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Methodologies to uprate an overhead line. Italian TSO case study

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The amount of wind power and other time-variable non-dispatchable electricity generation is rapidly increasing across the world, causing a significant change in the electrical system configuration. The existing structural asset isn't adequate to dispatch these new power that have a priority in the energy dispatching. In addiction the outage of substations on the grid and the increase of consumptions have caused growing load currents. In order to satisfy these needs, TSOs have adopted new measures on existing power lines and N-1 criteria to ensures the electrical grid security. These particular devices are Dynamic Thermal Rating (DTR) systems. After introducing thermal resistant conductors and DTR solutions, the paper reports different applications used by TERNA - Italian TSO. These systems are already installed on lines and they are contributing to increase power flows thanks to raise by 10-30% of the real time dynamic ratings than the static evaluations. Advantages for electrical systems are many such energy vectors optimizations, congestions reductions, reliability increasing, cross-border power flows increasing, smart grid development.

Keywords: Dynamic thermal rating; overhead conductor; uprating of overhead line, ampacity.

1. Introduction

Today the increasing of energy consumptions and the growing development of RES production units, above all wind farms, caused consequently the increasing of energy vectors in the transmission and distribution power lines [1,5] causing particular problems in islanded system [6-8]. Now energy flows on these lines have bidirectional versus according of new flows entered by these new small units production across the territory making more and more complex the management of system's security [9-13]. For this reason TSO adopted deterministic security criteria (N-1). This criterion ensures the normal operation of the grid even when element grid goes out of working.

This criteria expresses the ability of the transmission system working in security conditions in circuit outage situation, in order to avoid overload failure in other lines. Building new power lines means taking into account economic, politic and social problems; so the better solution is to adopt measures on existing overhead lines. So this paper describes thermal resistance conductors and DTR systems with their applications by Italian TSO.

List of symbols:

q_c	heat loss by convection
q_r	heat loss by convection
q_s	heat input by sun
I^2R	heat input by ohmic losses

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E_1 ; I_1 voltage and current phasors in the line input terminals
E_2 ; I_2 voltage and current phasors in the line output terminals
θ complex line angle
Z_c line characteristic impedance

2. Methods

In previous years, several methods to increase line ampacity have been used; they consist in compensation actions and use of Phase Shifter Transformer. Actually TSOs are using other solutions type in their power lines: thermal resistant conductors and dynamic rating systems.

2.1. Thermal resistant conductors

Usually overhead transmission lines use bimetallic conductors (ACSR-Aluminium Conductor Steel Reinforced). They consist of a steel core characterized by high mechanical resistance and outer layers of several aluminium row wire helically wound on that support. In some critical lines these conductor types have been replaced with thermal resistant conductors that support greater working temperatures and a larger capacity to increase power flows on the network. Main thermal resistant conductors are: TACSR, GTASCR, ZTACIR, ACSS [14]. These conductors may work at temperatures between 150°C and 250°C without changing mechanical and chemical properties. TACSR conductor (Thermal Resistance Aluminium Alloy Conductor Steel Reinforced) presents steel wires in the core and TAL wires (Aluminium-Zirconium alloy which have stable mechanical properties up to 150°C) around it (Fig. 1).

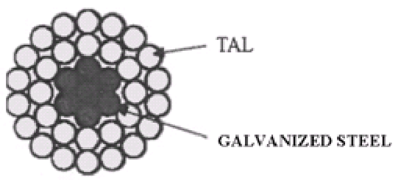

Fig. 1. Cross section's TACSR conductor.

GTACSR (Gap-type Thermal Aluminium Conductor Steel Reinforced) conductor presents a small gap between steel core and aluminium outer layers in order to apply strain only on the steel. The gap is filled with heat resistant grease (filler) to decrease friction between core and outer layers and to prevent water penetration (Fig. 2).

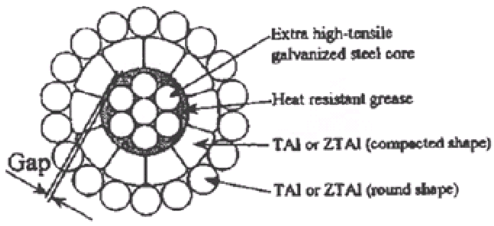

Fig. 2. Cross section's Gap-type conductor.

ZTACIR (Super Thermal Aluminium Conductor Invar Reinforced) conductor consists of steel-invar galvanized alloy core and ZTAL wires in the outer layers. It doesn't present annealing phenomena up to 210 °C (Figure 3).

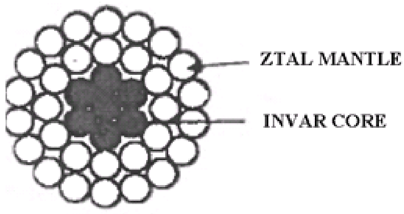

Fig. 3. Cross section's ZTACIR conductor.

ACSS (Aluminium Conductor Steel Supported) conductor presents steel wires on the core and aluminium wires in the outer layers subjected to an annealing process. There're two different types: "Standard Round Strand ACSS" (aluminium rope with circular cross-section's wires) or "Trapezoidal Aluminium Wire ACSS" (aluminium rope with trapezoidal cross-section's wires) shown in Figure 4.

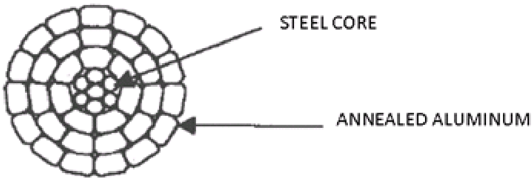

Fig. 4. Cross section's ACSS/TW conductor.

2.2. DTR solutions

Another method to uprate existing electrical structures is the installation of DTR Systems in order to value real time ratings regarding meteorological conditions and conductors temperature. The knowledge of these parameters allows increasing ampacity with favourable environmental conditions (in most cases) as shown in Fig. 5 (green area) and, at the same time, to avoid rare situations of overload (red area).

Dynamic valuations may be made up detecting dynamically electrical and mechanical conductor variables in addition to the thermal parameters; it goes under the name of Dynamic Rating systems (DR) or Dynamic Line Rating systems (DLR) [15] based on: Weather-based Model, Temperature-based Model, Sag/Tension-based Model, Electrical Model. In correspondence to the particular applications, every type of model has its advantages and disadvantages. The weather-based model calculates the conductor temperature and the rating using only measurements of load and weather conditions. It uses a steady state heat balance method to determine conductor temperature and to calculate the rating consisting of heat input and output equality [16,17]:

$$q_c + q_r = q_s + I^2 \cdot R(T_c) \tag{1}$$

This expression may be solved for current imposing maximum conductor temperature provided by manufactured, as shown in the following equation:

$$I = \sqrt{\frac{q_c + q_r - q_s}{R(T_c)}} \quad (2)$$

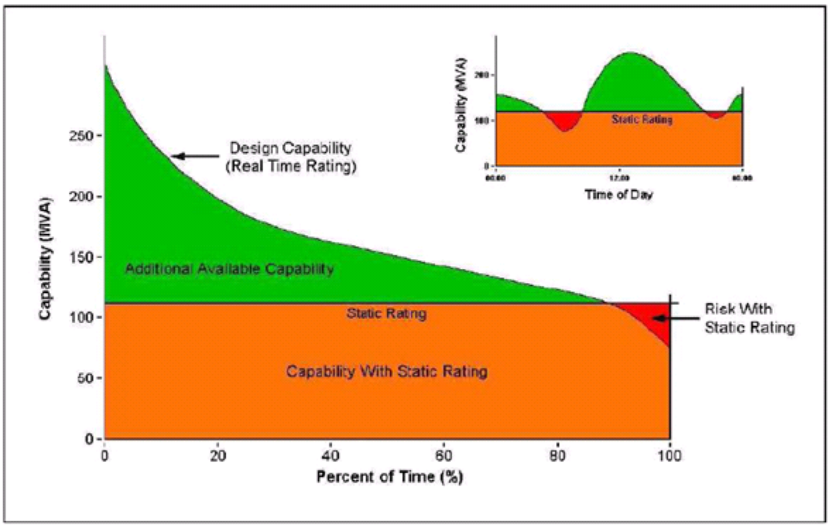

Fig. 5. Static and dynamic rating capability.

This model is usually the simplest method of dynamic thermal rating to implement. It results very accurate if multiple weather stations are installed along line and close to it. The main problems are due to high weather station availability because meteorological conditions can change in a few km distances. Temperature-based model is capable to calculate line dynamic rating by direct measurements of conductor temperature. In combination with the load, air temperature and solar heating, the real-time conductor temperature is converted to an equivalent wind speed that is used together with weather data to determine line dynamic rating. The advantage of this method is that user has a direct measurement of conductor temperature; the knowledge of this parameter is important because span may be monitored in high power transits condition.

In order to overcome weather data constrains, it’s possible to monitor line sag and tension. In fact Sag/Tension-based model responds to the weather conditions along the line section rather than to weather conditions at a single point along the line. Therefore, ratings based on a single sag-tension monitor are equivalent to several weather stations along the line. Tension is converted to an equivalent wind speed by 2 steps: first the tension is converted to an average conductor temperature based on field calibration data or catenary equations. Second, the average conductor temperature (in combination with the load, air temperature, and solar heating) is converted to an effective average wind speed along the line. The line rating is then calculated using the weather based heat balance algorithm. Another method to determine dynamic rating through conductor average temperature is the electrical model. Phasor measurement units (PMU), located on line’s extreme substations, detect voltage and current phasors synchronized by GPS systems. Line model is shown in Fig. 6.

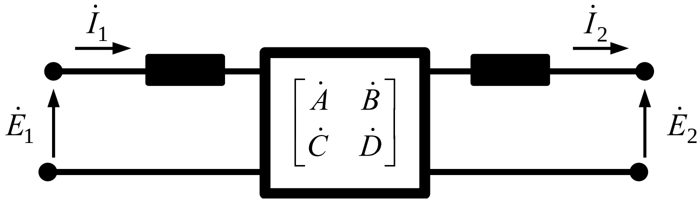

Fig. 6. Line equivalent quadrupole.

Equations that describe operation are:

$$\overline{E}_1 = \overline{E}_2 \cosh \overline{\theta} + \dot{Z}_c \overline{I}_2 \sinh \overline{\theta} \tag{3}$$

$$\overline{I}_1 = \frac{\overline{E_2}}{\dot{Z}_c} \sin \overline{\theta} + \overline{I}_2 \cos \overline{\theta} \tag{4}$$

With simple considerations Z is determined. Knowing conductor material properties, conductor average temperature it's then calculated. To obtain dynamic rating it has been used thermal balance equation seen previously. In the last years it has been developed various systems implementing such models. Some of these systems have been already installed by different TSOs in their systems but someone is resulted only an experimental prototype. Actually the most used are: Ampacimon, CAT-1, Thermal Rate, Power Donut and LTM ABB.

2.3. Ampacimon™

Ampacimon™, a Sag-tension-based model application, is a patented trademark device that analyses conductor vibration and detects span's fundamental frequency. Conditions regarding load, weather, creep, presence of snow/ice, etc. are incorporated into frequency readings. Thanks to this direct measurement of sag frequency, the system provides an accurate real-time line ratings. The Figure 7 shows Ampacimon monitor installed on the conductor.

Fig. 7. Ampacimon monitor on conductor.

In order [18] to extract the fundamental frequency from the vibration spectrum, a Span Vibration Signature is needed (that's characteristic vibration). Line fundamental frequency is obtained by comparing actual vibration spectrum to Vibration Signature and the span sag is calculated simply from a direct relation with the fundamental span frequency.

Real-time ampacity is calculated in three steps. The ruling span concept has been used [19]. The first step is used to define "actual" State change equation constants through two synchronous inputs: sag (detected by monitor) and conductor average temperature (by local weather station and using IEEE or CIGRE dynamic thermal model). Once the constants have been determined, the measured sag is converted to the average conductor temperature using the State Change Equation. The conductor temperature is also simulated using the IEEE model with the actual load (provided by TSO) and environmental conditions (by web/weather station). To determine the ampacity the IEEE dynamic model is used with the effective wind speed and solar radiation. Real time ampacity of each potentially critical span is determined for the maximum sag or the maximum conductor temperature whichever comes first. Real time ampacity is finally the result of the minimum ampacity of all observed spans. Ampacimon [20] is supplied directly by line and it embeds a DSP processor and various sensors. It has two radio systems: 433 MHz with limited power emission and standard cellular module (GSM/GPRS). Monitors installed on the grid send their data to Ampacimon server which implements vibrations spectrum analysis, determines ampacity and makes real-time/short time ampacity forecast. Through standard protocol, ampacity and span signals are sent to TSO control center and they are displayed directly on energy flow control's systems (EMS). Data transmission system is shown in Figure 8.

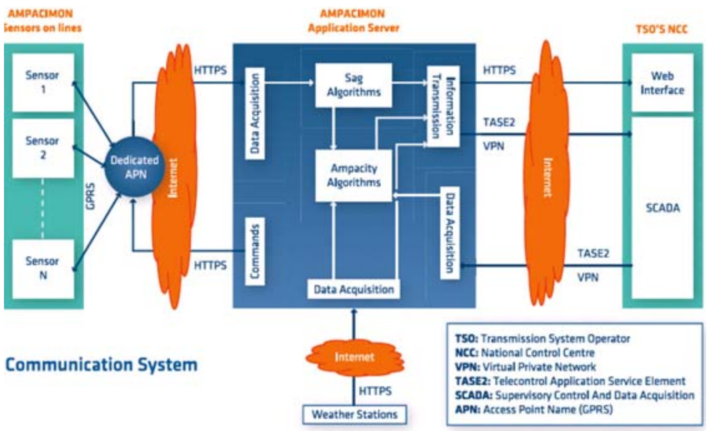

Fig. 8. Ampacimon transmission system.

The Ampacimon monitors should be installed on critical span (i.e. lines in correspondence with street, railways, rivers). The span is indicative of physical conditions of line and therefore "health" status of it. This parameter is very important to increase real time ampacity. Installation of device may be on live-line and the time installation expected is less of an hour. Data are sent to server directly without any local control station. Disadvantages of this system are mainly related to costs.

2.4. CAT-1^{TM}

The CAT-1^{TM}[21,22] system is designed to monitor the mechanical tension of the transmission conductor. As the sag of any transmission span is inversely proportional to the horizontal component of the tension, the CAT-1 system can accurately report the actual clearance status. Moreover through IntelliCAT software, the system can calculate conductor temperature, the sag, and trends in tension providing advance warning of impending clearance violations. Each CAT-1 main unit monitors the performance of two line sections terminating at a dead-end structure by two tension monitoring load cells and various sensors. This unit is connected to CAT-PAC unit that provides the supply through solar panels. Figure 9 shows CAT-1 and CAT-PAC units on pylon. Communications of CAT-1 and CAT-PAC data to CATMaster Base Station is accomplished via 900 MHz unlicensed spread spectrum radio, or by GPRS system or by fiber optic. The RTU card contained within the CATMaster provides protocol translation to facilitate transfer of data from the remote CAT-1 systems and the EMS/SCADA system.

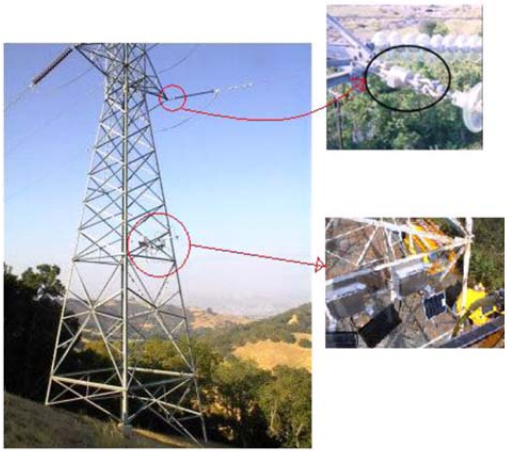

Fig. 9. View of CAT-1 and CAT-PAC units.

IntelliCAT software works in conjunction with the EMS/SCADA system by exchanging data via either periodic file transfer or ICCP network integration. Then the data are transferred back to the EMS/SCADA database to be accessed and displayed on existing operator consoles. In Figure 10 is represented complete data transmission system.

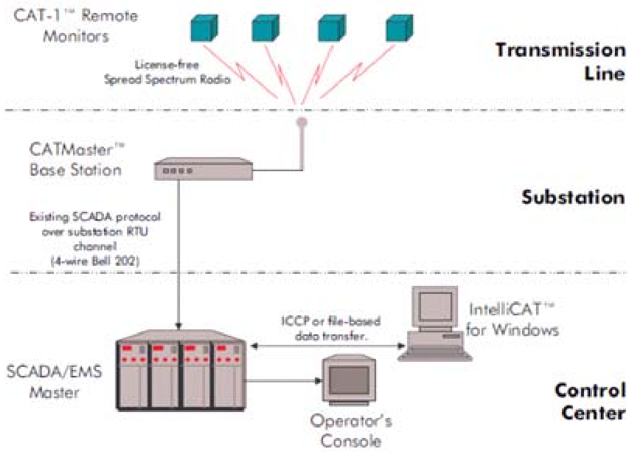

Fig. 10. CAT-1 transmission system.

Dynamic line rating is calculated through tension measurements and it constitutes an indicative parameter of the line status. Load cells, once installed on dead-end structures, don't need others sensors along the line. Main disadvantage is base station installation near the line able to collect temperature and tension information. Also it's necessary to verify line calibration to determine tension-temperature curve. In addition load cell installation requires line outage and the dropping of insulators string. Data update interval is 10-15 minutes due to conductor time constant.

2.5. ThermalRate™ System

The ThermalRate™ System [23] is a dynamic line rating approach that uses the patented ThermalRate™ Monitor (TRM) to determine a line rating by measuring how much actual weather conditions heat or cool a conductor. This system is an application of weather-based model. The TRM consists of ThermalRate Sensor (Figure 11) and ThermalRate Controller.

Fig. 11. ThermalRate Sensor.

The First includes two conductor replica sections, which are similar to the actual conductor in material, size, and surface. Each of the replica includes an embedded temperature sensor, and one of the replica sections contains an electric heater. It's mounted roughly at the same line height, located in the same direction and in proximity of it. The controller is located under the sensor and it measures the two replica temperatures to determine the effective wind speed and solar effects (direct and indirect) detected by the TRM. The heater power is constant, so the increase of wind causes a dropping temperature. The relationship between conductor temperature and wind is identified by IEEE-738 thermal model. The TRM then calculates the actual rating of the line by using again IEEE-738 model with the effective wind speed and the parameters of the line conductor. In addition it includes a spread-spectrum radio modem communicating the rating information to SCADA system of TSO control center. A receiving radio is provided for the SCADA side and it's connected to an existing local RTU or it's present in a substation line terminal. No software changes are required in SCADA, since the ThermalRate™ Monitor calculates the rating. ThermalRate™ System has low installation costs, it can be installed without taking an outage but it's necessary a separated supply (photovoltaic panel). Also it needs an high number of TRM to have corrects results as weather conditions may be very different for few km. Typically it is installed one monitor every 10 km.

2.6. Power Donut™

Power Donut device [24,25] is a sensors platform to measure and monitor electrical, thermal, mechanical parameters of high voltage overhead conductors. In particular it measures: currents, voltage, conductor and ambient temperature, conductor inclination, active and reactive power. The apparatus described in this paper is the version called Power Donut 2 (PD2). Recently a third version has been developed. Power Donut device on conductor is shown in Fig. 12.

This is an application of temperature-based model. On the basis of measured conductor temperature, Power Donut determines firstly heat loss by convection (q_c) and then the line dynamic rating. In the system may be included weather station close to the line but it isn't necessary because there are two ambient temperature sensors within Power Donut. PD2 has two options to transmit data: GSM/GPRS/EDGE and 2.4 GHZ "ZigBee" radio. First system requires no local RTU. The receiving station can be anywhere if broadband access is available. The GSM of the Power Donut2 (which has embedded SIM card) transmits secure TCP/IP data to a unique, fixed, IP address utilizing a GSM/GPRS/EDGE wireless data service (Fig. 13).

Fig. 12. Power Donut device.

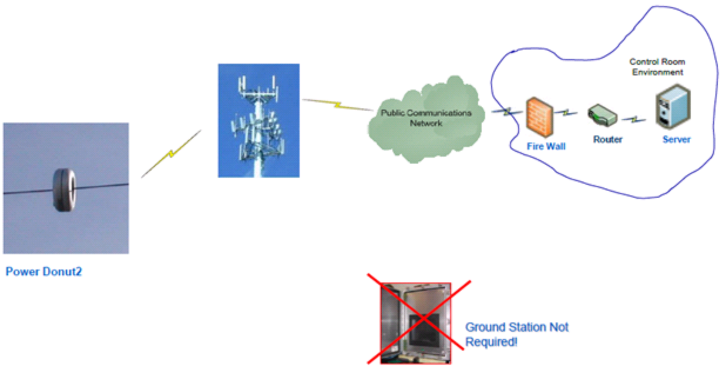

Fig. 13. Data transmission system through GSM/GPRS/EDGE.

The Power Donut2 with 2.4 GHZ "ZigBee" radio transmits secure data to a ground station receiver (Figure 14). Data is relayed to Customer RTU using Modbus or OPC. Weather station's measures are transmitted by BlueToothTM wireless connection. PD2 is able to determine dynamic line rating and at the same time monitors conductor temperature, span and tension.

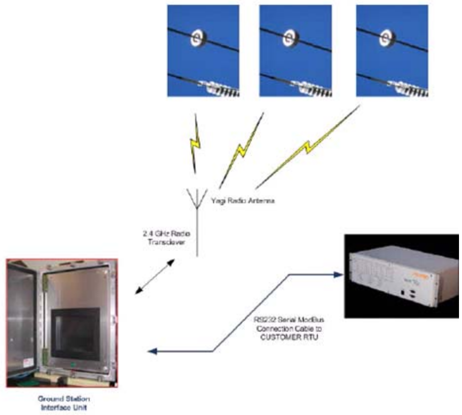

Fig. 14. Radio transmission system 2,4 GHz standard “ZigBee”.

2.6. Line Thermal Monitoring (LTM) ABB

LTM system is an application of WAM (Wide Area Monitoring) which includes others functions: phase angle monitoring, voltage stability monitoring, power oscillation and frequency stability monitoring and others applications. The main intention [26] behind developing Line Thermal Monitoring (LTM) has been to monitor and display the actual situation regarding thermal stability of a transmission line. The operator can decide about the load on the basis of the conductor temperature provided. This temperature is calculated by two PMU (Phasor Measurements Units) located at the ends of overhead line. De facto LTM is an application of electrical model. The algorithm provides an operation with precise outputs every second. The voltage and current phasors measured at both ends of a line (collected by GPS synchronized PMUs) allow to compute line’s actual impedance and shunt admittance. Then it is extracted line resistance and the actual average temperature of the line is determined on the basis of the known conductor material properties. Typically wind speed and direction, ambient temperature and sun emission influence the line resistance directly, making necessary that all these essential temperature factors must be measured additionally. The results of the LTM application are visualized with the PSGuard Basic Monitoring module and can additionally be integrated in SCADA EMS/Network control systems with RTU live interfaces. The Wide Area Systems based on PMUs are using a specific protocol for communication, standardized in IEEE C37.118 standard (parts 1 and 2). For this application isn’t necessary the installation of others sensors along the line. Also data updating is very fast (seconds) due to system time constant which are very small. But main disadvantage is the calculation of the “worst” conductor temperature; in fact it is an average value of the line and it’s difficult to determine ampacity because temperature may have different values in various sections.

3. Italian Case Study

Actually Terna is testing a particular control system consisting of two Power Donuts installed on the line and two PMUs located on extreme substations [27]. System provides dynamic rating by maximum conductor temperature determined through two methods: first detects average conductor temperature through electrical model (see previously), while the other method provides maximum line temperature thanks to distributed thermal model implementation (designed by University of Pisa). It adopts weather forecast data input detected on some points of the line (by Epson Meteo Center) and asset structural data. These temperatures will be compared also with temperature detected by Power Donuts and through a software implementing IEEE or CIGRE thermal model; dynamic rating will be obtained giving more guarantees. In Italy pilot applications of these systems are on four power lines:

- Spezia-Vignole 380 kV
- Bargi-Calenzano 380 kV
- Misterbianco-Melilli 220 kV
- Benevento2-Foiano 150 kV

This paper describes Dynamic Rating systems applications on the power lines 150 kV Benevento2-Foiano and 220 kV Misterbianco – Melilli.

3.1 Benevento2 - Foiano 150 kV application

The choice to install these devices is motivated by the need to favourite max energy generation by RES (wind in particular) due to the high production units presence located in the area (equal about 660 MW). Figure 15 shows various wind farms (white-green square) connected on 150 kV connection Benevento2-Foiano-Volturara-Montefalcone-Celle S.Vito.

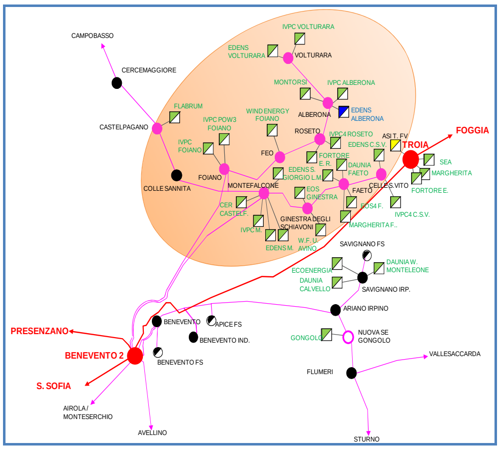

Fig. 15. Benevento2-Foiano area.

In particular on Benevento2-Foiano line, susceptible to the high current flows, two Power Donuts and two PMU are mounted. The first are installed on line close to starting and ending bus (Benevento2 and Foiano) while PMUs are functionality integrated in the new distance protection apparatus located on the line extreme substations.

Figure 16 represents conductor temperatures (violet and red lines) and load current trends (light blue line), detected by two Power Donuts. The graph shows a particular January's week (10/1/2013-18/1/2013) which windy conditions were very favourable to the energy generation by wind source. This is proven by current peaks logged that exceeded several time operating static rating value H1 (equal to 1020 A in winter) and once safety static rating H2 (equal to 1134 A in winter). In these critical situations small energy generation limitations by wind farms occurred in order to manage in security power line.

Nevertheless, during these peaks, conductor temperature was maintained under operating thermal limit, logging max value around 35°C.

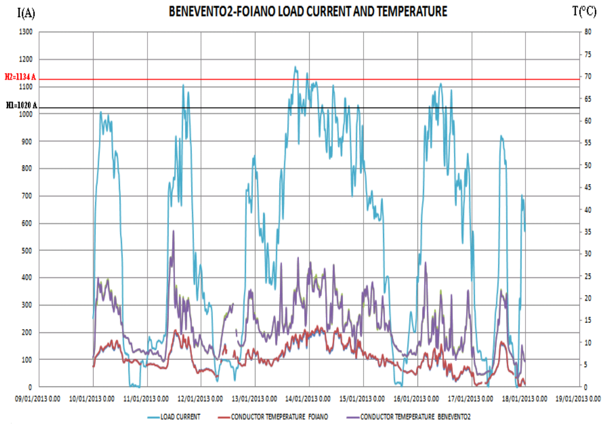

Fig. 16. Temperatures and load current trend.

In general during favourable weather conditions (high windy) dynamic rating exceeds seasonable static rating allowing a greater energy transmission on overhead power lines. The absence of these devices should have caused, vice versa, more significant limitations to the energy generation by wind farms, reducing energy vectors on the power line.

In the past, instead, the high RES production units presence connected on this power line caused often the limitation of wind generation due to several factors as: the limited transmission line capability and the presence of elements with lower power than ampacity line. Instead Dynamic Rating systems allows to manage in security electric grid and to the maximum power permissive, taking full advantages of existing assets.

Figure 17 shows two curves: the green one shows the trend of power installed by various production unit connected on the system; the second one (red curve) indicates the installed power capability trend not susceptible to the production limitations. This means that their difference represents the power capability susceptible to limitation if grid working conditions and wind were able to satisfy total wind generation of the farms. In January 2010 the power capability susceptible to limitation was equal to 235 MW as long as actually it's lower (156 MW) thanks to some measures adopted by Terna, like Dynamic Rating systems application and other development actions.

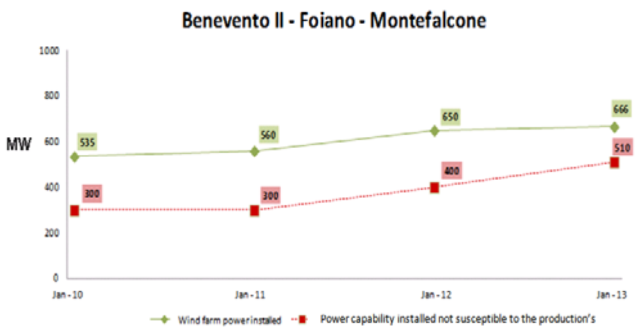

Fig. 17. Power installed and max power entered on grid trends.

Figure 18 shows the trend of the ratio between power installed and power capability not susceptible to limitation. It's possible to note that it's increased in the last four years from 56% to 76% reducing power capability not susceptible to limit of wind generation.

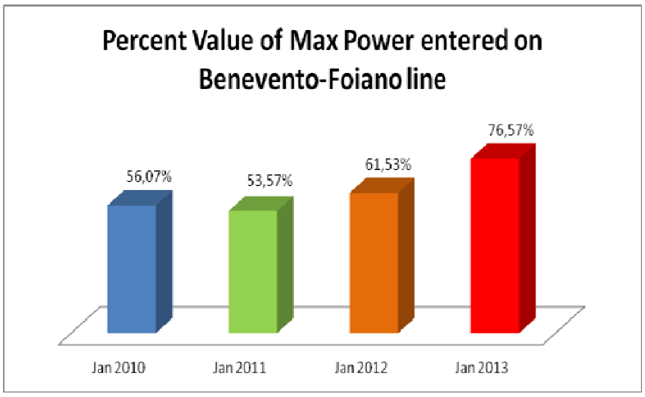

Fig. 18. Power installed and power capability not susceptible to limitation of wind gen.

As Dynamic Rating system installation occurred on September 2012, this percentage value are intended to increase. In fact in the wind favourable conditions, energy generated by wind farms grows but in the same time energy flows on overhead line increases too, being conductors not susceptible to excessive overheating thanks a greater heat dissipation per convection. This means that the two curves (figure 17) will become closer thanks to the application of Dynamic Rating systems in addition to other development actions.

The reduction of production limitations involves obviously the lowering of MPE (Mancata Produzione Eolica - i.e.: lack of wind generation). It's the energy amount for each hours not generated by a wind production unit due to the implementation of the dispatching directive given by Terna, as well as defined by Italian Authority deliberation ARG/elt 05/10. In fact the GSE (the Italian state-owned company which promotes and supports RES) uses a model to simulate the operation of these production units determining energy generated not entered on grid. MPE is, de facto, a sort of refund to wind auto-producer.

Figure 19 shows the trend of the ratio between MPE and energy entered on the connection. Note that it's decreased in the years above all in the 2012 where there was a MPE of 101 GWh (due mostly local congestion and unfavourable weather event causing structural damages to the connection) and a record entered energy of 1.291 GWh.

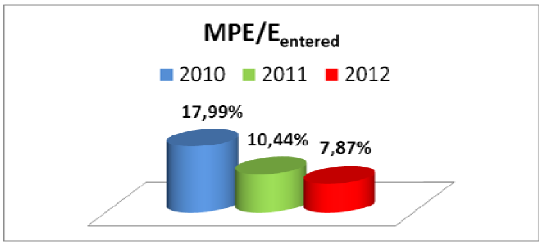

Fig. 19. Ratio MPE/Energy entered trend on Benevento2-Foiano.

In the next years, reducing the production limitation of wind farms and increasing energy entered on grid the ratio between MPE and Energy entered shall have percentage value close to zero.

3.2 Misterbianco-Melilli 220 kV application

Here is analyzed DTR system's application on Sicilian electrical grid in order to increase N-1 security. The experimental line is 220 kV Misterbianco-Melilli where two Power Donuts and two PMU on ending substations are installed (mounted in 2012).

Power line results particularly critical on some system's operational conditions regarding the Priolo energy generation area (close to Melilli station). In that area the majority of conventional power plants of Sicilia island is concentrated. When both energy generation of the Priolo area and energy produced by RES is high (in this case occidental Sicily loads are satisfy), Misterbianco-Melilli line is overloaded. This is in N grid's condition. If it occurs, a 380 kV Chiaramonte Gulfi-Paternò power line's outage, line object to monitoring is constrained to increase energy flows transmission in order to provide for the lacked operation of the lines mentioned above. So Melilli-Misterbianco load current could overcome line static rating causing consequently the "cascading effect".

Figure 20 shows the 220 kV ring grid (green lines) and 380 kV power lines in Sicily (red lines).

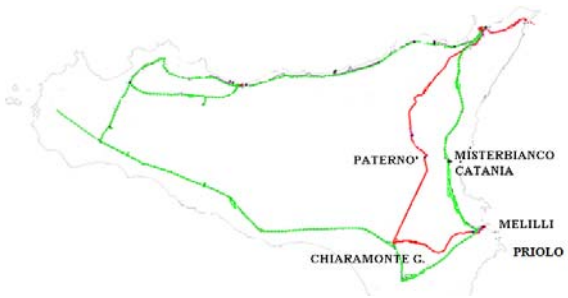

Fig. 20. 380-220 kV Sicilian electrical grid.

The application of Dynamic Rating systems on this line allows the respect of security's conditions N-1 on grid evaluating conductor thermal properties and avoiding "cascading effect". Indeed in favourable weather conditions for the conductors, particularly in winter, although load current overcomes the static rating conductor, thermal conditions are acceptable to guarantee system security. This is demonstrated by the following case study, reported as an example, showed in Figure 6. On 21 December 2012 high load current (almost 500 A at 10:00 am) with conductor temperature of about 16°C were recorded, detected by two Power Donuts.

Figure 21 shows load current trend (black line), temperature conductor trends detected near Melilli substation (blue and red lines) and temperature conductor trends recorded near Misterbianco substation (blue and orange ones).

Performing with a load-flow software the outage simulation of the 380 kV Chiaramonte G.-Paternò power line, the current's surplus on Misterbianco-Melilli line would be equal to 914A. It overcomes winter operation static rating (H1) equivalent to 837A and it's approaching winter emergency static rating equal to 930A.

The low conductor temperature in N system condition (16°C) allows to assert that conductor temperature remains below to the thermal limit allowed in N-1 system condition.

This means that overloaded power line doesn't risk further outage. Often TSOs forced to ordain real time precise dispositions to the unit productions and to specific loads to ensure the normal operation of grid. In particular occurred limitations to the energy generation by wind farms. These are generally necessary:

- to solve local congestion
- to ensure N-1 system security
- to maintain grid elements
- to execute development and renewal works
- to repair faults.

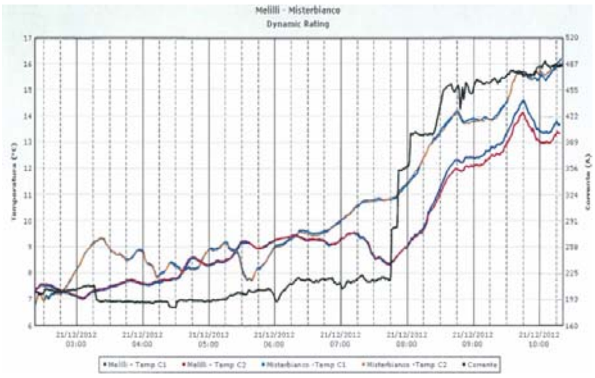

Fig. 21. Load current and temperature conductor trends.

These limitations entail considerable costs for electrical system. In Italy the limitations to the energy generation by wind farms is called MPE [27] (Mancata Produzione Eolica- i.e.: lack of wind generation). It's the energy amount for each hours not generated due to the implementation of the dispatching directives given by Terna. This energy amount is remunerated to the producers. Table I shows the comparison of MPE for 2012 and 2013 years related to different motivations.

Table I: Comparison between MPE for 2012 and 2011 years.

ITALY (JAN-DEC 2012/JAN-DEC 2011)		
MOTIVATION	MPE (MWh)	
	2012	2011
LOCAL CONGESTION	105481	139724
N-1 GRID SECURITY	164	32563
MAINTENANCE WORKS	6418	19740
DEVELOPMENT AND RENEWAL WORKS	17900	64191
FAULTS	12879	655
OTHERS	15711	7413
TOTAL MPE	158553	264286

Table I highlights that Dynamic Rating systems, in conjunction with other measures, allow to decrease these limitations bringing various benefits to the grid. One of these is to maximize energy generation by RES in the favourable weather conditions, exploiting the maximum overload capacity of the conductors.

Table II reports the energy entered in grid by wind farms and Figure 22 shows the percentage ratio trend of energy entered regard MPE for 2010, 2011 and 2012 years.

Table II: Comparison between energy entered on grid for 2012 and 2011 years.

ENERGY ENTERED ON GRID BY WIND FARM (GWh) 2012	ENERGY ENTERED ON GRID BY WIND FARM (GWh) 2011
12412	9220

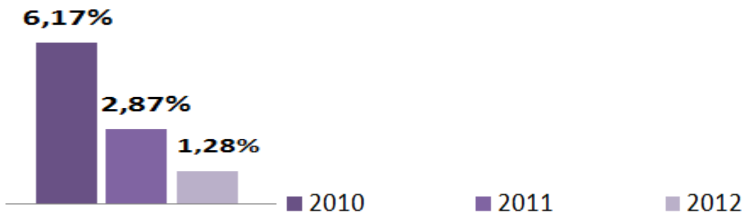

Fig. 22. Percentage ratio trend between energy entered on grid and MPE.

Considering that the main constraint to the max power generation is the conductor's ampacity, the decreasing of percentage ratio of energy entered on grid by wind farm regard MPE is merit of Dynamic Rating systems too.

Therefore the use of the devices could save a lot of economic resources to the system compared to a limited costs for the device's purchase and installation. For this reasons Terna, as well as others TSOs, are investing heavily on these systems in order to manage in optimal manner power flows, maintaining the grid's security and favouring max power generation by RES. The result of this success is spread in recent years of different types of these devices and many are still in the experimental stage.

4. Conclusion

In Italy many investments are doing on existing overhead lines through the replacement of ACSR conductors for those thermal resistant and introducing Dynamic Rating solutions.

These systems represent a transmission and distribution network's evolution contributing to the smart grid development. The possibility to manage conductor thermal, mechanical and electrical parameters allows to exploit maximum existing structural assets without causing excessive lowering of conductors.

In Italy the Benevento2-Foiano power line application proved that in the max wind generation hours, seasonable static rating (operating and safety limits) have been exceeded without involving excessive conductor overheating. This is due to the favourable wind conditions that caused a greater heat dissipation per convection and a real increase of line transmission capacity. In these situations however it was decided to perform small wind generation limitations to avoid local congestions (security N). Instead the absence of Dynamic Rating devices would have caused significant wind power generation limitations.

In case of wind absence and high solar radiation dynamic rating could assume lower values than static ratings. Another benefit to electrical system is the MPE index reduction due to a less limitations of energy generation by wind farms. This results in a substantial saving for the system. In Italy the Misterbianco-Melilli power line's application proves that it's possible to manage positively high energy flows in the unfavourable situations of congestion (overcoming static rating) because conductor isn't subject to excessive overheating remaining well below to thermal limit of operation. This means that energy dispatching is performed in security avoiding “cascading effect”.

Often the constrains to the max generation by RES are due to the conductor ampacity. The Dynamic Rating systems utilization allow to decrease the energy generation limitations ordered by TSO in order to avoid congestions. The target is the reduction of these limitations to save a lot of economic resources to electrical grid.

So these systems are important instruments for control room operator able to manage better energy flows in the electrical grid.

The low costs/benefits ratio of these devices has led Terna Group to invest significantly on critical power lines. In particular besides those that contribute to favourite max RES production, there are line susceptible to high load currents in case of any grid elements outage (N-1 security criterion).

Generally these devices allow to optimize power flows, to reduce congestions, to increase electrical system reliability and security and to make grid smarter.

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