instantly affect a large number of critical infrastructure sectors.

For transport operators, the need and opportunity to carry out online monitoring of high voltage OHLs is determined by the following factors [Reid2002], [Doug2014]:

1) obtaining real-time data on operating parameters and technical status;
2) providing advance warnings in case of operating problems near or above the permissible limits of conductor temperature, arrow, traction force, oscillations of the conductor and inclination of the pole above the alarm limit;
3) fast reaction time for unforeseen situations and increased ability to react to bad weather;
4) the correlation between the degree of actual charging of the power line, the designed charging capacity and the weather conditions (for the application of the dynamic charging mode of the power line - DLR);
5) elimination of unnecessary and often risky interventions;
6) minimum network interruptions in order to remedy some malfunctions notified in time;
7) obsolete installations / equipment and / or low investment budgets make it mandatory to increase the operating life of all active components of the OHL in the RET up to the limit of the operating life and even beyond;
8) the increasing costs for the elimination of technical restrictions and internal congestion of the electricity network (by implementing Smart-Grid systems, which include equipment for monitoring OHL parameters, these costs can be reduced by half).

Here are some examples of damage to Romanian power lines, consisting of triggers caused by severe weather conditions, damage caused by environmental action and material aging, line failures subject to special mechanical stress due to harsh weather conditions (strong wind, frost, very low temperatures).

During the operation of high voltage overhead power lines, a series of defects appeared due to various causes, often not immediately identified or difficult to identify:

- triggers due to severe weather conditions;
- faults determined by the action of the environment and the aging of the material (fig. 3.1.2);
- faults of the lines subjected, in certain periods of the year, to special mechanical efforts due to extremely harsh climatic conditions (strong wind, frost, very low temperatures), such as OHL 400 kV CNE Cernavoda - Gura Ialomiţei, CNE Cernavoda-Pelicanu, Ţânţăreni- Sibiu Sud, Bradu-Ţânţăreni, Gutinaş-Braşov, 220 kV OHL Portile de Fier - Resita, Paroşeni-Târgu Jiu, Lotru-Sibiu Sud and others (fig. 3.1.3).
- failures of OHL components for which there was no storage and processing of detailed information about the environment and their condition, such as: poles, active conductors, insulator chains, etc .;
- reduction of the overhead line of the overhead power lines due to the vegetation and / or the constructions under or near the line conductors;
- vandal actions on high voltage poles (by cutting anchors or metal structures of the pole) which caused the interruption of power lines and significant economic damage.

a)

b)

Fig. 3.1.2. 400 kV OHL: 400 kV pole that fell during a snowstorm
due to the rupture of the eclipses holding two anchors to the underground foundation

a) b)

Fig. 3.1.3. 220 kV OHL: Metal poles affected by very strong winds

At the same time, this chapter focuses on the presentation of the operating and technical status parameters of the OHL, as well as the presentation of the equipment or systems for online monitoring of the OHL, currently existing in the world, depending on the methods used to determine the operating parameters.

In order to optimize the operation of electricity transmission and distribution systems, it is necessary to install systems for monitoring the functional parameters and local climatic conditions. These systems include high-sensitivity sensors, which can transmit real-time information on the OHL [CIGRE2016].

In order to establish the operating conditions of the high voltage OHL and the possibility of applying their Dynamic Line Rating (DLR) technology, the following parameters are important that define the technical state of operation of an OHL:

- current intensity through the active conductor of the line;
- line conductor temperature;
- line conductor arrow;
- tension / traction force in the line conductors;
- line conductor oscillations.

The mentioned parameters, referring to the operation of high voltage OHL, are strongly influenced by the weather conditions:

1) ambient air temperature near the OHL conductor;
2) wind pressure and direction in relation to the direction of the OHL;
3) solar radiation;
4) deposits of frost or ice on the OHL conductor.

For the online measurement and monitoring of the above mentioned parameters, there are international high-voltage OHL online monitoring systems, which are divided into two categories, depending on the methods used to determine the parameters:

a) direct methods;
b) indirect methods.

Currently, there are at least 20 commercial types of online OHL monitoring systems on the international market, some more complex and some simpler, each of which differs depending on several factors:

a) the type and number of sensors for direct measurement of the mentioned OHL parameters (tables 3.3.1, 3.3.2 and fig. 3.3.1);
b) the measured technical characteristics, the field and the measurement accuracy;
c) the power supply mode, etc.

Direct monitoring equipment obtains data on line characteristics through one of the following variables: conductor arrow, traction force in line conductors, conductor gauge / arrow or conductor temperature. Direct monitoring systems typically use additional inputs from an environmental monitoring system to calculate operating parameters. The monitoring equipment is installed on the OHL, from where it transmits the data directly or through an Intelligent Electric Device (IED) mounted locally on one of the poles, to the management and control system.

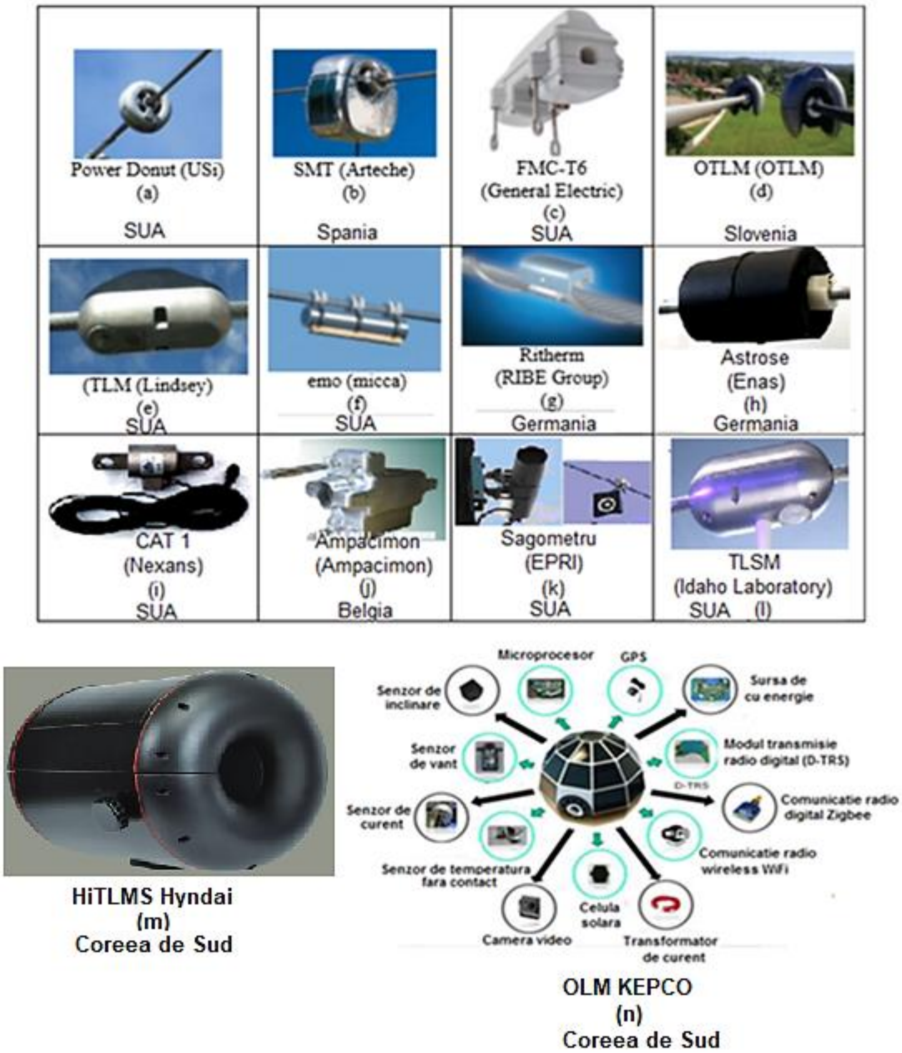


Fig. 3.3.1. Types of commercial systems based on / and temperature monitoring of the OHL conductor (positions a, b, c, d, e, f, g, h, i, j, l, m, n) (examples)

Indirect measurement methods are based on the measurement of the parameters of the environment along the line and on the fact that the value of the current on the OHL is known from the measurements in the station.

Monitoring systems can have different functions. Some of them are used for on-line monitoring of weather conditions and / or for measuring the temperature of the OHL conductor and / or for measuring the current through the OHL conductor and / or for measuring the arrow of the OHL conductor and / or for measuring the voltage in the OHL conductor.

Table 3.3.1. OHL operating parameters, measured directly by the monitoring system

No.	Type of monitoring system	OHL conductor temperature	Current inside conductor	Tilt angle of the conductor	Conductor arrow	Traction force in the conductor	Conductor oscillations
1	Power Donut (USA)	x	x	x			
2	SMT (Spain)	x	x				
3	OTLM (Slovenia)	x	x				
4	TLM (USA)	x		x			x
5	FMC-T6 (USA)	x	x				
6	Emo (USA)	x					
7	Ritherm (Germany)	x					
8	Astrose (Germany)	x	x	x	x		x
9	CAT1 (USA)					x	
10	Ampacimon (Belgium)						x
11	Sagometru (USA)				x		
12	TLSM (USA)	x	x				
13	OLM (South Korea)	x	x	x	x		

Table 3.3.2. Influence of the type of monitoring equipment

No.	Type of system monitoring (measured parameter)	Cost				Precision				
		Cost of purchase	Cost of building	Maintenance costs	OHL disconnection is necessary for installation	Measuring domain	Normal wind High current on the OHL	Normal wind Low current on the OHL	Low wind High current on the OHL	High wind Low current on the OHL
1	OHL conductor temperature	Medium	Medium	Medium	No(*)	Variable	Medium	Low	Medium	Medium
2	Current inside conductor	Medium	Medium	Medium	No( )	Punctual	Medium	Low	Medium	Medium
3	Tilt angle of the conductor	Medium	Medium	Medium	No(*)	Multiple opennings	Medium	Medium	High	Medium
4	Conductor size	Medium	Medium	Medium	No(*)	Multiple opennings	Medium	Low	Medium	Low
5	Traction force in the conductor	Medium	High	High	Yes	Multiple opennings	Medium	Low	High	Medium
6.	Environmental parameters	Medium	Low	Low	No	Variable	Medium	Medium	Low	Medium
7.	Combined	Medium	Medium	Medium	Yes	Multiple opennings	Medium	Medium	High	Medium

NOTE: (*) the assembly can be done with the line under voltage or unplugged (a short period of time-maximum one hour).

From table 3.3.2. the following important conclusions are taken:

- each method of measuring and monitoring the operating parameters of the high voltage OHL has advantages and disadvantages;
- he method based on measuring the driver's arrow provides the most advantages;
- to reduce the risk of incorrect assessment of the operating parameters of an OHL, the basis for the application of the dynamic charging mode of the line, electricity companies use monitoring equipment that has at least three sensors for simultaneous measurement (usually current, temperature and inclination), to which is added the weather station, and for difficult operating situations can be added the sensor for measuring the traction force.

Chapter 4 aims to introduce and theoretically develop OHL dynamic loading (DLR) technology using several online measurement / monitoring and forecasting techniques available.

First, a series of considerations regarding the DLR regime are reviewed, the purpose of assessing the technical condition of the OHL and the application of this technology, highlighting the difference between the static regime and the dynamic line loading regime, as well as the factors affecting the thermal load capacity of the lines. The final objective of the chapter is to present the charging regimes of the OHL (static, respectively dynamic), mentioning the critical parameters to be followed, especially in the case of the dynamic charging regime, and the benefits of DLR technologies.

The need to reduce congestion in electricity transmission networks and the increased use of transmission system infrastructure has led Electric Transmission System Operators (TSOs) to conduct investigations into appropriate measures to achieve these objectives. In addition, for TSOs, the construction of new transmission lines is not a simple procedure, due to strict environmental regulations, but also to high investment costs. One of the possible options identified is based on the application of DLR technology of the line by using several online measurement / monitoring and forecasting techniques available [Puf2012], [Wang2014].

The related data acquisition is very often combined with meteorological measurements. With both pieces of information available, they can be used in a process of obtaining variable limits on the operating parameters of a transmission line using predicted data on cooling or heating of the environment, as well as data on wind direction and speed as factors. input majors [WMO2008], [CIGRE2010].

DLR implementation is an important and promising solution, replacing the static charging mode. The static line loading regime is based on certain rather conservative assumptions regarding the atmospheric operating conditions [Pohl2000]. The need and purpose of the introduction and use of DLRs is to safely use the existing high voltage OHL carrying capacity, based on the actual conditions under which they operate [Doug2014], [EPRI2013], [Falc2015], [Mold 2016], [Step2012], [USDE2014].

A crucial difference between the static charging mode and the dynamic charging mode of the lines is that the "static current" is calculated on the basis of fairly conservative atmospheric conditions, while the dynamic mode takes into account the actual atmospheric conditions, which they often provide better cooling and thus allow a higher "dynamic" current.

Calculating the dynamic loading regime of a transport OHL is a difficult task, as it has to solve two inherent problems:

- determination of the thermal limit current for a certain section of line, which may involve different measurements and different calculation techniques;
- determination of the weakest line section, ie the section that represents a limitation for the entire power line, which means that the determination of the thermal limit current for all sections has been performed.

Figure 4.2.1 describes the main factors that influence the load capacity of an OHL, for a typical corridor. It is observed that the same conductor temperature can be reached with low load in hot environment and light wind or with high load in low ambient temperature and strong wind.

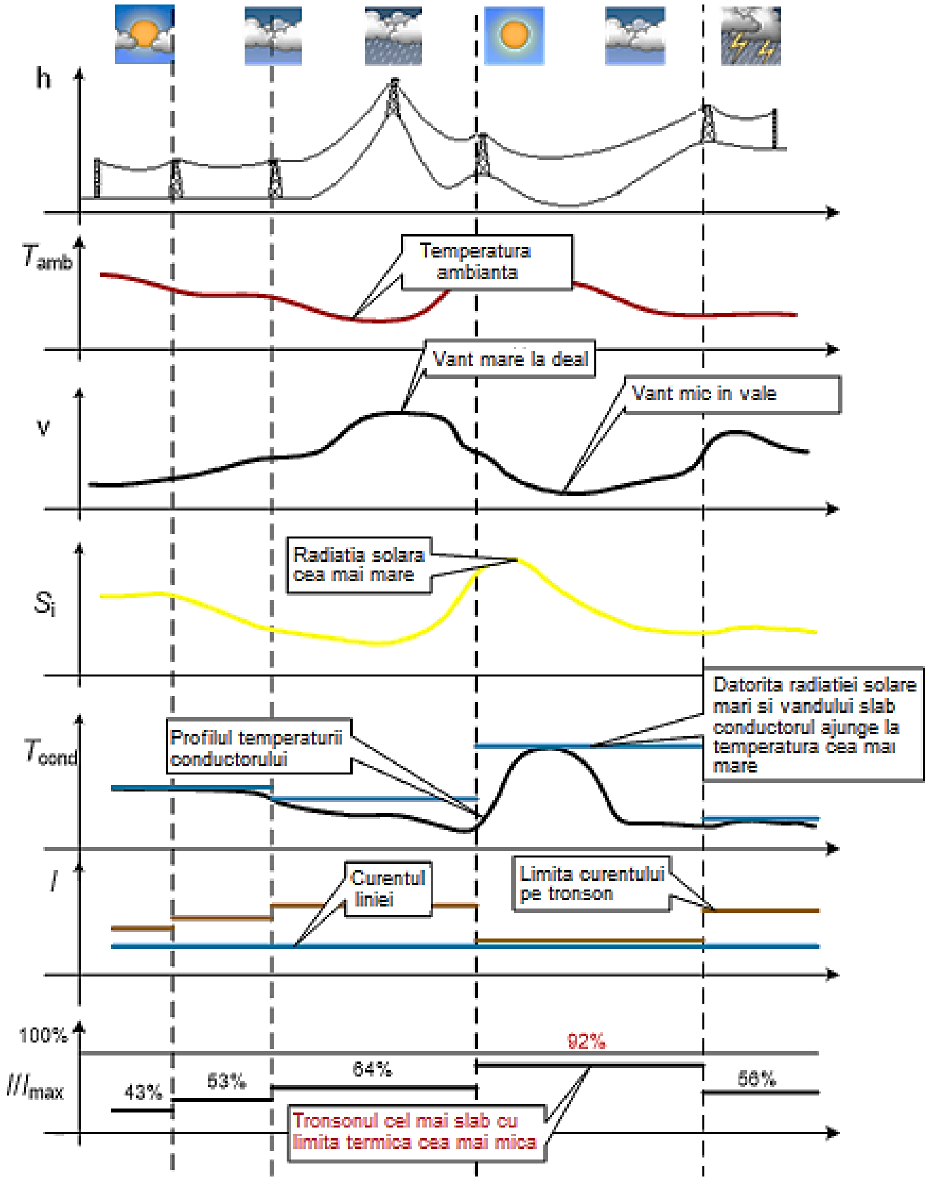


Fig. 4.2.1. The variety of factors that influence the carrying capacity of a transport OHL

As a result, European TSOs have concluded that temperature monitoring for DLR purposes is not sufficient, as line loading and weather conditions are completely unrelated.

The dynamic charging mode of the line is based on the evaluation of the maximum permissible current from the thermal point of view of the line (amplitude) in real time, obligatorily taking into account the atmospheric conditions along the overhead power line, as they define the conditions. of the conductor of the line [Gran2010], [IEEE2012].

The thermal capacity of an OHL is determined by the maximum current that the line can carry / the maximum allowable thermal current (line amplitude), without overheating and other side effects, in ideal conditions for the environment of the line [IEEE2012b].

The factors that limit the magnitude of the current through the OHL conductor are:

- conductor temperature;
- effects of temperature on the line;
- environmental parameters:
  - ambient air temperature;
  - wind speed and direction;
  - solar radiation;

In the international practice of operating high voltage overhead power lines, two charging lines are used: static and dynamic (Fig. 4.4.1).

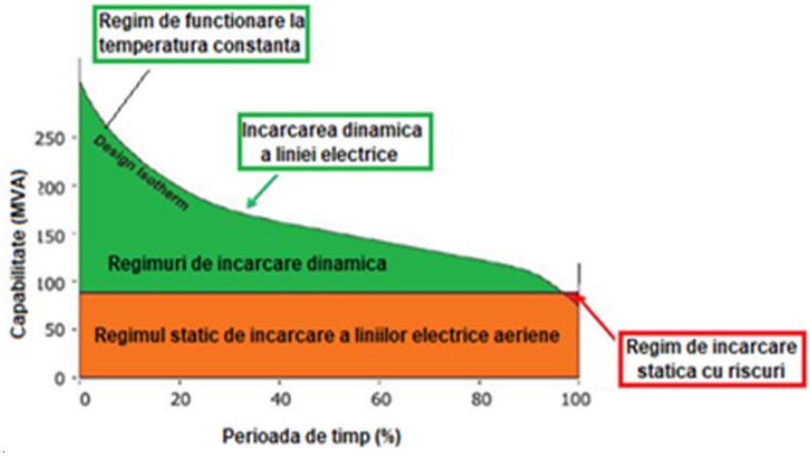


Fig. 4.4.1. Static and dynamic loading regimes of an OHL

In static mode, the line can be charged up to the maximum value of the current that is constantly transported, taking into account the following factors:

- safety and security in operation of the line;
- constructive parameters of the line conductor (Figure 4.4.2);
- the most unfavorable environmental conditions: ambient temperature: 35° C or 40° C; wind speed: 0.6 m/s; wind direction: 90° to the conductor; solar radiation: 1,000 W / m^2; conductor absorbance: 0.6.


Conductoare din otel-aluminiu
Aluminium Conductors Steel Reinforced
ACSR
CATALOG IPROEB
Conductoare din otel-aluminiu, conform CEI 61089-1991
ACSR, Aluminium Conductors Steel reinforced, according to CEI 61089-1991

Tip conductor	Sectiune			Otel		Aluminiu		Conductor		Forta de rupere nominala	Rezistenta electrica la 20 °C	Capacitatea de transport a curentului
	Aluminiu	Otel	Totala	Numar sarme	Diametru	Numar sarme	Diametru	Diametru	Masa			
Code	*Cross sectional area*			*Steel*		*Aluminium*		*ACSR*		*Breaking Load*	*Resistance at 20 °C*	*Current carrying capacity*
	AL	*ST*	*ACSR*	*No. of wires*	*Diameter*	*No. of wires*	*Diameter*	*Diameter*	*Weight*			
	mm²	mm²	mm²		mm		mm	mm	kg	N	Ohm/km	A

400	400	27.70	428.0	7	2.24	45	3.36	26.90	1320.1	98360	0.0722	1169
400	400	51.90	452.0	7	3.07	54	3.07	27.60	1510.3	123040	0.0723	1177
450	450	31.10	481.0	7	2.38	45	3.57	28.50	1485.2	107470	0.0642	1261
450	450	58.30	508.0	7	3.26	54	3.26	29.30	1699.1	138420	0.0643	1271
500	500	34.60	535.0	7	2.51	45	3.76	30.10	1650.2	119410	0.0578	1351
500	500	64.80	565.0	7	3.43	54	3.43	30.90	1887.9	153800	0.0578	1362

Nota: Capacitatea de transport a curentului, in cazul acestor conductoare a fost calculata folosind urmatoarele valori pentru conditiile de mediu (conform Publicatiei Comisiei Electrotehnice Internationale IEC 61597 TR 3-1995):

Viteza vantului :	1 m/s
Intensitatea radiatiei solare :	900 W/m^2
Coeficient de absorbtie solara :	0.5
Emisivitatea in raport cu un corp negru :	0.6
Temperatura aluminiului :	353 K (80 °C)
Temperatura mediului ambiant :	293 K (20 °C)

*Ampacity rating based on 20°C ambient, with 900 W/m^2 solar heating and 1m/sec wind, 80°C conductor temperature, 0.6 coefficient of emissivity, 0.5 coefficient of solar absorptivity.

Fig. 4.4.2. Conditions for defining the amplitude of the OHL conductor by the conductor manufacturer

Disadvantages of the static regime are observed in Table 4.4.1, where under certain weather conditions the line can be loaded above the limit value set for a static loading regime, which takes into account the ambient temperature of + 40 ° C and a maximum allowable thermal current of 787 A.

Table 4.4.1. Steel-aluminum conductor (ACSR) amplitude change
for a static charge of 787 A at an ambient temperature of 40 ° C

No.	Influence of environmental parameters (example)	Variation of line ampacity (%)	New ampacity (A)
1.	**Environmental temperature**		
	2 °C fluctuation	± 2	
	10 (°C) environmental temperature decrease	+ 11	874
2.	**Solar radiation**		
	Cloudy / clear sky	± a few percentage	
	Midnight	+ 18	929
3.	**Wind speed increase with 1 m/s**		
	Wind direction at an angle of 45 (°) to the OHL conductor	+ 35	1.060
	Wind direction at an angle of 95 (°) to the OHL conductor	+ 44	1.130

In the dynamic operation mode of the OHL, the charging of the line is estimated in real time and can be done up to the maximum value of the current at which there is certainly no thermal defect, for the current environmental conditions. Usually IDLR> Static

The DLR mode requires online monitoring of the line and environmental parameters. The critical parameters to be followed in the case of the dynamic loading regime are the following:

a) conductor temperature;
b) the arrow / ground gauge of the line conductor;
c) thermal operating limits for the overhead power line and for the equipment in the power stations connected in series to the same power line with the overhead power line: current transformers, switches, separators, busbars in the station;
d) the parameters of the environment.

In the dynamic charging mode of the line, the maximum thermal allowable current (ampacity) of both the line and the equipment in the station to which the line is connected are taken into account (switches, separators, current transformers, busbars), fig. 4.4.3.

The technological scheme for the application of the dynamic loading regime of the OHL is presented in figure 4.4.4.

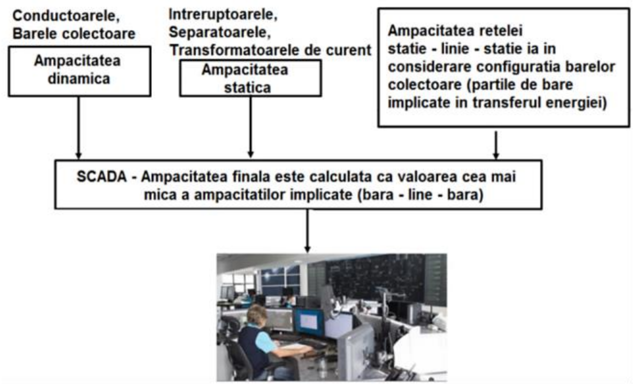


Fig. 4.4.3. Factors influencing the amplitude of an overhead power line

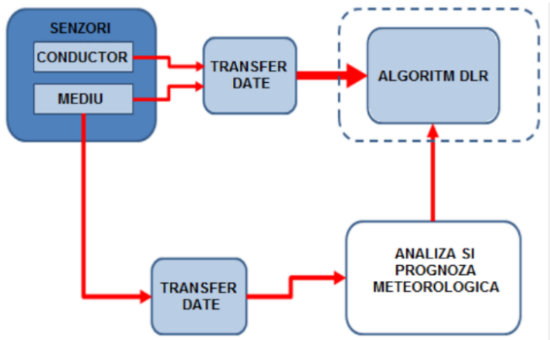


Fig. 4.4.4. Technological scheme for the application of the dynamic loading regime of the OHL

The benefits of using DLR technologies are:

- increasing the reliability of the electricity network;
- reducing the weakening of transport capacity during congestion;
- optimized use of assets and additional income from existing assets;
- better prices for consumers;
- better market access for wind turbines;
- well-informed decisions of system operators based on real-time transmission capacity of power lines;
- rapid integration of distributed energy resources;
- improving the knowledge of the situation in a wide area;
- increasing the economic efficiency of power lines;
- avoiding the costs of building new power lines just to meet the requirements for short periods of time in a year;
- reduction of overall costs for upgrading power lines due to their multi-year extension.

The outstanding economic efficiency of the current application of the dynamic charging mode of overhead power lines is also mentioned (see the data in Table 4.5.1 resulting from the experience of the US electricity company ONCOR).

Table 4.5.1 Experience applying the dynamic charging mode of overhead power lines

No.	**Line type**	**Description of the alternative solution**	**New ampacity (% relative to the static one)**	**Cost/km (USD)**
1	138 kV grills, wooden H structure	Aluminum conductor with composite core reconducting (ACCC)	193	201.157
		DLR	110	35.125
2.	138 kV, wooden H structure	Upgrade to 125 °C Structural improvements	130	6.600
		Upgrade to 125 °C Structural changes Reconstruction	 130 209	 4.325 468.750
		DLR	110	18.420
3	138 kV, wooden H structure	Reconstruction	140	148.670
		DLR	110	10.480
4	138 kV, wooden H structure	Reconducting	212	468.750
		DLR	110	17.700
5	345 kV grills	Raising the height of the structure	120	46.000
		DLR	110	16.641

Chapter 5 aims to present the details regarding the implementation of the monitoring systems of the functional and state parameters of the OHL. In the first subchapter, after stating the objectives, indicators and coordinates that underlie the operation of the transmission network,

a critical analysis is made of the currently existing monitoring systems at the international level. The systems described and analyzed in this subchapter are: Power Donut (Doors, USA), ASTROSE (The Fraunhofer Institute - ENAS, Germany), HiTLMS (Hyundai, South Korea), OLM (Kepco Research Institute, South Korea), TLSM (Idaho Laboratory Inc., USA), SMT (Arteche Groupe, Spain), Ampacimon (Ampacimon, Belgium), OTLM (OTLM, Slovenia), LINEAMPS (Electrotech, USA) and CAT 1 (The Valley Group Inc / Nexans, USA). Along with the description of the composition of each system, the advantages / disadvantages of each are presented, the subchapter concluding with some conclusions regarding their realization and efficiency.

Data presented in subchapter 5.1 show the following:

a) the systems differ significantly from each other in terms of technical-constructive solution, technical performance and purchase price, maintenance price, etc.
b) there is intense publicity and incisiveness in terms of market dominance by certain manufacturers of simplistic monitoring systems (eg for Ampacimon, CAT 1 etc.), technically and economically incomparable products with the complex type mentioned (e.g. products Donut, Astrose, HiTLMS, OLM, TLSM, etc.).
c) the redundancy and security of the data resulting from the online measurement and monitoring of the operating parameters of the high voltage overhead power lines, justifies the confidence of the electricity transmission companies in the application of the dynamic charging and operation regime of the existing power lines, with considerable economic effects.

Given that the systems described and analyzed in Subchapter 5.1. differ significantly from each other in terms of technical-constructive solution, in subchapter 5.2. the principles underlying the technical specification for the Romanian on-line monitoring system, proposed in the thesis (NOVA OHLM) are defined:

1) the system must directly measure, in real time, the main operating parameters of the high voltage OHL (current through the OHL conductor and on the line, conductor temperature, conductor arrow), similar as in the case of intelligent Power Donut and TLSM monitoring systems (USA), Astrose (Germany), HiTLMS and OLM (South Korea), etc .;
2) the system must also allow the measurement of the traction force in the line conductor (s) and in the insulator chain (s), similar to the CAT1 (USA) and OLM (South Korea) monitoring systems;
3) the system must also measure the oscillations of the conductor of the OHL, highlighting the situations of galloping of the conductor, when the operation of the OHL requires special attention, similar to the monitoring systems TLSM (USA) and Astrose (Germany);
4) the system must be able to measure the inclination of the column, similar to the OLM (South Korea) monitoring system;
5) the system must allow, optionally, the integration of the module for measuring the leakage currents on the isolator chains related to the OHL, for highlighting the corona discharges, similar to the OLM system (South Korea);
6) for the application of the dynamic charging regime of the OHL, the monitoring system must also include a weather station module;
7) the system must allow the measurement of the inclination of the OHL conductor for two measuring ranges;
8) the system must be able to measure and monitor the main operating parameters of the power line and when the line is poorly charged or is withdrawn from operation.

This last requirement determines the need for two independent sources of self-power supply inside the module mounted directly on the line conductor and at the potential of the OHL conductor:

- a power supply from the current transformer;
- the second is powered by a battery (self-charging from the first source).

The duration of the measurement of the parameters when the line is poorly loaded or decommissioned must be specified as realistically as possible as it determines the sizing of the self-power supply of the module at the potential of the line. The maximum duration is 12 hours.

Subchapter 5.3 outlines the technical specification for the monitoring system proposed in the thesis, specifying the reference standards and technical conditions for the implementation in Romania of the on-line monitoring system of 110-750 kV OHL, so that it can be part of the integrated Smart Grid type for online monitoring and diagnosis of the current technical condition of the OHL. The technical specifications are designed in such a way that the monitoring system ensures the measurement of the main operating parameters of the OHL and the parameters of the environment in the OHL corridor.

The technical characteristics of the Romanian OHL monitoring system were established through a reunion of the best technical characteristics of the systems currently existing in the world. The subsystems of the Romanian OHL monitoring system are presented in table 5.3.3.

Table 5.3.3. Subsystems of the complex OHL monitoring system

No.	**Subsystems**	**Monitored parameters**		**Caracteristics**
1	Subsystem for monitoring line operating parameters	OHL transport capacity		0 ÷ 1500 [A]
		OHL transport capacity /phase		N(*) x (0 ÷ 1500) [A] (*) N is the number of conductors per phase
		OHL active conductor temperature	Standard variant	-40 ÷ +150 [°C]
			Variant for OHL with increased operating temperature	-40 ÷ +250 [°C]
		Tilt angle / arrow of the active conductor (determined indirectly by measuring the angle of inclination)	Standard variant	± 10 [°]
			Special variant (2 sensors)	± 10 [°] and ± 90 [°]
		Conductor oscillations:	Acceleration	± 2 [g]
			Conductor oscillation measurement range	± 90°
		Traction in conductor	Capacity	250 [kN]
			Precision	± 1 [%]
			Permissible overload	150 [% F.S.]
			Breaking load	>300 [% F.S.]
		Video camera mounted on a pole, for images along the OHL, in the mounting area of the monitoring system (video sachometer - optional)		DA
		OHL pillar tilt sensor	The range of variation of the inclination	± 90 [°]
2.	Subsystem for monitoring operating environment parameters	Air temperature		-40°C - +80°C
		Relative humidity of the environment		0 ÷ 100 %RH
		Atmospheric pressure		60 ÷ 110 kPa
		Wind speed and direction		0,1 ÷ 60 m/s
		Liquid precipitation		
		The duration of the rain		$\geq$10 s
		The intensity of the rain		0 - 200 mm/h
		Solar radiation [W/m^2]		0 - 1.400 W/m^2
		Hoar/Ice (prezenţa)		$\geq$0.05 mm of ice
3.	Module for acquisition, processing, local storage of monitored data (IED)	Number of entries for data acquisition		Corresponding to the needs of monitoring the OHL
		Frequency of data acquisition:		Corresponding to the needs of monitoring the OHL
		In normal operation		at intervals determined by time
		In case of incident or undesirable phenomena		online
		Local storage capacity of all purchased data for a period of at least 30 days		minimum 30 days

No.	Subsystems	Monitored parameters	Caracteristics
4.	Communication mode / data transmission	GSM	GSM
		Wireless	Wireless to fiber optic junction box
		Optical fiber	In the fiber optic network of CNTEE “Transelectrica” - SA
5.	modules independent power supply	Independent power supply of the electrical and electronic components related to the module mounted on the OHL conductor	Source 1, supplied from the secondary of the current transformer
			Source 2, battery powered
		Independent power supply, for the components of the monitoring system mentioned, mounted on the pole)	Power supply from an independent photovoltaic source with storage battery
6.	Specific software programs	Application software	The monitoring system software will allow you to set minimum, maximum, and various thresholds, or status values, for all monitored sizes
		Client software	The software will present the values of the monitored parameters, both as instantaneous values and their evolution over time

Chapter 6 contains a description of the local system for online monitoring and dynamic loading of OHL (OHLM). After the first subchapter which contains some general considerations regarding the OHLM equipment, and subchapter 6.2 presents its architecture, with the description of each component part (fig. 6.2.1).

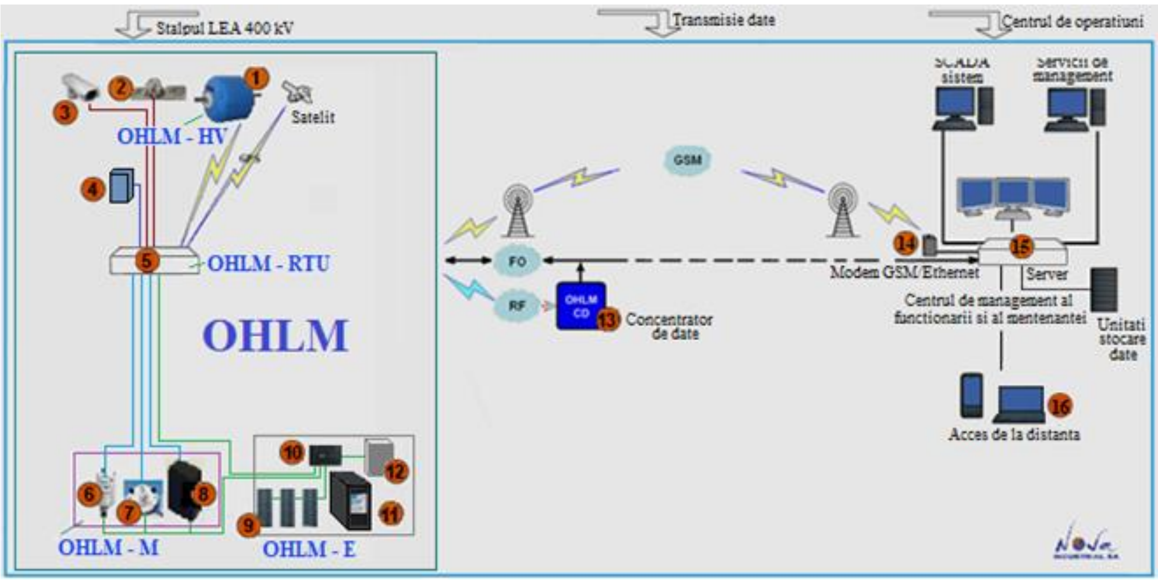


Fig. 6.2.1. Nova OHLM system architecture

The meanings of the notations in figure 6.2.1 are:

- OHLM-HV (1) is the module at the potential of the OHL conductor, for measuring the operating parameters of the OHL, which includes the following main elements: current measuring transformer, temperature transducers (2 pcs.), tilt angle (2 pcs.), conductor oscillation sensor, independent sources (2 pcs.), self-powered, for powering electrical / electronic and IT components;
- OHLM-T (2): the module for measuring the traction force in the OHL conductors;
- OHLM-V (3): for viewing and photo images along the OHL;
- OHLM-H (4): module for measuring the angle of inclination of the column;

- OHLM-RTU / IED (5): module for acquisition, local storage processing, two-way remote communication and data transmission;
- OHLM-M: module for measuring the parameters of the environment, composed of the following main components: weather station (6), for measuring the parameters of the environment; pyranometer (7), for measuring solar radiation near the OHL conductor, apparatus (8) for measuring ice / frost deposition;
- OHLM-HV (1) is the module at the potential of the OHL conductor, for measuring the operating parameters of the OHL, which includes the following main elements: current measuring transformer, temperature transducers (2 pcs.), tilt angle (2 pcs.), conductor oscillation sensor, independent sources (2 pcs.), self-powered, for powering electrical / electronic and IT components;
- OHLM-T (2): the module for measuring the traction force in the OHL conductors;
- OHLM-V (3): for viewing and photo images along the OHL;
- OHLM-H (4): module for measuring the angle of inclination of the column;
- OHLM-RTU / IED (5): module for acquisition, local storage processing, two-way remote communication and data transmission;
- OHLM-M: module for measuring the parameters of the environment, composed of the following main components: weather station (6), for measuring the parameters of the environment; pyranometer (7), for measuring solar radiation near the OHL conductor, apparatus (8) for measuring ice / frost deposition;
- OHLM-E: independent source (photovoltaic), for the power supply of the components of the OHLM system mounted on the pole, composed of photovoltaic panels (9), charge controller (10), battery (11), degree monitoring system battery charging (12);
- Data concentrator (installed in the RTU box).

The OHLM subsystem for on-line monitoring of OHL operating and technical parameters consists of:

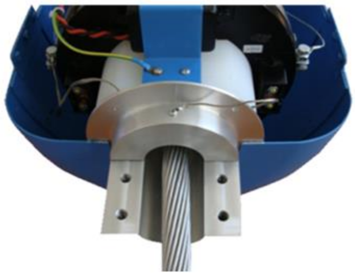
- the module mounted on the OHL conductor containing the temperature sensor (2 pcs.), The tilt sensor, the acceleration sensor, the current transformer for measuring and self-powering with electricity, the electronic module for measuring and processing data;
- dynamometric traction force sensor;
- the video gauge for determining the arrow / gauge of the OHL conductor;
- remote data acquisition, processing and transmission unit (RTU);
- GPS module;
- communication module: fiber optic, radio, GSM / GPRS.

Subchapter 6.3 describes the functional characteristics of the monitoring system, taking into account: the technical characteristics of the electricity transmission network, the climatic and environmental conditions in which the system will operate, the general conditions and the main technical characteristics that the system must meet. OHLM monitoring system, the signals it has to provide in the central data acquisition system and its software.

Subchapter 6.4 presents the constructional features of the OHLM system and describes each subsystem: the OHLM subsystem for monitoring the operating parameters of the OHL, the OHLM M subsystem for monitoring environmental conditions and the OHLM E subsystem (independent power supply).

The OHLM subsystem consists of:

- **The OHLM - HV** module (fig. 6.4.1) which is the result of the research carried out by the author together with the research team from Nova Industrial SA. It is arranged directly on one of the active conductors, on a phase of the OHL, ensuring on-line monitoring of the following operating parameters of the OHL: the temperature of the OHL conductor, by direct measurement; electric current through the OHL conductor, by direct measurement; OHL conductor arrow, by direct measurement of the conductor inclination angle; conductor oscillations, by direct measurement.

a) b)

Fig. 6.4.1. Nova OHLM - HV module on the ground

- **The OHLM-T module** includes the power transducers, mounted on the ground connection of the insulator chains, for the direct measurement and on-line monitoring of the traction force in the insulator chains and in the OHL conductors (fig. 6.4.4). The module must be composed of force transducers with a rated measuring capacity over the breaking force of the tension insulators and the line conductor.

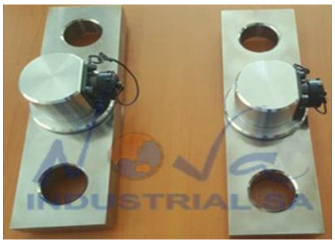


Fig. 6.4.4. OHLM-T module, transducers used for the pilot project
on the 400 kV OHL Bucharest South - Pelicanu

- **The OHLM-V module** includes a digital camera and an infrared illuminator, for viewing and obtaining photo images along the overhead power line (fig. 6.4.5). The camera case is of the sun visor type (for clear images in strong sunlight) and with its own heating (for proper operation of the camera at negative atmospheric temperatures down to -35 ° C). In the mentioned pilot project, the “Video Sachometer” method [EPRI2001], Nova Industrial variant, for determining the arrow of the OHL conductor (method patented by Electric Power Research Institute, Inc. - EPRI, USA) was also tested. The camera + illuminator + marker assembly was used to apply this method (fig. 6.4.5).

a) b)

Fig. 6.4.5. OHLM-V module - camera, illuminator and video marker marker

- **The OHLM-H module** (fig. 6.4.6) is made by Nova Industrial and ensures the measurement of the inclination of the column, in the measuring range ± 90 °.

Fig. 6.4.6. The OHLM-H module

➢ **The OHLM-IED / RTU module** (fig. 6.4.7) has the role of acquisition, processing, local storage and data transmission through optical fiber. Provides two-way communication with the server at the monitoring center, operational command and / or maintenance management.

Fig. 6.4.7. **OHLM-IED / RTU** module mounted on the 400 kV OHL pole Bucharest South **-** Pelicanu

The OHLM M subsystem for monitoring environmental conditions consists of:

a) **Weather station module**, figure 6.4.8, for online monitoring of the following meteorological parameters and prediction of their variation over a limited period of time: ambient temperature and humidity, wind speed and direction, barometric pressure, precipitation.

Fig. 6.4.8. OHLM M subsystem - weather station

b) **Pyranometer module.** For the measurement of solar radiation, the Nova OHLM system uses the pyranometer produced by Masa (Japan), fig. 6.4.9.

c) **Module for measuring frost / ice** deposited on the conductor. For the measurement of frost / ice deposited on the OHL conductor, the Nova OHLM system is ready to integrate the Ice Detector (UK) transducer, fig. 6.4.10.

Fig. 6.4.9. The Masa Pyranometer

Fig. 6.4.10. Ice Detector Module

The OHLM E subsystem (independent power supply) is an independent, photovoltaic, power source for powering the entire OHLM monitoring system located on the OHL pole / poles (in the grouped or distributed assembly line variant).

The NOVA OHLM E subsystem is composed of photovoltaic panels and a cabinet / cabinet in which they are included (fig. 6.4.11).

a) b)

Fig. 6.4.11. The Nova OHLM-E module is the independent power supply
of the entire monitoring system

Subchapter 6.5 introduces the OHLM software application, which is a client-server application and is developed in the Visual Studio.NET programming environment.

NOVA OHLM Server is an application that runs under the Microsoft Windows operating system and connects to a MySQL or Oracle database server;

NOVA OHLM Client is a web application, independent of the operating system used, developed using the Microsoft IIS web application server.

The NOVA OHLM software application allows:

- setting the threshold limit values and / or conditions for the parameters monitored online: nominal electric current through the line conductor; nominal line conductor temperature, maximum conductor arrow, maximum conductor tension, etc .;
- online data acquisition and processing;
- generating real-time warnings / alarms, when the limits of the parameters are exceeded;
- storing data in a local database (for a limited period of time) and in a PC server database in the active management / monitoring center (monitoring parameters, alarms / displacements, limit values and / or conditions, etc. .);
- display of measured parameters online, via a web interface, using an internet browser.

Each RTU integrates the data received from the module fixed on the OHL and from other sensors (eg from the weather station). The information purchased from these submodules is included in the data packet transmitted to the server. The NOVA OHLM Server application connects to the NOVA OHLM CD hardware module (data concentrator) that acquires data from one or more IEDs / RTUs (remote terminal units).

The server at the management center retrieves information on the monitored OHL parameters from one or more NOVA OHLM CD hubs, while each NOVA OHLM CD hub can acquire data from one or more RTUs (Fig. 6.5.1).

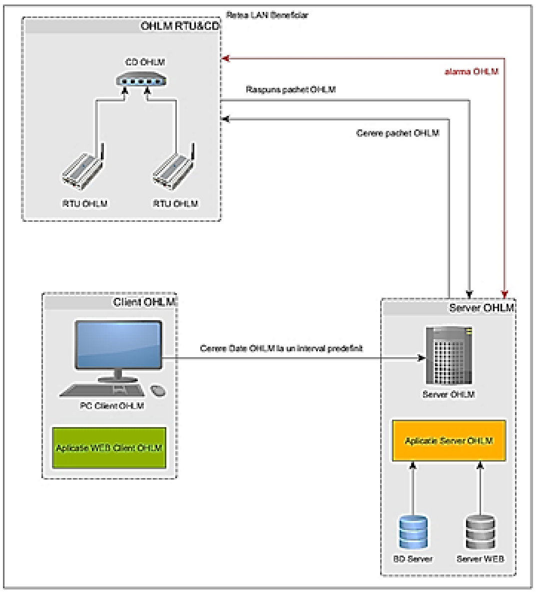


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Fig. 6.5.1. NOVA OHLM software architecture

NOVA OHLM client software allows users to access and view:

- online data for monitored poles and airlines (line and pole selection is done from two drop-down lists and the information is updated accordingly in visually distinct modules);
- current data report - report with instant information about the monitored values;
- historical data - information of the monitored parameters, tabular and graphical;
- data and self-test calculations;
- databases, etc.

OHL monitoring data are divided into the following main categories:

- OHL and pole data (OHL name, line type, conductor type, pole name, number of conductors per phase, latitude, longitude, etc.);
- weather data (ambient temperature, wind speed and direction, solar radiation, etc.);
- parameters and operating conditions of the OHL (data obtained from monitoring equipment - current through conductor, conductor temperature, conductor tension, arrow, frost data, oscillation data, etc .; data obtained by calculating OHL operating parameters using 4 modules that have as input the current through the conductor, the temperature of the conductor, the extension of the conductor or the arrow);
- alarms;
- OHL technical condition.

The chapter concludes with the presentation of the pilot project for on-line monitoring of the 400 kV OHL Bucharest South - Pelicanu, describing the architecture of the measurement system and the measurements performed, the results being particularly relevant in order to elucidate incidents accidentally produced at composite insulators. 400 kV, respectively in the 400/220/110 kV Bucharest South station.

The analysis of defective insulators found the following:

- the faults occurred at the end of the insulator at the high voltage potential;
- the defects were manifested by the breaking of two insulators at 2, respectively 3 rows / skirts of the metal end;
- on the surface of the insulator housing, between the metal end and the breaking area there are traces of high energy electrical discharges;
- at a distance of about 14 knots from the potential end, the rails and the housing are blackened by corona discharges.

The mentioned researches, carried out by the author in collaboration with Nova Industrial SA, used for the first time nationally and internationally the data and information obtained simultaneously from two online monitoring systems, in real time:

a) the Nova OHLM system for on-line monitoring of the operating parameters and technical condition of overhead power lines;
b) Nova Izomon system for on-line monitoring of leakage currents on high voltage isolator chains related to OHL and high voltage power stations.

The following online parameters were measured in real time:

- operating parameters of the 400 kV power line: current through the line conductor, line conductor temperature, line conductor arrow / gauge, line conductor acceleration;
- mechanical stresses and insulation at 400 kV composite insulators: traction force in line conductors and insulators, leakage current on insulators;
- parameters of the environment: ambient air temperature and humidity, wind speed and direction, atmospheric pressure, solar radiation.

The elements of the system used for measuring the electrical and mechanical parameters of the operation of the 400 kV overhead power line Bucharest Sud - Pelicanu and of the 400 kV composite insulators are presented in figure 6.6.2.

Following the measurements performed, the following conclusions could be summarized:

1) The pilot project, to which the author of the thesis contributed significantly, represents a national and international premiere, as it used on-line monitoring systems for the operation parameters of the OHL (in this case the Romanian NOVA OHLM system) and the on-line

monitoring system. line of leakage currents on 400 kV isolator chains (NOVA IZOMON system) as a technical solution Smart Grid applied concretely to solve operational problems of high voltage OHL management.

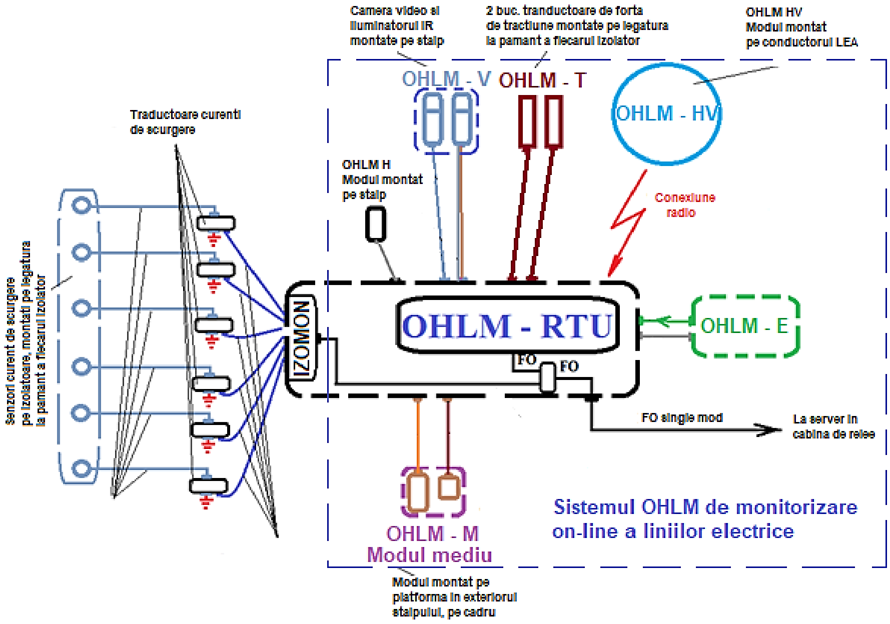

Fig. 6.6.2. The architecture of the measurement system used in the pilot project on-line monitoring of the 400 kV OHL Bucharest South - Pelicanu

2) Regarding the NOVA OHLM system, the following were found:
   a) fully complies with the technical requirements mentioned in the technical specification and in the Internal Technical Standard of CNTEE Transelectrica SA regarding the measured parameters and the measurement accuracy;
   b) the installation of the OHLM-HV module on the 400 kV OHL conductor is relatively easy and in a short time (maximum 30 minutes of work at height).
   c) for determining the arrow of the OHL conductor, the NOVA OHLM system allows the use of at least five methods;
3) The Ampacimon solution was tested, based on the indirect method consisting of measuring the acceleration, determining the fundamental frequency and calculating the arrow. The method errors determined arrow values higher than the other methods and above the limit imposed in the internal technical norm of CNTEE Transelectrica SA (± 5 cm). The results confirmed the information in the literature that errors in the determination of the arrow of ± 20 cm are to be expected with the Ampacimon method.
4) Among the methods tested in the project for measuring the arrow, the most accurate and safe is the one based on measuring the inclination angle of the OHL conductor (less than 5 cm);
5) For the determination of the current through the OHL conductor, the NOVA OHLM system allowed the use of 4 methods, the most accurate and reliable proving to be the one based on direct measurement.
6) To determine the temperature of the OHL conductor, the NOVA OHLM system allowed the use of at least 4 methods, the most accurate and safe method proving to be the one based on direct measurement.
7) The experience gained confirmed the opinion of specialists internationally, taken from the technical specification of the Nova OHLM system and the technical norm of CNTEE Transelectrica SA, according to which the online monitoring of the OHL operating parameters must be based on the simultaneous measurement of the three parameters. . mains (current through the OHL conductor, temperature of the OHL conductor and respectively the inclination of the OHL conductor) completed by on-line measurement of the environmental parameters. This minimizes possible evaluation errors, especially in situations of application of the DLR regime for the operation of the OHL.

8) The results required by the pilot project confirmed that the innovative NOVA OHLM system is a high-performance system, at least in terms of technical requirements and performance provided by the most advanced similar systems internationally manufactured in the USA, Germany, Korea. South, Spain, etc.
9) The on-line measurements performed at the 400/220/110 kV Bucharest South station and on the 400 kV Bucharest South-OHL OHL - Pelicanu demonstrated that the NOVA OHLM NOVA IZOMON monitoring systems can be used for multiple purposes in the electric transmission networks:
    - for on-line monitoring of 110-400 kV OHL operating parameters;
    - for the application of the DLR concept in the efficient operation of the existing power lines;
    - for on-line monitoring of the technical condition of electrical insulators, for obtaining useful information about the combined requirements to which composite insulators are subjected, etc.

Chapter 7 is entirely original and aims to present the technical data necessary for the application of the dynamic loading regime of the OHL (DLR) and the methods for establishing it. This framework details the calculation programs and steps required to implement the dynamic OHL loading regime:

- obtaining preliminary information and data for the analysis of the possibility and conditions of application of the dynamic loading regime (DLR);
- control of the veracity of the values of the operating parameters of the OHL measured online;
- establishing the type of DLR of the OHL and the admissible limits of its operation;
- validation of the DLR regime.

The last subchapter details the conditions for the introduction of the DLR regime. As mentioned in Chapter 4, the maximum allowable thermal current and thermal capacity of a high voltage OHL depend on several factors, as can be seen by analyzing the specific characteristics of the 400 kV OHL Bucharest South - Pelicanu:

1) the manufacturer of the line conductor;
2) the constructive type of the conductor: ALOLN 450/75 mm^2;
3) the constructive parameters of the line conductor (fig. 7.1.1)

Conductoare din otel-aluminiu, conform SF 35/1999
ACSR, Aluminium Conductors Steel reinforced, according to SF 35/1999

Tip conductor	Sectiune			Otel		Aluminiu		Conductor		Forta de rupere nominala	Rezistenta electrica la 20 °C	Capacitatea de transport a curentului
	Aluminiu	Otel	Totala	Numar sarme	Diametru	Numar sarme	Diametru	Diametru	Masa			
Code	*Cross sectional area*			*Steel*		*Aluminium*		*ACSR*		*Breaking Load*	*Resistance at 20 °C*	*Current carrying capacity*
	AL.	*ST.*	*ACSR*	*No. of wires*	*Diameter*	*No. of wires*	*Diameter*	*Diameter*	*Weight*			
	mm^2	mm^2	mm^2		mm		mm	mm	kg	N	Ohm/km	A
16/2.5	15.27	2.54	17.8	1	1.80	6	1.80	5.40	61.7	5800	1.8793	145
25/4	23.86	3.98	27.8	1	2.25	6	2.25	6.75	96.4	8950	1.2028	192
35/6	34.35	5.73	40.1	1	2.70	6	2.70	8.10	138.8	12370	0.8353	243
50/8	48.25	8.04	56.3	1	3.20	6	3.20	9.60	195.0	16810	0.5946	302
70/11	68.05	11.34	79.4	1	3.80	6	3.80	11.40	275.0	23360	0.4217	376
300/69	305.3	68.98	374.3	19	2.15	30	3.60	25.15	1384.7	129560	0.0947	1000
450/75	445.3	75.55	520.9	19	2.25	63	3.00	29.25	1823.4	164090	0.0649	1264
450/97	449.1	97.03	546.2	19	2.55	68	2.90	30.15	2002.5	186970	0.0644	1281
680/85	678.6	85.95	764.5	19	2.40	54	4.00	36.00	2550.8	206560	0.0426	1662

Capacitatea de transport a curentului, calculata pe baza urmatoarelor valori pentru conditiile de mediu (conform Publicatiei Comisiei Electrotehnice Internationale IEC 1597):

- 20 °C temperatura mediului ambiant;
- 900 W/m^2 intensitatea radiatiei solare;
- 1 m/s viteza vantului;
- 80 °C temperatura aluminiului;
- 0.6 emisivitatea in raport cu un corp negru;
- 0.5 coeficient de absorbtie solara;

Fig. 7.1.1. Constructive parameters of the OHL conductor type IPROEB ALOLN 450/75 mm^2

There is an important difference between the conditions in which the manufacturer guarantees the operating parameters of the line conductor and the conditions in which the dispatcher applies the static charging mode of the power line: ambient temperature - 35 °C or 40 °C; wind speed - 0.6 m/s; wind direction -90 °C to the conductor; solar radiation - 1,000 W /m NOVA; conductor absorbance: 0.6.

The steps of applying the dynamic charging mode of the power lines are the following:

Step 1. Obtaining information and preliminary data for the analysis of the possibility and conditions of application of the dynamic loading regime: general data about the OHL; data on OHL design parameters; data on OHL operating and status parameters, measured and monitored online; data on the equipment at the power line end stations, connected directly to the line

Step 2. Checking the accuracy of the values of the operating parameters of the overhead power line measured online.

Step 3. Determining the type of dynamic load regime (DLR) and the permissible operating limits of the OHL.

Step 4. Validation of the DLR regime

In this step, it is determined that an overhead DLR charging regime is validated if the following conditions are met simultaneously:

a) a) the charging current of the OHL in DLR mode (I_{DLR}) is lower than the maximum current allowed on the OHL from the thermal point of view and by the equipment in the station inserted with the OHL $I_{DLR} < I_{lim}$;

b) OHL operating temperature $(T_{fDLR}) \leq (T_{ncOHL})$;

c) OHL operating gauge $(G_{fDLR}) < (G_{limita})$;

Six examples of the application of the dynamic charging regime of an OHL according to the predicted parameters of the environment are presented, for pre-established initial conditions:

- the maximum permissible charging current of the line conductor is 1264 A;
- the thermal limit current allowed by the station equipment on the OHL is 1000 A;
- maximum conductor temperature: 70 °C (OHL not upgraded, with old conductor);
- maximum permissible conductor arrow: 8 m;
- maximum traction force of the conductor: 35 kN.

Case 1: The ambient temperature changes, the current passing through the conductor remains constant I = 760 A and the other environmental parameters also remain constant (table 7.2.4): ambient temperature: variable; wind speed: 0.6 m / s; wind direction: 90 ºC; emissivity coefficient: 0.5; absorption coefficient: 0.5; solar radiation: 1120 W/m.

Table 7.2.4. Example 1: Applying DLR mode according to the predicted environmental parameters

No.	**Functional parameter**	**Values**								
1	Current through OHL [A]	760 A								
2	Ambient temperature [ºC]	0	5	10	15	20	25	30	35	40
3	Conductor temperature [ºC]	31,7	36,1	40,5	45	49,4	53,8	58,3	62,7	67,2
4	Conductor arrow [m]	6,017	6,186	6,353	6,523	6,688	6,851	7.017	7,177	7,339
5	Traction force of the conductor [kN]	34,287	33,36	32,487	31,647	30,873	30,143	29,438	28,737	28,157

Case 2: The wind speed changes, the current through the conductor remains constant I = 760 A and the other environmental parameters also remain constant (table 7.2.5): ambient temperature: 40ºC; wind speed: variable; wind direction: 90º; emissivity coefficient: 0.5; absorption coefficient: 0.5; solar radiation: 1120 W/m.

Table 7.2.5. Example 2: Application of DLR mode according to the predicted parameters of the environment

No.	Functional parameter	Values					
1	Current through OHL [A]	760 A					
2	Wind speed [m/s]	0,6	1	5	10	15	20
3	Conductor temperature [ºC]	67,2	62,7	48,5	45,1	43,7	42,9
4	Conductor arrow [m]	7,339	7,177	6,654	6,525	6,469	6,432
5	Traction force of the conductor [kN]	28,157	28,787	31,028	31,636	31,909	32,09

Case 3: The wind direction changes, the current through the conductor remains constant I= 760 A and the other environmental parameters also remain constant (table 7.2.6): ambient temperature: 40 ºC; wind speed: 0.6 m/s; wind direction: variable; emissivity coefficient: 0.5; absorption coefficient: 0.5; solar radiation: 1120 W/m.

Table 7.2.6. Example 3: Application of DLR mode according to the predicted parameters of the environment

No.	Functional parameter	Values						
1	Current through OHL [A]	760 A						
2	Wind direction [º]	90	75	60	45	30	15	0
3	Conductor temperature [ºC]	67,2	67,5	68,6	70,6	73,7	78,399	83,399
4	Conductor arrow [m]	7,339	7,35	7,389	7,461	7,57	7,735	7,909
5	Traction force of the conductor [kN]	28,157	28,126	27,968	27,703	27,305	26,729	26,15
					Conductor Alarm			

The conductor temperature is higher than the permissible limit (70 °C at the old OHL).

Case 4: DLR mode: the current through the conductor and the ambient temperature change, the wind direction 90º and the other environmental parameters remain constant (table 7.2.7): ambient temperature: variable; wind speed: 0.6 m/s; wind direction: 90º; emissivity coefficient: 0.5; absorption coefficient: 0.5; solar radiation: 1120 W/m.

Table 7.2.7. Example 4: Application of DLR mode according to the predicted parameters of the environment

No.	Functional parameter	Values								
1	Ambient temperature [ºC]	40	35	30	25	20	15	10	5	0
2	Current through OHL [A]	760	810	870	925	970	1020	1062	1100	1150
3	Conductor temperature [ºC]	67,2	65	63,5	62	60,3	58,9	57,3	55,6	54,8
4	Conductor arrow [m]	7,339	7,26	7,206	7,152	7,09	7,039	6,98	6,918	6,888
5	Traction force of the conductor [kN]	28,157	28,461	28.672	28,888	29,138	29,347	29,591	29,856	29,983
							Equipment Alarm			

In this example, a thermal limit current of 1000 A was established, determined by the thermal limit characteristics of the equipment in the station inserted with OHL.

Case 5: DLR mode: change the current through the conductor and the ambient temperature, the wind direction 45º and the other constant environmental parameters (table 7.2.8): ambient temperature: variable; wind speed: 0.6 m/s; c. wind direction: 45º; d. emissivity coefficient: 0.5; e. absorption coefficient: 0.5; f: solar radiation: 1120 W/m.

Table 7.2.8. Example 5: Application of DLR mode according to the predicted parameters of the environment

No.	Functional parameter	Values								
1	Ambient temperature [ºC]	40	35	30	25	20	15	10	5	0
2	Wind direction [º]	90								
3	Current through OHL [A]	760	855	940	1020	1090	1160	1220	1280	1337
4	Conductor temperature [ºC]	67,2	67,1	67,1	67,2	67,1	67,2	67,1	67,1	67,2
5	Conductor arrow [m]	7,339	7,336	7,336	7,339	7,336	7,339	7,336	7,336	7,339
6	Traction force of the conductor [kN]	28,157	28,17	28.17	28,157	28,17	28,157	28,17	28,17	28,157
					Temperature Equipment Alarm				Temperature Alarm Conductor	

Case 6: DLR: the current changes through the OHL conductor and the ambient temperature, the wind direction 45º and the other constant environmental parameters (table 7.2.9): ambient temperature: variable; wind speed: 0.6 m/s; wind direction: 45º; emissivity coefficient: 0.5; absorption coefficient: 0.5; solar radiation: 1120 W/m

Table 7.2.9. Example 6: Application of DLR mode according to the predicted parameters of the environment

No.	Functional parameter	Values							
1	Ambient temperature [ºC]	40	35	30	25	20	10	10	0
2	Wind direction [º]	45							
3	Current through OHL [A]	685	778	861	935	1003	1020	1125	1234
4	Conductor temperature [ºC]	67,2	67,2	67,2	67,2	67,2	67,2	67,2	67,2
5	Conductor arrow [m]	7,339	7,339	7,339	7,339	7,339	7,339	7,339	7,339
6	Traction force of the conductor [kN]	28,157	28,157	28,157	28,157	28,157	28,157	28,157	28,157
						Equipm. Alarm			Cond. Alarm

International experience recommends that the following conditions be met for the current application of the dynamic charging regime of the OHL in the electricity transmission system:

1) the operating parameters of the line are measured and monitored online;
2) the application of the DLR regime is technically approved by the factors involved in the operation of the electricity transmission system, the conditions for issuing the favorable opinion being the following:
   - the design temperature of the OHL (Tp) at which the DLR regime is possible is known;
   - the current corresponding to the nominal load of the OHL (I_{nOHL}) is known;
   - the maximum limit current (I_{lmax}) is known; admissible according to the long-term operation of the primary appliance (from the electrical stations connected to the OHL) and the OHL, in full safety;
   - the technical characteristics and the technical condition of the primary equipment (switches, separators, current transformers, connecting rods) in the electrical stations connected to the OHL, allow the DLR mode: the operation in DLR mode does not affect the technical and operating condition DLR; the appropriate technical condition for the primary apparatus;
   - the technical condition of the OHL components, which may affect the operation in DLR mode, is appropriate: conductors, sockets / connections, insulator chains;
   - protections - the protection setting allows operation in DLR mode.
3) the current through the line conductor does not exceed the maximum load capacity specified by the conductor manufacturer (otherwise the conductor temperature would exceed the limits at which the arrow / ground gauge does not fall within the permissible limits and / or the lubricant would change its state (s- it would melt, and thereby increase the friction between the conductor wires and the steel wire, eventually leading to their rupture);
4) the OHL conductor's gauge to the ground / conductor's arrow shall be kept within the permissible limits for safe operation of persons, machinery, constructions or installations;
5) the tensile force in the conductor and the tensile insulators is below the breaking force (of the conductor or insulator).
6) for primary equipment in series with the power line (from the terminating stations, connecting an overhead power line) current transformers, switches, separators, busbars the rated current or the thermal limit current must be below the charging current of the line.

Chapter 8 summarizes a series of more general conclusions resulting from the elaboration of the doctoral thesis, the original contributions presented in the thesis, the way of valuing the theoretical and practical results obtained and the possible directions for further and deepening research in the field.

Among the main contributions of the author in the thesis are:

1) Bibliographic research, critical analysis and systematization of existing information material in the literature on online measurement and monitoring of operating and status parameters of high voltage OHL, highlighting the topicality of the topic, new areas of research in accordance with European Commission directives on the introduction of smart grids based on online monitoring of electricity transmission and distribution networks from the manufacturer to local consumers, highlighting disruptions that could seriously affect the operation of power lines, summarizing the conditions for data acquisition and processing that define the parameters of operation and condition of high voltage power lines, study based on information contained in over 140 bibliographic references.
2) Based on bibliographic research and long experience in the field, the author has developed the technical specification underlying the implementation, for the first time in Romania, of the system for online measurement and monitoring of high voltage overhead power lines, in accordance with current international requirements and achievements.
3) During the paper, an own conception was developed regarding the management of the operation and of the high voltage OHL load, from the electricity transmission system;
4) Based on the research carried out, the author, in collaboration with a team of specialists in specific fields: industrial electronics, automation, informatics, telecommunications, developed, tested, experimented and used in the CNTEE Transelectrica SA installations the Nova OHLM system for measuring and monitoring line operating and status parameters of overhead power lines. The NOVA OHLM system is an original, high-performance and secure system as it simultaneously measures (compared to other internationally developed systems) all the parameters that define the operation of an OHL and verifies by calculation the veracity of the acquired data.
5) The innovative NOVA OHLM system designed with the personal contribution of the thesis author, proved to be in line with the requirements of international standards, reliable and useful to beneficiaries, it has already been tested with very good results in the Pilot Project of CNTEE Transelectrica SA of 400 kV Bucharest South - Pelicanu and respectively the on-line monitoring of the leakage currents on composite insulator chains of 400 kV on the mentioned line. On-line monitoring of leakage currents on 400 kV isolator chains was done using the high-performance NOVA IZOMON system.
6) It is a national and international premiere, the simultaneous use of the on-line monitoring system of the overhead power line and the on-line monitoring system of the leaks on the high voltage isolator chains of a line, for the diagnosis and determination of the causes untimely rupture of several insulator chains on that line.

The results obtained were and will be capitalized within the Romanian Transport and System Operator - CNTEE Transelectrica SA - the main beneficiary of such on-line monitoring systems. The new investment projects, consisting in the construction of new overhead power lines, initiated mainly in the Banat area, include in the specifications and the equipment of the lines with on-line monitoring systems. Also, the existing interconnection lines and those that ensure the evacuation of the electricity produced in the Dobrogea area, are to be equipped with such systems for monitoring the OHL parameters.

As it results from the list of own works from the end of the thesis, the activity of preliminary preparation of the doctoral student and the results obtained during the elaboration of the paper were capitalized by 9 indexed papers ISI [Iaco2015a], [Iaco2015b], [Iaco2017b], [Iaco2017c] , [Iaco2017d], [Iaco2018a], [Iaco2019a], [Iaco2019b], [Iaco2020], 3 papers indexed in other international databases (BDI) [Iaco2018b], [Iaco2020], [Mold2021], 8 papers published in volumes some international scientific events [Ghit2016a], [Ghit2016b], [Iaco2017a], [Mate2017], [Marc2017], [Mold2016], [Roma2017], [Talp2017] and 2 scientific reports made in the process of elaborating the doctoral thesis.

The theoretical analyzes carried out in the doctoral thesis, as well as the practical results obtained, open a series of clear perspectives for the continuation and deepening of research, but also solutions for the safe operation of the electricity transmission network. Both the current thesis, together with other concepts analyzed in this context, offers the perspective of initiating and developing a new *Energy Management Platform of the NTS*, in order to ensure a modern, unified and integrated IT platform for operational management. of NTS at a level of performance and reliability, in line with contemporary global standards, with the following major objectives:

- replacement of the existing EMS / SCADA system with a system integrated in a complex EMP solution;
- improving the acquisition of EMS / SCADA data, in order to extend the visibility of the SEN network and equipment;
- improving communications with systems and O.T.S. neighbors and market participants, with the European coordination centers of the ENTSO-E interconnection, both in terms of data volume and data exchange speed, on the principle of a service-oriented software architecture (software components and interoperable applications, with multiple functio-nalities, which allow the development and integration of the system / systems);
- development of an integrated IT platform.

In conclusion, the doctoral thesis is a serious starting point for the development of research on the implementation of the new energy management platform, the development of Smart Grid in Romania and the implementation of the concept of digitization of the national energy system.

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