The European Association of the Electricity Transmission and Distribution Equipment and Services Industry

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Monitoring and Control of MV and LV electrical networks: Towards smarter distribution grids

Executive summary

Driven by the goals in the Paris Climate Agreement, the EU is making an energy transition. The new energy reality will be increasingly decarbonised, digitised and decentralised. As we move from traditional energy systems, new and smarter solutions will be required to manage the changing generation mix, whilst maintaining affordability and ensuring security of supply. Smart metering deployments started the race to develop grid automation projects for a new, future-proof electricity grid. This results in more detailed, accurate and real-time information of the T&D networks and thereby in more added value for consumers and DSOs. Monitoring and control technologies for MV and LV electricity networks have a tangible positive impact on decarbonisation, quality of service and financial efficiency:

Decarbonisation

Improved flexibility and manageability enable the grid to accommodate renewable energy sources, thereby reducing curtailment due to operational and technical restrictions. The reduction of total energy consumption, as a result of improved grid efficiency and the reduction of losses further contribute to decarbonisation.

Quality of Service, grid resilience and safety improvement

Improvements in outage duration indexes up to 70% have been reported by DSOs deploying automated and remotely operated switchgears, advanced distribution management systems, including Fault Location Isolation and Service Restoration (FLISR), P2P communications between secondary substations and/or field equipment, LV monitoring systems and Automated Metering infrastructure (AMI)[1].

By means of automation and monitoring systems DSOs have the possibility to connect increasingly active consumers and prosumers with new agents to implement demand response schemes, manage the integration of DER, microgrids and EV charging infrastructure.

Financial efficiency

Monitoring and control technologies contribute to greater financial efficiency and cost-effectiveness by reducing operational expenditure and optimizing capital expenditure of DSOs. The increased use of automation in the MV and LV electricity networks reduces operational

[1] A. Amezua, "Metering beyond AMI: Low voltage grid operation," *Metering & Smart Energy,* no. Issue 4, pp. 20-21, 2017.

expenditure (OPEX) by up to 35% through the improvement in workforce management and the reduction of planning costs.

At the same time capital expenditure (CAPEX) can be optimised by the optimal exploitation of network assets through better asset management, life extension and condition-oriented maintenance. Sensors and actuators deployed in the field combined with data analytics and intelligent control of the grid can avoid the need for costly re-inforcement due to capacity constraints and focus the investments where they are necessary.

In view of the ambitious climate and energy target, T&D Europe sees the need to accelerate the pace of innovation and renovation of the electricity infrastructure started at the end of the 20th century. Future-proofing the electrical grid is a prerequisite for a successful energy transition. This requires the following actions:

1. **Retrofitting of existing installations**: DSOs, supported by regulators and technology providers, to reinforce the existing, un-monitored LV networks as a basis for better constraint management;

2. **Future-proofing the LV and MV networks**: DSOs, supported by regulators and technology providers, to prioritise projects on the basis of their contribution to improving the smartness of the network.

3. **Implementing the Clean Energy Package**: Member States to use the implementation of the Clean Energy Package - in particular Article 59(1)(l) of the EU Electricity Directive - as a way to put in place an operational regulatory framework promoting network modernisation;

4. **Unlocking investments**: Member State regulators to create the financial conditions for DSOs to invest in future-proofing the network by means of enhancing monitoring and control in MV and LV networks.

Monitoring and Control of MV and LV electrical networks: the way towards smarter distribution grids

The Energy Transition is a process towards more sustainable energy sources enabled by technological progress. T&D Europe members are fully committed to bring Europe to a low carbon economy in 2050. Our technologies enable power systems to accommodate the integration of the increasing share of renewable and distributed energy sources.

The new energy reality will be increasingly decarbonised, digitised and decentralised. At the same time citizens will be able to actively manage their energy consumption and production as a prosumer, as part of a microgrid[2] or otherwise engaging with a much more flexible electricity grid. New digital tools, data access and analytics will facilitate and enable this interaction.

In December 2015, 197 countries concluded the Paris Agreement[3], which commits them to reduce greenhouse gas emissions with the aim of keeping global average temperature increases to well below 2 degrees Celsius compared to pre-industrial levels. They also agreed to pursue efforts to limit temperature increases to 1.5 degrees Celsius compared to pre-industrial levels.

The EU has translated these global ambitions by setting itself the challenge to build an Energy Union that provides clean energy for all Europeans. This includes specific targets for 2030, including:

- 40% reduction in greenhouse gas emissions, compared to 1990 levels
- 32% share of renewable energy production
- 32.5% energy efficiency target
- 15% interconnection target

The EU has a longer-term ambition of reducing greenhouse gas emissions by 80-95% in 2050, compared to 1990 levels and has launched its strategy for long-term EU greenhouse gas emissions reductions in December 2018[4].

The European electricity grid needs to enable the entire power system to ensure cost-effectiveness whilst supporting the energy transition and security of supply as well as the participation for all users known today and in the future (e.g. generators, consumers, prosumers, aggregators).

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[2] For more information on microgrids see: T&D Europe, Harnessing Microgrid Technology Opportunities to lead the Energy Transition in Europe (February 2019)
[3] https://unfccc.int/files/meetings/paris_nov_2015/application/pdf/paris_agreement_english_.pdf
[4] https://ec.europa.eu/clima/policies/strategies/2050_en

As we move on from traditional energy systems, new, smarter solutions will be required to manage the changing generation mix, whilst maintaining affordability and ensuring security of supply. This means that not only the generation sector has to undergo a fundamental transformation, but also the grids have to change to continue to deliver value and quality of supply to consumers.

This paper describes how monitoring and automation technologies in the medium and low voltage distribution network help reduce greenhouse gas emissions, increase energy efficiency, enhance the quality of service and improve the financial performance of distribution system operators (DSOs).

In view of these ambitious climate and energy targets, it is necessary to accelerate the pace of innovation and renovation of the electricity infrastructure started at the end of the 20th century.

The paper concludes with four recommendations on how Member State Governments, regulators, DSOs, grid users and technology providers can future-proof the European electricity network.

Why monitoring and control are important

Smart metering has been one of the main drivers of grid modernisation pilot projects and deployments in recent years. Apart from creating value for consumers and industry, these deployments have also revealed a multitude of opportunities to modernise the distribution networks. At the same time consumers are asking for better and new services too. And they want to become an active part of the system.

Making this a reality will require grids adapted to new demands and new ways of operating them. More intelligence helps to make the distribution grid more resilient, efficient and environmentally friendly. Automation is the cornerstone of this evolution.

As low carbon technologies become more prevalent across distribution networks, more sophisticated network monitoring and control will be required to improve visibility and manageability of embedded generation, electric vehicle charging infrastructure, energy storage systems, sensitive loads, consumers and prosumers.

Understanding the impact on the network of these new technologies is key for network planning and making the right investment decisions. A report published by Scottish Power Energy Networks[5] found that up to 17.5% of secondary substations were above 85% of their rated capacity and 5% above 90%. Existing measurements do not allow the causes to be explored in any further detail therefore there is no certainity about the effect of changes in the way the network is operated. A variation could lead a transformer overload, which could cause a failure in the transformer, thereby provoking an outage. Hence, there is a real need for the

[5] SP Energy Networks, "Future Network Monitoring Strategy," p. 15, September 2015.

introduction of distribution substation monitoring to obtain detailed information of power flows and energy usage to avoid cascaded outages or, in the worst-case scenario, a blackout.

One step further is being able to control the network in real time and reconfigure it to dynamically adapt to the actual conditions. This capability is particularly beneficial in the case of outages when reducing the time needed to restore service is critical to avoid severe impact in consumers/prosumers. Curtailment of renewable energy production[6] due to a variety of operational and technical restrictions, is also reduced.

Whilst monitoring provides information and alarms, the ability to reconfigure the network improves availability, reliability and flexibility, which altogether constitute what is known as network resilience. Depending on the degree of MV and LV monitoring and control capabilities of the networks, there are different “smartness” levels in the grids. “Grid Smartness indicators” are a useful tool to assess and monitor the state of the network, on the basis of which the DSO can determine what needs to be done to future-proof its network.

The new EU electricity directive[7] provides a framework by requiring Member State regulators, *inter alia,* to monitor and assess the performance of the transmission and distribution grids. These new requirements[8] will help to create transparency on the transition to smarter grids in Europe, increase the awareness of smart technologies and their potential and promote the use of best practices. By doing so it is expected to help Member States investing to reach their emissions reduction and energy efficiency targets while incentivising investments in innovative technologies.

In a world of connected devices using public and private commmunication media, cybersecurity arises as an overwhelming concern which needs to be adequately addressed to guarantee the success of the deployment of MV and LV monitoring and automation technologies.

State of the art

DSOs around Europe have started to introduce automation in the LV and MV networks. The further automation and digitalisation of the electricity grid produces multiple benefits for operators and the users. Improved resilience and quality of service, reduced outage times, empowering consumers, optimizing expenditure, increasing cost-effectiveness, network

[6] Curtailment is the act of reducing or restricting energy delivery from a generator to the grid mainly due to technical restrictions to guarantee system stability. The consequence for the producer is the loss of production. Power purchase agreements, typically, do address curtailment and its economical compensation.
[7] DIRECTIVE (EU) 2019/944 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL on common rules for the internal market for electricity and amending Directive 2012/27/EU (recast) EU https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32019L0944&from=EN
[8] Article 59 (1)(l), DIRECTIVE (EU) 2019/944 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL on common rules for the internal market for electricity and amending Directive 2012/27/EU (recast) EU https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32019L0944&from=EN

planning, detection of losses and issues, active network management are among the benefits of increased automation. Let us take a closer look.

Automation in the MV and LV networks enables remote operation, fault location, isolaton and service restoration (FLISR)[9] and to help improve grid resilience and the quality of service delivered to the customer.

Automation is evolving from an automated breaker in the feeder output of an HV/MV substation towards distributed intelligence where it is possible to find a connection to the control centre and even peer-to-peer (P2P)[10] between intelligent electronic devices (IEDs)[11] deployed along the MV feeder, both overhead and underground[12] [13].

Fault passage indicators (FPIs)[14] play a key role in providing information to detect faults in the feeders resulting in power outages for consumers connected to such feeders. This is combined with geographical information systems (GIS), data from fault recorders and machine learning techniques to accurately locate the fault and reduce outage time by means of a rapid intervention by the crews and linemen.

New generations of Remote Terminal Units (RTU)[15] are being installed in MV/LV substations to provide the information to the Distribution Management System (DMS)[16] and to execute commands received from control centres.

Distributed energy resources (DER), energy storage and electric vehicle (EV) integration require flexible networks that adapt to their particular behaviour, *inter alia* intermittency and

[9] FLISR, also referred to as a “self-healing” grid capability, is an automatic system which ensures the more optimal grid configuration in faulty conditions, and the subsequent network reconfiguration to restore the service.

[10] P2P networking is a distributed application architecture that partitions tasks or workloads between peers. Peers are equally privileged, equipotent devices taking part in the application.

[11] IEDs are microprocessor-based controllers of power system equipment, such as circuit breakers, transformers and capacitor banks.

[12] A. Silos, A. Señis, R. Martín de Pozuelo and A. Zaballos, "Using IEC 61850 GOOSE Service for Adaptive ANSI 67/67N Protection in Ring Main Systems with Distributed Energy Resources," *Energies (MDPI).*

[13] A. Alvarez de Sotomayor, D. Della Guistina, G. Massa, A. Dedè, F. Ramos and A. Barbato, "IEC 61850 based adaptive protection system for the MV distribution smart grid," in *Sustainable Energy, Grids and Networks*, Brescia, 2017.

[14] FPIs are devices which provide visual or remote indication of a fault on the electric power system. The device is used in electric power distribution networks as a means of automatically detecting and identifying faults.

[15] An RTU monitors the field digital and analog parameters and transmits data to the control centre.

[16] A DMS is a collection of applications designed to monitor and control the entire distribution network. It is a decision support system to assist the control centre and field operating personnel. Minimizing outage time, maintaining acceptable frequency and voltage levels are the key deliverables of a DMS.

bidirectional power flow[17]. These technologies pave the way to an energy market, in which empowered consumers and distributed resources can actively participate.

Condition monitoring unlocks functionalities like Smart Asset Management which extend the life of the network components, thereby reducing capital expenditure (CAPEX), and help maintain adequate operating conditions, thereby helping to optimize operational expenditure (OPEX).

Evolution in materials and components has facilitated the adoption of solutions based on sensors or low power instrument transformers (LPIT) which are being standardised in the International Electrotechnical Committee (IEC)[18]. Additionally, a variety of sensors can be used to measure multiple variables such as temperature, flooding, fire, gases, humidity, motion, presence of crew, intruders, etc. The increased use of sensors provides DSOs with greater visibility on the state and performance of the network.

Traditional Supervisory Control and Data Acquisition (SCADA)[19], Distribution Management System (DMS) and network monitoring systems have evolved into advanced distribution management systems[20]. Integrated with other information and operational technology IT[21]/OT[22] systems such as GIS which help the DSO to plan the operation and development of the network in a particular area[23]. Connections with meter data management system (MDMS)[24] allow e.g. the detection of technical and non-technical losses. Valuable information for operation of the LV network can be obtained by interfacing with the systems that manage and collect the data from smart meters, known as metering Head End Systems (HES) provide.

For optimal DER management and integration, active network management (ANM) is a solution that interacts with DMS and EMS to actively manage constraints and settings of DER to adapt to current network conditions. ANM is being deployed especially in networks with high

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[17] Power flow is unidirectional in traditional distribution networks without distributed energy resources connected, from generators to consumers. When producers are connected to the distribution grid, power can flow from end users to the grid and vice versa, therefore in both directions, this is bidirectional.

[18] IEC 61869-6 Instrument transformers - Part 6: Additional general requirements for low-power instrument transformers https://webstore.iec.ch/publication/24662

[19] Computer system providing the operator interfaces that enable monitoring and the issuing of commands to field devices, i.e. RTU and IEDs

[20] J. Wang, "ADMS for Grid Modernization – Importance of DMS for Distribution Grid Modernization," Vols. ANL/ESD-15/16, Sep 2015.

[21] IT is the use of computers to store, retrieve, transmit, and manipulate data or information, often in the context of a business or other enterprise

[22] OT is the use of computers to monitor or alter the physical state of a system, such as the control system for a power station or the control network

[23] J. Dirkman, Best Practices for Creating Your Smart Grid Network Model, Vols. 998-2095-11-11-13AR0, Schneider Electric.

[24] A system which imports the data from meters, then validate, cleanse and process it before making it available for billing and analysis

penetration of RES. TSOs and DSOs have started collaborating on an integrated approach to active system management[25].

Online monitoring of LV networks is gaining momentum due to the impact of LV on end users, either consumers or producers by means of DER. In LV, systems such as MDMS can aid considerably in better understanding the behaviour and trends of consumers[26]. Modelling of the LV network in the DMS is also a current technology trend[27] [28] [29].

Applications built on data analytics are powerful tools to evaluate, detect and improve or fix issues that are seldom detected through a traditional approach. The nature of these issues goes from faulty lines through fraud detection to network asset inventory updates.

Load forecasting based on actual data enables optimisation of grid operation and adaptation to the needs of consumers instead of applying common criteria regardless of the particular behavior of each individual.

Communications systems are the cornerstone of any Smart Grid deployment. Communication infrastructures are becoming an essential part of the DSOs assets, and managing cybersecurity a business as usual activity.

The Benefits of automation

There is a wide range of technologies that enable the automation of the LV and MV networks. Automation, however, is not an end in itself, but a means to add value and deliver benefits to society in general and consumers, DSOs and Europe’s technology leadership in particular.

For Consumers

The prime expectation of consumers is continuity of supply. DSOs have reported reduction of up to 70% in the system average interruption duration index SAIDI[30] in the 2001-2016 period [31]. It is essential that investment in MV and LV monitoring and control systems is maintained to ensure continual reduction in outages experienced by customers.

EU policy aims to stimulate the active involvement of citizens and the empowerment of consumers. As more and more consumers are to become more active in the electricity network,

[25] TSO-DSO Report, An Integrated Approach to Active System Management with the focus on TSO-DSO coordination in congestion management and balancing (April 2019)
[26] A. T. Gordillo, "The Three Pillars for an Efficient AMI Operation," Schneider Electric, Paris, 2014.
[27] *UPGRID,* 01/01/2015 – 31/12/2017.
[28] *Integrid,* 01/01/2017 to 30/06/2020.
[29] *Thames Valley Vision,* 2012-2017.
[30] This is the average outage duration measured in minutes. The lower the index the better.
[31] Amezua, "Metering beyond AMI: Low voltage grid operation," *Metering & Smart Energy,* no. Issue 4, pp. 20-21, 2017.

DSOs will need to be able to provide their customers with timely information. DSOs are already working on becoming more “customer centric” and are looking for ways to enhance their customer relationship[32]. Improved monitoring and control capabilities will enable DSOs to better fulfil their role.

For DSOs

DSOs are becoming increasingly the central actors in the European electricity network. With more than 90% of all distributed renewable energy generation being connected to the distribution network[33] their role and responsibility are increasing dramatically. DSOs have the opportunity to embrace the transformation in their responsibilities and adapt the networks to the challenges derived from the energy market evolution, real-time system operation and cooperation with TSOs

Network monitoring and control drives asset management into a new stage where the asset life can be extended resulting in benefits due to the possibility of accurately analysing the actual performance of the individual devices instead of inferring the status of the assets based on theoretical calculations.

LV and MV monitoring providing reliable information from the field is critical for effective operation of the network. As the visibility of the grid increases, reaching down to the LV network, operators make faster and better decisions, reducing the impact of power outages, load and generation variations, and DER integration.

Integrating the OMS with the DMS and SCADA, the network can be automatically operated. This is a tremendous aid for the operators especially in case of multiple outages or critical situations, relieving the operator from stress.

Continuous monitoring combined with high-level algorithms using real time data provides information of the actual status and life expectancy of the installed base, reducing the total cost of ownership (TCO) and guaranteeing optimal operation of the electrical distribution infrastructure.

Cost reduction can be obtained by improving the management of resources and spare parts as part of the life cycle of network assets. Monitoring helps to make the best decisions about asset management resulting in an optimised CAPEX. Moreover, based on the actual data

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[32] GEODE Working Group Customer Dialogue, Distribution System Operators: Transforming the Customer Experience, May 2019 http://www.geode-eu.org/uploads/GEODE%20Publications/2019/REPORT%20DSO%20CUSTOMERS%202019%20FINAL.PDF

[33] Eurelectric, The Value of the Grid: Why Europe’s distribution grids matter in decarbonising the power system, June 2019 https://www.eurelectric.org/news/the-value-of-the-grid/

received from the field, maintenance schedules can be optimised resulting in a lower OPEX. Utilities have reported reduction of up to 35% reduction in OPEX in the 2001-2016 period[34].

For Europe's technology leadership

Europe is home to a world-leading grid technology sector, providing conventional, digital and innovative solutions for a future-proof electricity network that is more and more decentralised and more and more digital. Europe's grid technology sector is well placed to provide the necessary building blocks for a future-proof, smart, digital network with efficient and cybersecure data interoperability and with the necessary interconnections to manage the seasonal fluctuations in renewable generation. Constant evolution based on ambitious investment in R&D is one of the key factors for a manufacturer to survive and succeed in the marketplace.

At present, there is a huge opportunity to get a return on the investment being made to develop most modern monitoring and control systems. The result will be creating high quality, stable and durable employment.

The T&D industry makes a continuous effort to keep one step ahead of the needs of the market, investing significant amounts of money and hours of top-class engineers, scientists, and technicians in collaboration with the most prestigious research centres and universities to create competitive solutions.

This is business as usual for the industry and will persist because it is the proven way to succeed and guarantee a future for employees, shareholders, customers and society in general.

Moving forward, the manufacturers will keep on investing in new applications which will eventually unlock future business opportunities, distribution network enhancement and increased customer satisfaction. Ensuring the continued existence of a dynamic and challenging market will benefit grid operators, users and technology providers.

Other benefits

Some examples of other benefits aforementioned in the introduction and state of the art are:

a. Increased ability to accommodate DER, reasonable curtailment of RES and minimisation of fuel and carbon cost of conventional generation by maximizing accommodation of renewables due to increased network capacity, flexibility and manageability.

b. Support of electrification of new sectors, e.g. EV charging.

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[34] Amezua, "Metering beyond AMI: Low voltage grid operation," *Metering & Smart Energy,* no. Issue 4, pp. 20-21, 2017.

c. Increased resilience provided by on-grid micro- or nanogrids.

Smartness Indicator as a guide to the benefits

The new EU electricity directive is, inter alia, complementing this by requiring Member State regulators to monitor and assess the performance of the transmission and distribution grids. These new requirements will help to create transparency on the transition to smarter grids in Europe, increase the awareness of smart technologies and their potential and promote the use of best practices. By doing so it is expected to help Member States investing to reach their emissions reduction and energy efficiency targets while incentivizing investments in innovative technologies.

T&D Europe has published a first set of ideas on how Member States could develop these indicators[35] looking at technologies and solutions to be monitored.

A Grid Smartness Indicator or Monitoring Process reflects the ability of the grid to enable the entire power system to ensure cost-effectiveness whilst supporting the energy transition and security of supply as well as the participation for all users known today and in the future (e.g. generators, consumers, prosumers, aggregators, etc.).

Different levels of smartness can be found in the MV and LV grids depending on the capabilities that deployed devices provide. Applying a Grid Smartness Indicator or Monitoring Process to the MV and LV grids could result in the following classification:

- Level 0: No monitoring and no control
- Level 1: Monitoring of the facility but no control
- Level 2: Monitoring and control (remote operation) of the facilities
- Level 3: Stand-alone operation, optimisation and coordination of facilities (e.g. FLISR, Self-Healing)

It is now up to the implementation in EU Member States to enable consumers and DSOs to reap the benefits of the available technologies.

Conclusion

The three key factors for future-proofing the European electricity network are a robust policy and regulatory framework, technology and investments in deployment. With the adoption of the updated EU electricity regulation, the policy framework is up to date. The grid technology

[35] T&D Europe, Smart Digital Grids: At the Heart of the energy Transition, February 2019 https://www.tdeurope.eu/component/attachments/attachments.html?id=1187

is available. The smart grid infrastructure depicted throughout this paper consists of monitoring and control solutions already being deployed and many others that are ready to be deployed in the marketplace, thereby contributing to reaching the goals of regulators, DNO/DSOs and consumers/prosumers. The final step towards a future-proof electricity network consists of investments in the large-scale deployment of the technology in the distribution grid.

Recommendations

In view of the ambitious climate and energy target, T&D Europe sees the need to accelerate the pace of innovation and renovation of the electricity infrastructure started at the end of the 20th century. Future-proofing the electrical grid is a prerequisite for a successful energy transition. This requires the following actions:

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2. **Future-proofing the LV and MV networks**: DSOs, supported by regulators and technology providers, to prioritise projects on the basis of their contribution to improving the smartness of the network.

3. **Implementing the Clean Energy Package**: Member States to use the implementation of the Clean Energy Package - in particular Article 59(1)(l) of the EU Electricity Directive - as a way to put in place an operational regulatory framework promoting network modernisation;

4. **Unlocking investments**: Member State regulators to create the financial conditions for DSOs to invest in future-proofing the network by means of enhancing monitoring and control in MV and LV networks.

Glossary of terms

ANM	Active Network Management
AMI	Automated Metering Infrastructure
CAPEX	Capital Expenditure
DER	Distributed Energy Resources
DSO	Distribution System Operator
EMF	Electromagnetic Field
EMS	Energy Management System
OMS	Outage Management System
EC	European Commission
EU	European Union
EV	Electric Vehicle
FLISR	Fault Location Isolation and Service Restoration
FPI	Fault Passage Indicator
GIS	Geographical Information System
HV	High Voltage (depending on the context, above 1kV AC or above 36kV AC)
IEC	International Electrotechnical Committee
IED	Intelligent Electronic Device
IT	Information Technologies
LV	Low Voltage (below 1kV AC)
LPCT	Low Power Current Transformer
LPIT	Low Power Instrument Transformer
MDMS	Meter Data Management System
MV	Medium Voltage (between 1kV and 36kV AC)
OLTC	On load tap changer
OPEX	Operational Expenditure
OT	Operational Technologies
P2P	Peer-to-Peer
PCC	Point of Common Coupling
PD	Partial Discharge
R&D	Research and Development
RES	Renewable Energy Sources
RTU	Remote Terminal Unit
SAIDI	System Average Incident Duration Index
SAIFI	System Average Incident Frequency Index
SCADA	Supervisory Control and Data Acquisition
TCO	Total Cost of Ownership

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[1] SP Energy Networks, “Future Network Monitoring Strategy,” p. 15, September 2015.

[2] A. Silos, A. Señis, R. Martín de Pozuelo and A. Zaballos, “Using IEC 61850 GOOSE Service for Adaptive ANSI 67/67N Protection in Ring Main Systems with Distributed Energy Resources,” *Energies (MDPI)*.

[3] J. Wang, “ADMS for Grid Modernization – Importance of DMS for Distribution Grid Modernization,” Vols. ANL/ESD-15/16, Sep 2015.

[4] J. Dirkman, Best Practices for Creating Your Smart Grid Network Model, Vols. 998-2095-11-11-13AR0, Schneider Electric.

[5] A. T. Gordillo, “The Three Pillars for an Efficient AMI Operation,” Schneider Electric, Paris, 2014.

[6] A. Amezua, "Metering beyond AMI: Low voltage grid operation," *Metering & Smart Energy,* no. Issue 4, pp. 20-21, 2017.

[7] “Migrate Project,” https://www.h2020-migrate.eu/ , October 2017.

[8] G. Glinka, T. Schmidt and C. Bennauer, “Challenges and solutions for MV & LV Protection in grids with large amount of distributed generation. A Final Report from the german research project Profudis. Paper 0714,” in *CIRED. 24th International Conference on Electricity Distribution*, Glasgow, 12-15 June 2017.

[9] T&D Europe, “A smartness indicator for grids: Increasing transparency on the ability of electrical grids to support the energy transition,” 2017.

[10] L. Guise and T. Coste, “IEC 61850 in the Smart Grid,” *PAC World,* pp. Pages 18-25, March 2017.

[11] A. Alvarez de Sotomayor, D. Della Guistina, G. Massa, A. Dedè, F. Ramos and A. Barbato, "IEC 61850 based adaptive protection system for the MV distribution smart grid," in *Sustainable Energy, Grids and Networks*, Brescia, 2017.

[12] *UPGRID,* 01/01/2015 – 31/12/2017.

[13] *Integrid,* 01/01/2017 to 30/06/2020.

[14] *Thames Valley Vision,* 2012-2017.

ABOUT T&D EUROPE

T&D Europe is the European Association of the Electricity Transmission & Distribution Equipment and Services Industry, which members are the European National Associations representing the interests of the electricity transmission and distribution equipment manufacturing and derived solutions. The companies represented by T&D Europe account for a production worth over € 25 billion EUR, and employ over 200,000 people in Europe. Further information on T&D Europe can be found here: http://www.tdeurope.eu

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