R&D APPLICATION REPORT 2014

APPLYING R&D RESULTS TO DAILY OPERATIONS

European Network of
Transmission System Operators
for Electricity

entsoe

COVER IMAGE:
Nikola Tesla, (10 July 1856 – 7 January 1943) was a Serbian-American inventor, electrical engineer, mechanical engineer, physicist, and futurist best known for his contributions to the design of the modern alternating current (AC) electrical supply system. Tesla appears on the cover of the R&D Roadmap 2013–2022 as well as on the cover of the R&D Monitoring Report 2014 contributing to the device "Writing History Again".

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THE SCIENTIFIC MAN DOES NOT AIM AT AN IMMEDIATE RESULT. HE DOES NOT EXPECT THAT HIS ADVANCED IDEAS WILL BE READILY TAKEN UP. HIS WORK IS – LIKE THAT OF THE PLANTER – FOR THE FUTURE. HIS DUTY IS TO LAY THE FOUNDATION FOR THOSE WHO ARE TO COME, AND POINT THE WAY.

NIKOLA TESLA

INTRODUCTION

The R&D Application Report 2014 is an ENTSO-E publication aimed to assess the application and deployment of both theoretical and practical results provided by several Research and Development (R&D) projects carried out by European TSOs (Transmission System Operators) during the last few years, as well as to identify the main barriers faced and the lessons learnt, in order to draw useful conclusions to foster the R&D activities.

The R&D Application report 2014 is a special issue in the series of the R&D Monitoring Report, which is an ENTSO-E annual publication that assesses the research and development work performed by European TSOs. The previous R&D Monitoring Reports issued in 2012 and 2013 were focused on the assessment of the progress in achieving the overarching goals of the ENTSO-E R&D Roadmap 2013–2022, and on the identification of knowledge gaps to be fulfilled in subsequent years. The normal R&D Monitoring Report is expected to be released by the end of 2015 or beginning of 2016.

Objectives of R&D Application Report 2014

- To measure the success of R&D achievements and their practical applications in order to justify their effectiveness, to find best practices and to learn from experiences
- To identify lessons learnt where R&D has been successful and unsuccessful, and what obstacles remain for deployment
- To summarise main R&D applications and assess their outcomes as technologies or tools; to ascertain which results are being used and what the time scale is to deploy R&D in real applications
- To support communication and foster R&D work

Scope

- This report looks into already completed R&D projects and applications thereof, which have been demonstrated and deployed directly by TSOs involved in the projects during the last few years. Even though knowledge-sharing and transfer are crucial, this report does not study how R&D results were gathered and deployed by other TSOs not directly involved in the projects.
- This report is intended to demonstrate how the results of R&D projects are being deployed after their project's lifetimes. Instead of going into great detail here on how this has been achieved for each project, the Appendix of this report instead provides links to each project website where the reader can find more information.

METHODOLOGY OF R&D APPLICATION REPORT 2014

In developing this report, first the intended audience was determined followed by the questions the report should attempt to answer:

- This report is addressed to the TSO community at large, consisting not only of those carrying out the projects, but also all other TSOs who could potentially benefit from the R&D results.
- This report describes why TSOs have participated in the R&D projects, what some potential applications are, and how these applications are relevant to daily operations in transmission systems.

In order to be accurate and concise, this report addresses only nine relevant EU-funded projects that were finalised between 2009 and 2013 and involved one or more TSO members of ENTSO-E. Indeed, a certain time lag is deemed necessary to allow transmission system operators (TSOs) to demonstrate and deploy the results in daily operations. Now that many projects' outcomes have been tested under real-life operating conditions, TSOs can provide their feedback on what has been achieved and whether further improvements remain to be made.

These projects are: ANEMOS Plus, EWIS, ICOEUR, MERGE, OPTIMATE, PEGASE, REALISEGRID, TWENTIES and WINDGRID.

For each of these projects, this report seeks answers to the following four essential questions:

- **Improvements:** what are the most significant improvements – technical, operational, regulatory, social, environmental and economic – provided by each R&D project with respect to daily operations?
- **Demonstration and/or deployment:** have the R&D results been demonstrated and/or deployed by TSOs and, if so, how?
- **Wide-scale results:** have R&D results been disseminated to stakeholders, society, regulators, industry and other players and, if so, how?
- **Lessons learnt:** what lessons have been learnt through the project and what further steps are needed to make it easier to deploy the results?

This report does not attempt to assess the many other parameters linked to R&D results including the following:

- **Monetisation:** no attempt has been made to quantify the improvements R&D applications have brought to daily operations; this is not a straightforward matter to verify since it would require a set of assumptions that go beyond the scope of this report.
- **Ranking of R&D results:** this also would have proven to be difficult since each project has its own scope and objective.

The questionnaire was prepared and sent to TSOs directly involved in the projects being assessed. The feedback received was further evaluated by experts and grouped on a project-by-project basis. To further improve these analyses, all available information and deliverables from project websites and elsewhere was scrutinised in an unbiased manner.

Due to data collection constraints, not all of the expected responses were received. 31 of the 47 expected responses were received, which is equivalent to 66 %. Detailed information is given in the Appendix.

SIGNIFICANT R&D APPLICATIONS

This section concentrates on recent applications derived from the assessed R&D projects. The Appendix contains yet more discussion and additional details on the various applications. The Appendix also illustrates the most significant improvements provided by each R&D project in terms of technical, operational, regulatory, social, environmental and economic aspects.

The following main outcomes of performing R&D projects have been analysed:

- Technological advances and improvements
- Knowledge reinforcement and development of new tools
- Wider impact on power system stakeholders: society, regulators, industry, etc.
- Discovering new avenues for R&D activities to be pursued

The main objective of this section is to inform stakeholders about significant R&D applications resulting from the assessed projects. Furthermore, it allows stakeholders to monitor ENTSO-E progress in pursuit of the destinations given in R&D Roadmap 2013–2022.

TECHNOLOGICAL ADVANCES AND IMPROVEMENTS

Many technological advances and improvements were achieved during the course of the R&D projects. Many important power technologies were demonstrated and studied in TWENTIES and other R&D projects. These include power devices and power flow management, dynamic line rating, direct-current grid structures, balancing fast winds in storm conditions, balancing winds using virtual power plants, and system services provided by wind farms. Some concrete examples of R&D applications are given on the next pages.

DYNAMIC LINE RATING APPLICATION FOR EXTRA TRANSMISSION CAPACITY

While dynamic line rating (DLR) has already been used by National Grid on a few selected assets, the EWIS project results convinced the British TSO to extend it to several other transmission assets. For instance, TenneT TSO B.V. in Netherlands has begun to apply DLR to a few 150 kV lines with the aim of eliminating dispatching costs. Furthermore, some of the recommendations set out in the project's final report were accepted into the Polish TSO's national development plan, hence highlighting how the results of this project have helped to unify requirements for generators at the pan-European level.

Successful demonstrations of the TWENTIES project have shown that the power infrastructure can be used much more efficiently than it currently is. By using the combined effect of DLR and power-flow controlling devices to manage flows in the European grid, more wind infeed can be integrated and local congestions can be alleviated in a flexible manner. TWENTIES was a demonstration project and almost all of the technologies proven in this project have been installed. For instance, DLRs and the DLR forecasts are currently in use in Belgium while Overhead Line Controllers and Real-Time Thermal Rating are already being applied in Spain on a daily basis.

SIGNIFICANT MILESTONE ACHIEVED TOWARDS REALISATION OF HVDC GRIDS

Knowledge and information on the feasibility of high-voltage direct current (HVDC) grids is being utilised in current HVDC interconnector projects between France and Spain (INELFE) and France and Italy (Piémont–Savoie project). TWENTIES results have also shown that additional R&D effort is still needed on specific issues such as interoperability in multivendor multi-terminal HVDC grids. Indeed, while efficient and secure operation of HVDC networks could be demonstrated, technical specifications and standards are still required in a multivendor context to ensure good performance in transient regimes and to prevent adverse interactions between terminals and devices. The BEST PATHS project currently underway will tackle some of these issues.

KNOWLEDGE REINFORCEMENT AND DEVELOPMENT OF NEW TOOLS

RESULTS FROM R&D PROJECTS APPLIED IN NATIONAL CONTROL CENTRES

The ANEMOS Plus project has developed a probabilistic forecast tool and method for mobilising reserves that has mainly been applied at the control centre of TSO REN (Portugal). This has increased transparency at REN by quantifying the additional reserves required especially due to high penetration of wind power in this market.

The results of the WINDGRID project have been applied within REN at the control centre. Now that the respective protocols are compatible with each other, it is now possible to link the control centre with the renewable control centre. This makes it possible to define a setpoint that limits the active and reactive power output for each individual wind farm. The project results provide TSOs with a means of controlling the maximum plant output using different methods of regulating reactive power (from constant tangent phi, constant reactive power and the innovative method of constant voltage at 150 kV level).

The results of the MERGE project have been already applied by TSOs REN and REE (Spain) for time domain simulations. One of the most significant developments was the realisation of a new enhanced version of the RESERVAS Model. A software tool has been created to simulate different system scenarios with varying penetration levels of electric vehicles for short and long-term planning purposes. This provides information about potential impacts on the system (transmission grid and demand). Both TSOs (REE and REN) performed a reliability assessment of the Iberian (Spanish and Portuguese) power systems with a focus on EENS (Expected Energy Not Supplied) reliability indexes. The adequacy of the Iberian transmission system in 2020 and 2030 was assessed through probabilistic and fuzzy analyses respectively. It was observed that transmission networks are robust enough to integrate the expected number of electric vehicles.

TSO Terna (Italy) plans to utilise the R&D results of the ICOEUR project to develop new automatic procedures for stability analyses with energy management system (EMS) tools. They can be run in offline mode for inter-area oscillation analyses of the interconnected network. If not connected to EMS tools, they can only be run as standalone applications. By applying the R&D results, Terna is improving these security analysis tools.

The results of the PEGASE project have already been applied within TSO RTE (France) to improve several tools and processes. Most notably, many of the algorithmic advances in time-domain simulation were implemented in the EUROSTAG simulation software and are now being used in operational studies. As a result of the gains, studies with models representing the complete network of continental Europe are more commonly run, thus removing any limits and uncertainties associated with dynamic network equivalents.

REINFORCEMENT OF ENGINEERING EXPERTISE THROUGH R&D RESULTS

Through the PEGASE project, several young engineers at TSO RTE have gained considerable knowledge and expertise by developing and maintaining the EUROSTAG simulation and other similar tools. By collaborating on research with leading academic partners, these engineers have learned about the challenges and difficulties of simulating the dynamic phenomena of large power systems. They have developed a clear understanding of the innovative ideas which have come out of the project, and have readily implemented them in operational tools within a year or two subsequent of the project. They are now able to provide key guidance within RTE on these issues at a time when dynamic simulations are increasingly being used to make critical decisions for network operation and planning. They also share this knowledge with other members of the RTE R&D teams.

As illustrated here with dynamic time-domain simulation tools, the involvement of dedicated RTE R&D engineers in PEGASE can therefore be regarded as one of the key success factors in transferring the results of the project into concrete achievements and gains within RTE.

TSO Elia (Belgium) purchased a license for the OPTIMATE platform and is mainly using it in the framework of other research projects. Energy market designers are amongst its main users. Elia has trained its personnel to deploy the R&D results in applications and a cloud-based platform is available.

WIDER IMPACT ON STAKEHOLDERS

The results of the EWIS project have had a positive effect on TSOs but also on other actors. For instance, both stakeholders and society will benefit from reduced CO_2 emissions. By integrating massive quantities of wind power into the grid, environmentally friendly electricity can be transferred to customers and hence cleaner energy will be consumed.

In addition, the EWIS results provided understanding for national regulatory agencies to support the need to harmonise network code requirements and this has encouraged them to work more transparently and effectively by utilising both cost-benefit and system need analyses.

The energy industry at large is becoming more aware of supply contract issues. Rather than just sourcing the cheapest energy, some have partnered with suppliers specialised in renewable energy. This allows them to communicate to their customers that the energy used to create their product was generated from renewable sources.

A cost-benefit analysis of the TWENTIES project has been performed for the electrical power system as a whole, not under a particular TSO business perspective. Another main issue was to ensure that application of these technologies does not undermine current reliability and security standards.

Multi-criteria cost-benefit analyses (as adopted in the REALISEGRID project) have been and remain a subject of interest and learning. Depending on how European grid methodologies are further developed, it may become possible to apply them.

By participating in these projects, TSOs have gained much new expertise beyond planning aspects. R&D has provided an opportunity for deepening knowledge of certain subjects and opened dialogues with stakeholders. It has also fostered communication between TSOs and other stakeholders.

DISCOVERING NEW AVENUES FOR R&D TO PURSUE

The results of PEGASE have contributed positively to the R&D Roadmap and established a good basis for subsequent R&D projects such as Umbrella and iTesla. The iTesla project, for instance, follows up on many of the improvements and modules developed through PEGASE with the aim of combining them into a single prototypical suite. RTE also continues to exploit PEGASE R&D to improve its simulation tools. Some ideas whose feasibility was demonstrated in PEGASE have also been integrated into R&D projects in other areas, such as the concept of distributed state estimation for digital substations.

A follow-up to OPTIMATE is a European project called Market4RES which investigates the potential evolution of the Target Model for integrating EU electricity markets. This will establish a secure and sustainable power system with a high mix of renewables. With a focus on wholesale market design, Market4RES aims to recommend the required steps for implementing policy, legislation and regulation across the different timeframes of the energy markets. One of the key objectives of the project is to facilitate dialogue between stakeholders concerning which steps are required to achieve the most economically sustainable market design.

A direct-current circuit breaker prototype was tested successfully within the TWENTIES project. This establishes confidence in continuing the BEST PATHS project started in October 2014. This project will demonstrate large-scale integration of innovative transmission systems and operational solutions for inter-connecting renewable electricity production.

LESSONS LEARNT

In the process of carrying out R&D projects, many project management issues arise from which the success of the project highly depends. Specifically, this pertains to international projects involving different actors and stakeholders with diverse organizational cultures and priorities.

Even though this particular topic was addressed in the survey, many of the responses received were not particularly clear. For the majority of the projects, it can be assumed that post-review processes were insignificant or omitted entirely.

Interestingly, this could be the first lesson learnt from this survey, namely the importance of a post-review process following the completion of each project. A validation and summary report including the positive and negative aspects of each phase should be shared amongst all project participants. With this kind of evaluation summary, it will be much easier in the future to have clear answers on this subject.

As a result of the analyses performed, it was nonetheless possible to extract some key lessons regarding the life cycle of the R&D projects.

These are the recommendations on how to successfully deploy the results from R&D projects.

INITIAL STAGE

- Define your priorities (participation work packages): what do you wish to achieve with the project? Are these goals feasible and are they aligned with your TSO strategy?
- Get approval from a senior level within the organization.
- Good communication between TSOs and their partners is essential – define your message according to your target audience; select the best channel/tool for this. The project objectives and main results must be clearly understood. This helps to involve the team and mobilises crucial support from other departments.

DEVELOPMENT STAGE:

- Validate the intermediate results and invite operating personnel (end users) and, if applicable, manufacturers to participate.
- Cost-benefit analyses should be done for new tools requiring significant financial investment prior to deployment. This also applies to data gathering and data management. It may be necessary to make adjustments during this phase to ensure the successful deployment.
- The technical personnel/departments of TSOs (as final users of the project results) have to get involved in the early stages of the project in order to smoothly apply and exploit the new methodologies and tools to their daily activities.

IMPLEMENTATION STAGE:

- Main results should be disseminated to all potentially interested parties in order to promote their exploitation and sharing.
- Whenever necessary, project staff should be trained on the job.
- Beware of some common barriers/challenges:
  - Lack of human resources for in-house deployment of tools
  - Availability of requisite technical expertise
  - Lack of regulatory framework

CONCLUSIONS

R&D Application Report 2014 provides an overview of the significant R&D achievements, together with lessons learnt by members of ENTSO-E. It also assesses and verifies the theoretical and practical results ensuing from R&D performed by European TSOs and explains how TSOs have been able to successfully demonstrate and/or deploy the results.

Although R&D is still a relatively new field for many TSOs and collaborations have only just begun, many significant results have already been achieved through R&D such as the following:

- Technological advances and improvements to integration and testing of HVDC technologies, dynamic line rating, flexible devices
- Knowledge reinforcement for workforce and extra tools for system operation and market simulation
- Wider impact on stakeholders (society, regulators, industry, etc.)
- Pursuing new directions in R&D

It is challenging to perform R&D that can be well exploited for the improvement of TSOs and society as a whole. Appropriate measures should be considered before, during and after an R&D project to ensure that the results can be deployed successfully.

These achievements are helping to catalyse and establish the trust of personnel currently working on R&D and deployment. The projects referred to in this document also demonstrate that TSOs are increasingly pursuing joint projects of importance for all of Europe. Thus, the results stimulate further collaboration on R&D that will lead to yet more knowledge and tools, while also establishing the trust of funding institutions and regulators.

APPENDIX
SUMMARY OF MAIN R&D APPLICATIONS PER PROJECT

To enhance the readability of this Report, the summary of the main R&D applications per project has been placed in this Appendix. The summary reflects feedback received from the TSO questionnaire.

Since responses were not received on all topics from all recipients, this summary may not cover the entire spectrum of potential applications for TSOs resulting from a particular R&D project. Nonetheless, the results are very encouraging even though R&D is still new to TSOs.

As mentioned in section 2, this Appendix addresses nine relevant EU-funded projects that were finalised between 2009 and 2013 and involved one or more TSO members of ENTSO-E (table 1). A questionnaire was sent to TSOs who were directly involved in the projects. The feedback received has been further evaluated by experts and grouped on a project-by-project basis. To further improve these analyses, all available information and deliverables from project websites and elsewhere was scrutinised in an unbiased manner.

Due to data collection constraints, not all of the expected responses were received (table 2). 31 of the 47 expected responses were received, which is equivalent to 66 %.

No	Projects	Start/End
1	ANEMOS Plus	2008/2011
2	EWIS	2007/2010
3	ICOEUR	2008/2010
4	MERGE	2010/2011
5	OPTIMATE	2009/2012
6	PEGASE	2008/2012
7	REALISEGRID	2008/2011
8	TWENTIES	2010/2013
9	WINDGRID	2006/2009

Table 1: List of R&D projects under analysis

TSOs/Projects	ANEMOS plus	EWIS	ICOEUR	MERGE	OPTIMATE	PEGASE	REALISE-GRID	TWENTIES	WINDGRID	No of projects TSOs involved
50Hertz		x			x			x		3
Amprion		x								1
APG		x					x			2
CEPS		x								1
EirGrid	x	x								2
Elia		x			x	x		x		4
Energinet.dk		x						x		2
HEP-OPS		x				x				2
LITGRID						x				1
National Grid		x								1
PSE		x								1
REE	x	x		x	x	x		x	x	7
REN	x	x		x		x			x	5
RTE		x			x	x	x	x		5
SONI	x									1
TenneT DE		x								1
TenneT NL		x					x	x		3
Terna			x				x			2
Transelectrica						x				1
TransnetBW		x			x					2
No of TSOs involved in R&D projects	4	16	1	2	5	7	4	6	2	47

Table 2: 'X' indicates projects with TSO participation; dark orange fields indicates projects where responses were received in questionnaire

ANEMOS PLUS

ANEMOS Plus

Brief description:
ANEMOS Plus developed and demonstrated advanced tools for managing electricity grids containing large-scale wind generation.

Start/End: 2008/2011 **Budget:** € 5.7 million **Funding scheme:** Granted by 6th Framework Programme

Consortium:

TSOs: REN (PT), REE (ES), EIRGRID (IE), SONI (GB)

Others: EWE (DE), Acciona Energia (ES), DONG Energy Generation (DK), Danish Technical University (DK), OVERSPEED GmbH (DE), Energy & Meteo Systems GmbH (DE), ENFOR (DK), University Carlos III Madrid (ES), INESC Porto (PT), CENER (ES), University College of Dublin (IE), University of Antilles & Guyane (FR), National Technical University of Athens-ICCS (GR), PPC (System Operator of Crete Island, GR), EDF-Guadeloupe (System Operator of Guadeloupe Island, FR).

Website: www.anemos-plus.eu

Cordis: cordis.europa.eu/project/rcn/86586_en.html

1. RATIONALE

The ANEMOS Plus project assessed optimal management of electricity grids with large-scale wind power generation. The project developed new intelligent management tools for addressing the variability of wind power with an emphasis on integrating wind power forecasts and related uncertainty into the key management functionality of power systems. The project demonstrated the applicability of such prediction tools at an operational level both for managing wind penetration and for trading wind generation on electricity markets.

TSOs were motivated to join the project to improve the wind power forecast tool.

This summary reflects where feedback was received from REE and REN.

2. MAIN R&D PROJECT RESULTS

Here are the most significant results and achievements of the project:

- A probabilistic approach to wind forecast was developed that gives more information than the traditional deterministic forecast, thus enabling the deployment of innovative tools to aid in the decision-making process for system operators.
- TSOs can quantify their confidence in the forecast and the error size.
- Better assessment of additionally required reserves through wind power forecast errors, thus optimizing the reserves mobilised in the power market.

3. TSO DEPLOYMENT OF R&D

The REN control centre tested a probabilistic forecast tool and method for mobilising reserves developed through this project. But further applications of this project are restricted by the lack of human resources.

REE has chosen to not use this tool for the Spanish system since the results obtained using the ANEMOS Plus upscaling method were not an improvement over the results from REE's own tool (SIPREOLICO). The latter tool allows REE to receive real-time measurements from almost all of their wind farms.

For REN, the R&D results allow them to better quantify the need for additional reserves ensuing from high penetration of wind power. The ANEMOS Plus upscaling method could be interesting for REE in cases where real measurements are not available.

4. LESSONS LEARNT THROUGH R&D DEPLOYMENT AND DISSEMINATION

The advances related to this European project made it possible to continue and improve the development of a predictive solution of wind power electricity generation developed by REN in direct collaboration with a national academic institute.

The sharing of information between partners generated surplus value in daily base operations as evidenced by the files shared by the Spanish electricity network for the purpose of calculating weekly interconnection capacities.

However, the developed wind forecasting model had some challenges to overcame, such as the ability to anticipate wind or increases in generation over longer time horizons. This project represents the opportunity to improve the existing tools and projects related to this subject.

It is important to note that throughout the life cycle of the project, some workshops (at national and international level) were held to present the results of the ANEMOS Plus project and to discuss the state-of-the-art of energy production forecasting. For instance, at national level, a workshop took place in Portugal (Lisbon) to demonstrate the main results of the project as well as demo cases tested by REN.

At the international level, a workshop was held in Paris in collaboration with the other project partners.

EWIS (European Wind Integration Study)

Brief description:
EWIS addressed immediate network-related challenges by analysing detailed representations of the existing electricity markets, network operations, and the physical power flows and other system behaviours. It began with actual conditions in 2008 and future challenges were assessed through realistic representations of network extensions and reinforcements taken from national development plans. In general, detailed information on user and network developments are only available for a limited number of future years and 2015 was chosen as a suitable horizon for assessing how current plans will address future challenges. Given the importance of the 2020 targets, however, the study examined prospects for further developments beyond 2015. The projects has provided important input for Ten-Year Network Development Plan (TYNDP) from 2010, the system needs for Network Pilot Code and system security aspects for the future coordinated and stable operation of the pan-European transmission system.

Start/End: 2007/2010 **Budget:** € 4.0 million **Funding scheme:** Granted by 6th Framework Programme

Consortium:

TSOs: Elia (BE), Transpower GmbH (DE), 50 Hertz Transmission (DE), Amprion GmbH (DE), CEPS (CZ), Eirgrid (IE), Energinet.dk (DK), HTSO (GR), National Grid (UK), PSE (PL), REE (ES), REN (PT), RTE (FR), Tennet TSO B.V. (NL), Verbund (AT).

Others: EC, EWEA, Eurelectric, EFET, IEA, Tradewind…

Website: www.wind-integration.eu

Cordis: cordis.europa.eu/project/rcn/85678_en.html

1. RATIONALE OF TSO INVOLVEMENT

The main objective of EWIS was to analyse the pan-European impact of large-scale integration of wind power and to determine the most sustainable and effective means of integrating it into Europe's transmission networks and electricity system.

TSO participation was essentially motivated by the following:

- To find solutions for enhancing grid flexibility and avoiding congestions in windy conditions
- To verify the urgency of fulfilling a set of requirements so as to ensure system stability together with massive wind penetration
- To develop solutions for grid congestion by investigating additional/new grid infrastructure and control measures
- To investigate increasing use of balance power, reserve capacity, power flow control coordination and measures to operate transmission networks with rising uncertainties, deriving from wind generation

In the Polish case, for instance, the project was used to analyse the increased influence of loop flows from Germany on the Polish grid due to massive wind development in Germany.

This summary reflects feedback received from APG, Energinet.dk, National Grid, PSE, REE, RTE, TenneT NL and TenneT DE.

2. MAIN R&D PROJECT RESULTS

When interviewed, TSOs highlighted the following as the most significant results:

Network planning:
- A complete European-grid model was developed.
- Static studies identified where European grid reinforcements are needed and beneficial additional measures to those already identified in National plans.
- Dynamic studies were performed for the horizons 2011 and 2015.
- ENTSO-E subgroup System Protection and Dynamics is still using and improving this model.

System operation:
- A new approach was found on how to securely use dynamic line rating by defining rules for the coordination of protection settings, (n-1) and stability limits, power flows, congestion management and dispatching.
- Flexible line management could reduce overall generation cost and help to transport wind power around Europe for low investment costs.

Market:
- A European market model was developed and identified potential savings of 20 billion EUR for operating European electricity system.
- Quantification of benefits from wind power for reducing CO_2 emissions.
- An analysis of the need/feasibility of new pan-European interconnections was performed and hydraulic pumping stations.

Increased cooperation and coordination between European TSOs at both regional and inter-regional levels has led to sharing of operational planning information, improved grid power flow predictions, and also enabled outage scheduling and flow-based capacity assessments, while at the same time preventing congestion and local imbalances.

The overall results also justified the necessity of improved forecasting. In the British case, it was useful to build an initial business case for developing the Wind Power Forecasting System and enhancing business processes. In its first month of operation, average wind forecast errors in the system were reduced from 18 % to 14 %.

While, as far as the market is concerned, EWIS helped to develop a pan-European market model that improved power system economics by allowing for current and future development of support mechanisms for wind energy and/or network access rules.

Furthermore, EWIS accounts for the pros and cons of various market and network storage solutions in combination with the necessary grid development in Europe.

The final EWIS report contains recommendations for TSOs, NRAs (National Regulatory Authorities), governments and policy makers, and calls for immediate action.

3. TSO DEPLOYMENT OF R&D

EWIS results have been deployed widely by TSOs and ENTSO-E and helped ENTSO-E to draft the Requirements for Generators of the European Network Code (NC-RfG), particularly for wind power generation.

While dynamic line rating has already been used by National Grid on a few selected assets, the EWIS project results convinced the British TSO to extend it to several further transmission assets. For instance, TenneT TSO B.V., in Netherlands has begun to apply dynamic line rating to a few 150 kV lines with the aim of eliminating dispatching costs. Furthermore, some of the recommendations set out in the project's final report were accepted into the Polish TSO's national development plan, hence highlighting how the results of this project have helped to unify requirements for generators at the pan-European level.

There were several research challenges to be overcome in this project, including the following:

- Allocating sufficient project management resources
- Planning sufficient testing time
- Management of system interfaces
- Adequate staff training and engagement
- Post-deployment fixes
- Management of outsourced contracts

Applying the EWIS results has had a positive effect not only on TSOs but on other actors too. For instance, both stakeholders and society will benefit from reduced CO_2 emissions. By integrating massive quantities of wind power into the grid, environmentally friendly electricity can be transferred to customers and hence cleaner energy will be consumed.

National regulatory agencies now understand more fully the need to harmonise the network code requirements and this has encouraged them to work more transparently and effectively by utilising both cost-benefit and system need analyses.

The energy industry at large is becoming more aware of supply contract issues. Rather than just sourcing the cheapest energy, some have partnered with suppliers specialised in renewable energy. This allows them to communicate to their customers that the energy used to create their product was generated from renewable sources.

At the ENTSO-E level, the results have contributed positively to the R&D plan and established a solid basis for new R&D projects as Umbrella and iTesla. To a larger somewhat indirect extent, the project results are also having a positive impact on reaching the EC 2020 targets.

4. LESSONS LEARNT THROUGH R&D DEPLOYMENT AND DISSEMINATION

In the process of carrying out R&D projects, many project management issues arise from which the success of the project highly depends. First of all, there is always a lack of resources or budget. It is crucial to set the right priorities and make good choices. The best way of developing a project is by taking small steps and achieving reliable results that can be demonstrated to all stakeholders.

Major projects such as EWIS require approval and support from senior management. Without this, complex projects involving multiple departments can be very difficult to complete.

ICOEUR

ICOEUR

Brief description:
The ICOEUR project (Intelligent Coordination of Operation and emergency control of EU and Russian power grids) addresses the topic of innovative operational and monitoring tools for large power systems.

Start/End: 2008/2010 **Budget:** € 4.8 million **Funding scheme:** Granted by 7th Framework Programme

Consortium:

TSOs: Terna (IT), ELES (SI)

Others: TEIAS, IPS, State research institute – Institute of Physical Energetics (IPE), Power System Emergency Control laboratory, Ltd, ELPROS Electronic and Programming Systems, Siberian Electric Power Research Institute (SibEPRI), All-Russian Electrotechnical Institute named after V.I.Lenin" – FGUP VEI, Trapeznikov Institute of Control Sciences (ICS RAS), Suez-Tractebel, Regio Politecnico di Torino, ABB, Riga Technical University, Tallinn University of Technology, The Electric Power Systems Laboratory (LRE) of the Swiss Federal Institute of Technology, Lausanne (EPFL), University of Birmingham, ERSE S.p.A. (ENEA - Ricerca sul Sistema Elettrico), Energy Systems Institute (ESI), Technische Universität Dortmund.

Website: www.icoeur.eu

Cordis: cordis.europa.eu/project/rcn/90889_en.html

1. RATIONALE

The ICOEUR concept searched for the best interconnection between the EU and Russian electricity transmission networks. This interconnection should provide the best technical requirements with respect to security of supply and stability of operation for both the common and isolated power systems. Furthermore, it should also establish more secure "electricity highways" for the exchange of energy between these markets.

TSOs were motivated to pursue this project by the potential benefits of an improved interconnection between the two largest power systems, UCTE and IPS/UPS.

This summary reflects feedback received from Terna.

2. MAIN R&D PROJECT RESULTS

One significant achievement was that Terna collaborated with CESI-RICERCA (now RSE) to develop a new inter-area oscillation analysis tool.

3. TSO DEPLOYMENT OF R&D

Terna plans to apply the R&D results to develop new automatic procedures for EMS tools used in stability analyses. Offline mode can be used for inter-area oscillation analyses of the interconnected network but only as a standalone application without being connected to EMS tools.

The main barrier to overcome is the implementation of the newly experimented tools in TSOs' everyday activities.

By applying the R&D results, TSOs have improved the security analysis tools developed in cooperation with technology suppliers.

4. LESSONS LEARNT THROUGH R&D DEPLOYMENT AND DISSEMINATION

The results were used to re-calculate the setting of the Power System Stabilizer apparatus for the main power plants. The knowledge and experience acquired during the project should be shared with those who, although not project participants, are nonetheless involved in similar activities and tasks such as dynamic stability studies of the European interconnected system.

MERGE

MERGE (Mobile Energy Resources in Grids of Electricity)

Brief description:
The project mission was to evaluate the impact of electric vehicles (EV) on the EU electric power systems with respect to planning, operations and market functioning. The focus was placed on EV and SmartGrid/Microgrid deployment. This should involve an increase in the renewable energy and thus reduce CO_2 emissions. Furthermore, the project should identify suitable enabling technologies and advanced control approaches.

Start/End: 2010/2011 **Budget:** € 4.4 million **Funding scheme:** Granted by 7th Framework Programme

Consortium:

TSOs: PPC (GR), REE (ES), REN (PT).

Others: INESC Porto, ICCS/NTUA, TU Berlin, Cardiff, Comillas, Iberdrola, ESB, AVERE, RAE, Ricardo, IMR World, C4D and InSpire.

Website: www.ev-merge.eu

Cordis: cordis.europa.eu/project/rcn/94380_en.html

1. RATIONALE

The future integration of electric vehicles (EVs) into the electric grid will have a significant impact on the core activities of TSOs.

The MERGE project addresses this topic holistically by evaluating all of the potential effects of plugging EVs into the grid. By addressing the impacts on generation and grid infrastructure, the results of this project are directly relevant to the future development of European electricity.

This project summary reflects feedback received from REE and REN.

2. MAIN R&D PROJECT RESULTS

The MERGE project developed a new set of management and control concepts that would facilitate the safe integration of EVs into electrical grids, whereby as much renewable energy as possible should be used for battery charging. It also introduced a suite of simulation tools capable of analysing the impact and adequacy of different EV integration control strategies for the grid in consideration of different EV deployment levels. Using this simulation suite, it was possible to identify necessary policies and regulations and also plan the technical evolution of the required generation and network infrastructures.

The results of this R&D had the following impacts:

- Technical/regulatory
- Societal/environmental

Some of the quantitative results achieved with the potential impact of integrating EVs into EU power grid include:

- Load consumption profiles
- Generation schedules
- Power flow patterns
- Power quality and CO_2 emissions

3. TSO DEPLOYMENT OF R&D

Some results of the MERGE project have already been applied by TSOs REN and REE. One of the most significant applications has been the possibility of implementing a new enhanced version of the RESERVAS model.

A software tool has been developed to simulate various system scenarios considering different EV penetration levels for short and long-term planning purposes in order to provide information about consequent impacts in the system (transmission grid and demand).

At REE, departments in charge of network planning, network studies, demand management and regulatory affairs have been able to apply the project result for the following purposes:

- Transmission grid planning proposal to be submitted to regulator (considering EVs demand)
- Static and dynamic network studies
- Prediction and demand coverage
- Get different simulation results to be used as a support to define Time-Of-Use tariffs

Whereas, in REN the departments of electricity planning and engineering, studies and regulation, and energy market did the same for the following purposes:

- Assess the impact of EV on long-term operating reserve taking into account three EV penetration scenarios (realistic, aggressive and very aggressive) for 2020 and 2030
- Assess the impact of the additional EV-charging demand on a system (annual and daily), load diagram curves were identified for Portugal, considering different charging strategies (dumb, multi-tariff and smart)
- Grid Operation Analysis with EV presence, considering different EV penetration levels and charging strategies (dumb, dual-tariff and smart)
- Long-term system planning, considering different EV penetration levels and charging strategies (dumb, dual-tariff and smart)

Both REE and REN applied the results of this project for the following purposes:

- A reliability assessment analysis was performed for the Iberian (Spanish and Portuguese) power systems focussing on the EENS (Expected Energy Not Supplied) reliability indexes.
- The adequacy of the Iberian transmission system (Portugal and Spain) in 2020 and 2030 was assessed through probabilistic and fuzzy analyses respectively. It was observed that transmission networks are robust enough to integrate the expected number of electric vehicles.

Some of the main developments of the MERGE project relevant for day-by-day operations at REN include:

- New version of RESERVAS model for assessing impact of EV on long-term operating reserve
- Knowledge of how to handle EV penetration scenarios and analyse EV impact on system load diagram (annual and daily)
- New grid operation analysis to account for EVs with varying penetration levels and charging strategies
- New long-term system planning analysis, considering different EV penetration levels and charging strategies (dumb, dual-tariff and smart)
- Knowledge of EV integration in electricity grids, in particular regarding design of day-ahead and intra-day markets

For instance, REE did not previously consider EV integration to have a potential impact on system operation or grid development. Following this project, they now have a much better understanding of its effects.

4. LESSONS LEARNT THROUGH R&D DEPLOYMENT AND DISSEMINATION

The MERGE project concluded that EV impact will be influenced by several factors, including:

- Degree of EV integration
- EV owner behaviour
- Mobility patterns
- Network load profiles and technical characteristics
- Number and location of fast-charging stations on grid
- EV charging modes etc.

Regarding forecasts of EV integration levels in 2020 and 2030, it was concluded that, independently of the charging strategy adopted, no relevant technical problems are expected to occur in the majority of the European power systems until 2020. Conversely, in 2030, several problems may arise if EV charging is adopted in an uncontrolled manner. Besides postponing network reinforcements, controlled charging schemes allow larger amounts of renewables to be integrated without jeopardizing normal network operation.

In summary, the biggest immediate challenge is how to foster acceptance of this new technology. Once underway, the integration of EV via aggregation and market participation should be assessed. Ultimately, it should be possible to accommodate more complex and technically challenging services, such as provisioning of reserves.

Since the beginning of the project, technically experienced TSO staff and the future end-users of the project results were invited to participate, so their opinion and needs were taken into account. This was a critical to smoothly apply new methodologies and tools in a proper and efficient way.

A webpage has been set up at www.ev-merge.eu to disseminate the results of this project. This site has been run and maintained from the beginning of the project and has provided public access to approved deliverables and documents. The MERGE concepts and ideas developed throughout the project have been presented at various conferences and international gatherings, and they have also been published in journals and conference proceedings. Contacts with G4V have been established and three joint workshops have been held. Further dissemination has been achieved through CIGRE, EURELECTRIC, EDSO for SmartGrids and other organizations. MERGE partners have contributed to the IEC61851 standard.

OPTIMATE

OPTIMATE

Brief description:
OPTIMATE developed a numerical test platform for analysing and validating new market designs that allow massive integration of flexible generation dispersed throughout several regional power markets.

Start/End: 2009/2012 **Budget:** € 4.2 million **Funding scheme:** Granted by 7th Framework Programme

Consortium:

TSOs: RTE (FR), EnBW Transportnetze AG (DE), REE (ES), ELIA (BE), 50 Hertz (DE).

Others: Katholik University of Leuven (BE), Association pour la Recherche et le Développement des Méthodes et Processus Industriels, ARMINES (FR), University Comillas (ES), RISOE-DTU (DK), European University Institute (IT), University of Manchester (UK).

Website: www.optimate-platform.eu

Cordis: cordis.europa.eu/project/rcn/94490_en.html

1. RATIONALE

OPTIMATE is a numerical simulation platform designed to compare wholesale electricity market designs (both existing and innovative ones) for the integration of massive intermittent energy in compliance with the three EU energy pillars (economic efficiency, climate policy and security of supply). The objective is be to develop an European market simulator (day, intraday, congestion and complementary services) according to different market designs and considering the installed generation in 2015, which is expected to include a large amount of RES share.

OPTIMATE aimed to encourage dialogue between among network operators, regulators and other electricity stakeholders. It demonstrated the benefit of providing quantitative indicators to policy makers so that they can anticipate the effects of their short-term market design choices. By quantifying the economic and environmental impact of market design choices, they have solid grounds to discuss their own policy recommendations with policy makers and other electricity stakeholders.

TSOs were motivated to participate in this project for the following reasons:

- RTE wished to share a transparent platform where market designs could be discussed with all stakeholders, and where the impact of various market designs on short-term electricity markets (from day-ahead to intraday) could be seen.
- The Elia group wished to optimise reserves by accounting for wind fluctuation and green certificate payments.
- REE wished to investigate the impact of the variation of RES into the market behaviour, especially in the long term, where forecasts are more inaccurate.

This summary reflects feedback received from the Elia group (50Hertz and Elia), REE and RTE.

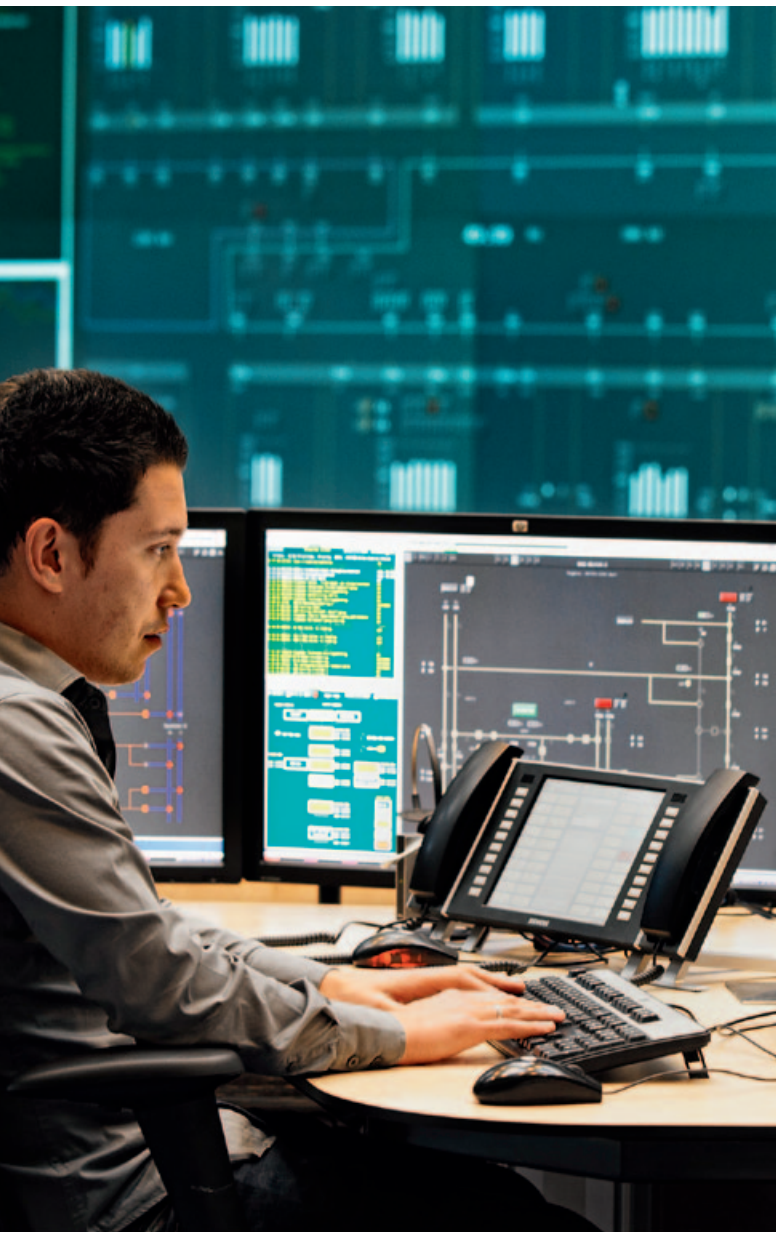
2. MAIN R&D PROJECT RESULTS

The most significant achievements of the project are:

- A prototype was developed as a genuine proof of concept. TSO now have a shared tool that they can use to assess short-term market design issues, and this was not possible before the project. This will help to improve the operational market-related activities of RTE by eliminating the need for special tools.
- A platform has been delivered that allows registered participants (customers) to make simulations by analyzing the impact of changing market design. It provides the capability of assessing how markets behave from day-ahead to real-time considering different designs in different countries.
- The results of the OPTIMATE project have been shared with TSOs, academics, regulators, the European Commission and other stakeholders.

The direct economic benefits associated with the project include:

- Reduction of time required to study market evolutions and faster implementation of better market designs.
- The project partnership made it possible to share capacities and develop a platform that no single partner could have done alone. By assessing the impact of market design changes, each partner can choose the most suitable solution to implement.



3. TSO DEPLOYMENT OF R&D

OPTIMATE is the first European market simulation tool whose results can be used by any stakeholder. By allowing more transparent and quantitative studies of innovative market designs, OPTIMATE makes it possible to quickly and efficiently implement changes to market designs as explained below in more detail:

- Redistributive effects between players and geographic areas can be measured in terms of social welfare, consumer surplus, generator surplus, congestion revenue, etc. This uncovers any issues that can potentially develop when new designs are implemented.
- OPTIMATE generates hypotheses that are transparent.
- The prototype can be used to assess various market designs and this flexibility will be improved in the industrial version of the tool.

A follow-up to OPTIMATE is a project funded by Intelligent Energy Europe called Market4RES (http://Market4RES.eu/). This project investigates how the target model can evolve to integrate EU electricity markets into a sustainable, functioning and secure power system with a high mix of renewables. With a focus on wholesale market design, Market4RES aims to identify and recommend the required steps for implementing policy, legislation and regulation across the different timeframes of the energy markets. One of the key objectives of the project is to facilitate dialogue between stakeholders concerning which steps are required to achieve the most economically sustainable market design.

TSO Elia purchased a license for the OPTIMATE platform and is mainly using it in the framework of other research projects. Energy market designers are amongst its main users. Elia has trained its personnel to deploy the R&D in applications and a cloud-based platform is available.

4. LESSONS LEARNT THROUGH R&D DEPLOYMENT AND DISSEMINATION

The results of OPTIMATE are currently being applied in the Market4RES project for instance. It is also important to differentiate between the direct benefits of OPTIMATE and the additional experience gained by testing various market designs within OPTIMATE. For example, OPTIMATE does not directly reduce operational risks but instead allows users to assess the impact of a market design on TSO risks.

One of the challenges is the complex nature of the platform. In fact, it must be used frequently to become familiar with its features. The simulation itself requires immense volumes of data to be managed. It is also difficult to assess quantitative improvements from the platform since they themselves are linked to market fluctuations.

It is suggested to mandate compulsory use of the tool in order to establish it as a platform. This rule is currently in place for RTE's market department and others who use the prototype within the Market4RES project.

Due to scarce resources, it is usually more costly in terms of time and resources to deploy fresh R&D results than conventional solutions. High cost plus high risk make it difficult to set a high priority on these deployments.

The results of OPTIMATE can be further disseminated to academics for their own research or even used for educational purposes.

PEGASE

PEGASE

Brief description:
PEGASE established improved state estimation, optimisation and simulation frameworks for Europe's transmission networks. It also assessed their performance and calculated their respective data flow rates. The overarching goal was to eliminate technical barriers to real-time state estimation across all of Europe for both offline and online simulations. PEGASE developed methodologies of building and validating static and dynamic models (including renewable energy sources, power electronics, etc.). This project also studied the architecture of real-time state estimation, simulation and training.

Start/End: 2008/2012 **Budget:** € 13.6 million **Funding scheme:** Granted by 7th Framework Programme

Consortium:

TSOs: RTE (FR), REE (ES), Litgrid (LT), Transelectrica (RO), REN (PT), SO UPS (RUS), HEP (HR), TEIAS (TU) and Elia (BE).

Others: TRACTEBEL (BE), DELING DOO (BA), DIGITEO (FR), CRSA-ECP (FR), AICIA (ES), FGH (DE), University of Liege (BE), University of Dusiburg (DE), University of Manchester (UK), University of Eindhoven (NL), RTU (LT), Energosetproject (RUS) and NUCLEO (ES).

Website: fp7-pegase.eu

Cordis: cordis.europa.eu/project/rcn/88387_en.html

1. RATIONALE

TSOs were motivated to participate in the PEGASE project because of the following challenges with respect to monitoring, simulating and optimising very large transmission networks:

- Integration of renewable energy into the European network will change the flow patterns across the network on a continental scale, with a higher degree of volatility related to the intermittent nature of renewable energy sources.
- Introduction of the single electricity market will lead to increasing cross-border flows and impacts, with a higher need of coordinating operations and planning between network operators.
- Expansion of synchronous area in continental Europe to other countries presents the challenge of modelling and simulating large-scale transmission networks. Integration of Turkey was underway when the PEGASE project was proposed. A feasibility study for interconnections to the Russian network (IPS-UPS) was recently performed. Currently, a feasibility study project is currently ongoing for connecting the Ukraine and Moldova.

For TSOs, the main rationale for participating in this project was to design algorithms to monitor and simulate system-wide phenomena and for instigating preventive and corrective actions. Substantial gains in performance were to be expected while still maintaining a high level of accuracy and flexibility.

Some of the specific rationales of TSOs for participating in PEGASE were:

- Improvement of external observability of state estimator
- Gaining new knowledge on power system modelling
- Performing dynamic security analyses on large-scale power systems
- Performing steady-state optimisation and dispatcher training simulations

This summary reflects feedback received from the Elia group (Elia), Litgrid, REE, REN and RTE.

2. MAIN R&D PROJECT RESULTS

The main result of this project was the development of new tools for enhanced pan-European cooperation between TSOs for real-time operation and operational planning. A key objective of the project was to develop prototypes and validate them using test networks analogous to the European networks. This would ensure that the project results would be concrete and readily applicable.

The following technical and operational improvements, together with their potential economic benefits, could be considered the main project results:

- New algorithms for time-domain simulations were developed and implemented in prototype tools with performance gains evaluated and validated on the test systems. Different approaches were investigated: fine grain parallelisation, advanced linear algebra, domain decomposition methods, multi-rate algorithms, localisation techniques, etc. A relevant combination of the research outcomes allowed a faster times to be achieved compared to existing solutions. By using dedicated solvers which filter out high frequency transients, simplified simulation schemes were also developed which allow additional significant gains in computation time while accurately simulating the slower dynamics of power systems. This is directly applicable to the study of voltage stability, for example. A key feature of these simplified simulation tools is that they use the same network component models as more detailed tools such as those used to study electromechanical transients, thus ensuring the consistency of the studies.

- Concerning optimisation algorithms, a discrete variable prototype capable of managing a grid model with a large number of discrete variables, modelling the discrete behaviour of equipment, has been developed considering some approximations. New formulations of the actual operating practices, favouring corrective actions against preventive actions, have been proposed. A "worst-case" approach has been developed as a screening method to anticipate any potential insecure states of the system. These research advances remove critical barriers concerning the security analysis of very large power systems with higher levels of uncertainty.
- Hierarchical state estimation for the ETN (European Transmission Network) was investigated with a two-step approach based on a decentralised state estimator. Therefore, this approach might be feasible for future ETN state estimations. It was also used to develop an algorithm for estimating states at the substation level. The simulations demonstrated that this approach provides a notable improvement to the global state estimation procedure.

The main result of the project is the development of new tools that improve pan-European cooperation between TSOs for real-time operation and operational planning. New powerful algorithms and full-scale prototypes have been developed to run the entire ETN model for state estimations, dynamic security analyses, steady state optimisations and dispatcher training simulators.

Other significant results include:

- Assessments of the security of the pan-European grid. The effectiveness of the new simulator was demonstrated to simulate very specific events that could not previously be simulated.
- The architecture has been determined for a two-step hierarchical system state estimation prototype running the entire ETN. This prototype maximises the accuracy and robustness of the procedure while minimising the volume of data exchanged. The phasor measurement units have also been introduced to this two-step state estimation algorithm.
- A real-time simulation engine for dispatcher training has been developed using algorithms gained through the PEGASE project, which are capable of high-resolution simulations of the entire ETN. These algorithms function regardless of the system's electromechanical behaviour, up to complete blackouts and subsequent restoration.

3. TSO DEPLOYMENT OF R&D

The results of PEGASE have been already applied internally by TSO RTE to improve several tools and processes.

Most notably, many of the algorithmic advances in time-domain simulation were implemented in the EUROSTAG simulation software and are now used in operational studies. As a result of the gains, studies with models representing the complete network of continental Europe are more commonly run, thus removing the limits and uncertainties associated with dynamic network equivalents.

PEGASE has allowed RTE to improve the performance, flexibility and accuracy of many of its simulation tools. RTE also developed and maintained core expertise in the area of modelling and optimisation tools for power systems.

Through the PEGASE project, several young engineers at TSO RTE have gained considerable knowledge and expertise by developing and maintaining the EUROSTAG simulation and other similar tools. By collaborating on research with leading academic partners, these engineers have learned about the challenges and difficulties of simulating the dynamic phenomena of large power systems. They have developed a clear understanding of the innovative ideas which have come out of the project, and have readily implemented them in operational tools within a year or two subsequent of the project. They are now able to provide key guidance within RTE on these issues at a time when dynamic simulations are increasingly being used to make critical decisions for network operation and planning. They also share this knowledge with other members of the RTE R&D teams.

As illustrated here with dynamic time-domain simulation tools, the involvement of dedicated RTE R&D engineers in PEGASE can therefore be regarded as one of the key success factors in transferring the results of the project into concrete achievements and gains within RTE.

The results of PEGASE are also being used in subsequent R&D projects. The iTesla project, for instance, follows up on many of the improvements and modules developed through PEGASE with the aim of combining them into a single prototypical suite. RTE also continues to exploit PEGASE R&D to improve its simulation tools. Some ideas whose feasibility was demonstrated in PEGASE have also been integrated into R&D projects in other areas, such as the concept of distributed state estimation for digital substations.

This project demonstrated the advanced time-domain simulation capabilities that will become more beneficial once input data is readily available. For this reason, the implementation capabilities of the project might be currently limited by the current cost of using the new PEGASE tools, especially with respect to data gathering and management.

Some TSOs (for instance, Lithuania and Portugal) have geographical locations that do not justify the need for pan-European time-domain simulations, optimisations and state estimations for real-time operation and planning.

4. LESSONS LEARNT THROUGH R&D DEPLOYMENT AND DISSEMINATION

The most important lesson learnt was that the best value of research is to find answers to questions rather than just delivering solutions. In other words, the first objective must be to show the effectiveness of the proposed concept by answering questions such as: is it useful? Or does it work adequately? And, if the answer is yes, keep working on the development/implementation stages.

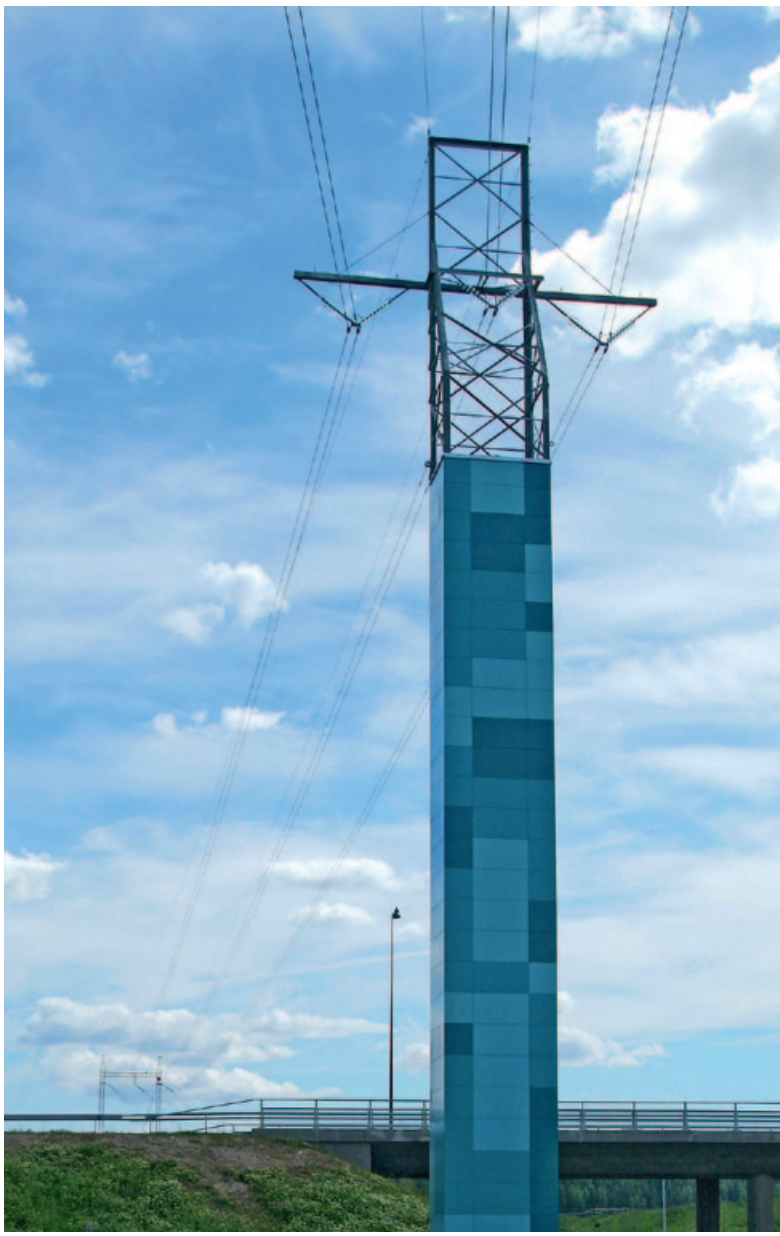
PEGASE particularly demonstrated the value and effectiveness of using prototype tools to validate the application of the proposed R&D concepts and methods. This provides much freedom to explore new ideas without the constraints and costs of a large development project, while also providing insight into the performance and usability of the proposed research ideas.

The prototype stage provides valuable information to take the 'go/no-go' decision, as well as for drafting detailed specifications for the development of operational tools. If the prototype performs poorly or unsatisfactorily, it is also possible at this stage to abandon or re-orient specific research ideas. In fact, such outcomes are probably valuable for successfully demonstrating the benefits of R&D.

Thanks to this project, TSOs were able to assess whether the tool was needed or not, which has nothing to do with its quality or performance, merely its practical usefulness. For example, in PEGASE, RTE concluded that it is very difficult to find efficient methods of parallelising spare linear solvers for power systems that are not large enough (no more than 200,000 variables) to achieve the expected gains. This was an important lesson since it initially seemed to be a very promising idea.

More generally, project evaluations could be improved if there was more incentive to mention unsuccessful research endeavours and the lessons learned therein. R&D projects provide a very good environment for exploring potentially ground-breaking ideas that can yield significant improvements but can also prove impractical when investigated in more detail. RTE regards a reasonable degree of "failure" as a good indicator of an ambitious R&D project, especially when such "failures" are treated as learning opportunities.

Many of the results of PEGASE have been made public and can be used as a basis for similar improvements and research initiatives by other TSOs, academic or industry actors in Europe and worldwide. While some partners of the project have benefited from these results, it is not clear how many of the project's advances can be used outside of this circle, since expert knowledge is probably required to implement them. For example, TSOs without such expert knowledge must rely on tool providers to implement the advances of PEGASE, and it is difficult to measure the extent they have been able to do so.



REALISEGRID

Brief description:
The REALISEGRID project developed a set of criteria, metrics, methodologies and tools for assessing how to best develop the European transmission infrastructure with the overarching goal of establishing a reliable, competitive and sustainable supply of electricity. REALISEGRID involved three main areas of activities:

1) Identification of performances and costs of new grid technologies aimed at increasing capacity, reliability and flexibility of the transmission infrastructure;

2) Definition of long-term scenarios for the EU power sector, characterised by different evolutions of demand and supply;

3) Implementation of methods and tools to assess the different benefits of transmission expansion investments. The main outcomes of REALISEGRID included:
   - Creation of a roadmap for the incorporation of new transmission technologies (including WAMS, FACTS, HVDC) into the electricity networks;
   - Analysis of the impact of different scenarios on future electricity exchanges between European countries;
   - Evaluation of benefits provided to the pan-European power system by the development of transmission infrastructure;
   - Testing of cost-benefit analyses for specific transmission projects, namely, nine electricity projects of European interest concerning the Trans European Network priority axis EL.2.

Start/End: 2008/2011 **Budget:** € 4.3 million **Funding scheme:** Granted by 7th Framework Programme

Consortium:

TSOs: APG (AT), RTE (FR), TenneT (NL), TERNA (IT).

Others: RSE (IT), EC JRC (BE), OME (FR). EEG TU Wien (AT), TU Delft (NL), TU Dortmund (DE), Politecnico di Torino (IT), TECHNOFI S.A. (FR), R&D Center for Power Engineering (RU), PRYSMIAN POWERLINK S.r.l. (IT), KANLO CONSULTANTS SARL (FR), RIECADO GmbH (AT), TU Dresden (DE), Univerza v Ljubljani (SI), ASATREM (IT), University of Manchester (UK).

Website: REALISEGRID.rse-web.it

Cordis: cordis.europa.eu/project/rcn/90334_en.html

1. RATIONALE

The REALISEGRID developed a set of criteria, metrics, methodologies and tools for assessing how to best develop the European transmission infrastructure with the overarching goal of establishing a reliable, competitive and sustainable supply of electricity.

TSOs were motivated to join this project for the following reasons:

- Integration of very large amounts of variable renewable energy sources (RES) while maintaining network security and reliability at acceptable levels.
- Aging of present transmission grid and need for new infrastructure to balance renewable generation across Europe and to liberalise European market.
- Increasing role of distributed generation and active demand.

This summary reflects feedback received from APG and Terna.

2. MAIN R&D PROJECT RESULTS

The main technical results are:

- Identification of performances and costs of new technologies aimed at increasing capacity, reliability and flexibility of transmission infrastructure
- Definition of long-term scenarios for European power sector, characterised by different evolutions of demand and supply
- Implementation of framework to foster creation of harmonised pan-European approach to electricity infrastructure evolution based on an overall evaluation of costs and benefits deriving from transmission expansion investments; this cost-benefit analysis framework has been applied to test specific transmission projects listed in the two EC documents TEN-E Guidelines (2006) and "Priority Interconnection Plan" (2007)

The cost-benefit analysis (CBA) developed by REALISEGRID was used as a starting point for the CBA of the e-Highway2050 project where the following categories were considered:

- Social welfare
- Reduction of losses
- Reduction of wind curtailment
- Reduction of load shedding
- Reduction of CO_2 emissions
- Reduction of cost for extra-EU fuel (sensitivity parameter).

Another important activity was the analysis of public consensus mechanisms for large infrastructural developments and of authorization procedures used by European countries for the approval of new transmission line construction projects. The first results were included in a special Interim Report requested specially by the European Commission and used as a starting point for the Infrastructure Package (Communication "Energy infrastructure priorities for 2020 and beyond"). This latter report was published by the European Commission in November 2010.

3. TSO DEPLOYMENT OF R&D

Participation in this project has increased knowledge of the electricity sector beyond planning aspects. It has also created an opportunity to expand expertise in some subjects and allowed for comparisons with stakeholders. It has also fostered communications between TSOs and other partners.

These R&D results have not yet been applied by TSOs due to a lack of resources. However, TSOs have been and remain interested in multi-criteria cost-benefit analyses (adopted in REALISEGRID project). Depending on how grid methodologies are further developed in Europe, it may be possible to implement the results.

4. LESSONS LEARNT THROUGH R&D DEPLOYMENT AND DISSEMINATION

Even if TSOs gain much knowledge and experience, more human resources must still be deployed in R&D activities. In most cases, project participants will also have to deal with their regular daily tasks and such projects represent an additional burden.

The results of the REALISEGRID project have been well disseminated within the scientific community through workshops and various publications (CIGRE 2010 and 2012, IEEE PES Conference Innovative smart grid technologies-Europe…).

TWENTIES

Brief description:
Using real-life, large-scale demonstrations, TWENTIES demonstrated the benefits and impact of several critical technologies required to improve the European transmission network, thus giving Europe the ability to increase the share of renewable energy in its mix by 2020 and beyond, while keeping its present reliability.

Start/End: 2010/2013 **Budget:** € 56.7 million **Funding scheme:** Granted by 7th Framework Programme

Consortium:

TSOs: REE (ES), Elia (BE), Energinet.dk (DK), RTE (FR), 50Hertz Transmission GmbH (DE),Tennet TSO (NL).

Others: DONG (DK), Iberdrola (ES), RISØ.DTU (DK), EDF (FR), ALSTOM (UK), Comillas-IIT (ES), Fraunhofer IWES (DE), SINTEF (NO), GAMESA (ES), SIEMENS (DE), EWEA (BE), CORESO (BE), ABB (ES), INESC-PORTO (PO), UCD (EI), RSE (IT), STRATHCLYDE (UK), ULG (BE), KUL (BE), ULB (BE).

Website: www.twenties-project.eu

Cordis: cordis.europa.eu/project/rcn/94496_en.html

1. RATIONALE

The main objective of the TWENTIES project was to overcome several technical barriers to integrating increasing wind power into the European electrical system by the year 2020. Specifically, the TWENTIES project focused on:

- Wind farms: capability of providing advanced active and reactive regulation services, and to withstand high wind periods
- Virtual Power Plants (VPP): technical and economic feasibility of VPP concept
- HVDC grid: design and operation of main building blocks for HVDC grid (optimal topology, protection schemes, DC-AC interactions, HVDC circuit breaker…)
- Novel solutions to increasing current operational limits: dynamic line rating tools and power flow controllers

TSO participation was essentially motivated by the need to integrate increasing amounts of renewable energy into the electrical system.

This project summary reflects feedback received from the Elia group (50Hertz and Elia), Energinet.dk, REE and RTE.

2. MAIN R&D PROJECT RESULTS

The TWENTIES project produced many scientific and technical advances. It addressed six different technologies all aimed at extending the integration of wind power. A complete overview of the results is available online at www.twenties-project.eu. The main results can be grouped as follows:

The main technical/operational improvements of TWENTIES are:

- Capability of wind farms to provide frequency and voltage control
- Successful testing of IT system for integrated operation of VPP within overall generation portfolio of largest Danish utility
- Successful testing of 120 kV DC breaker prototype
- Registered High Wind Ride Through (HWRT) system for wind generators has been developed, installed and tested at 200 MW Horns Rev 2 off-shore wind farm

Novel technologies and tools for extended use of transmission grid capacities have been demonstrated: DLR and phase shifter transformers.

According to the economic assessments, the results are:

Wind farms:
- Analysis of voltage control at wind farms shows that wind penetration not limited due to voltage issues.
- Active power control could reduce system operating costs by 1.1 % by 2020.
- Wind power could reduce cost of secondary control reserve market (downward) by up to 24 % with 99.99 % reliability in Germany.
- HWRT controller significantly reduces disturbances due to storms; in particular maximum ramp rates (in 15 minutes) are reduced from 1,343 MW to 209 MW in Denmark. This increases wind production at high wind speeds.

Virtual Power Plant "Power Hub":
- VPP can decrease costs in the European power system. With the predicted scenario for 2030 (400 MW cold storage and 300,000 electrical vehicles), the estimated cost savings in the day-ahead market are € 27 million/year, and in net balancing costs € 3.4 million/year. The reduction in wind curtailment due to the VPP is estimated to be 18 GWh/year.
- VPPs based on biomass and heat pumps provide 2.18 % reduction in average electricity prices and 3.46 % reduction in CO_2 emissions for German power system.

HVDC grid:

- A global cost-benefit analysis revealed that HVDC grids are more costly but also provide operational benefits and remain competitive overall.

Novel solutions to increasing current operational limits:

- Adequate coordination mechanisms between Dynamic Line Rating, Power Flow Controlling (PFC) devices and Wide Area Monitoring Systems (WAMS) make electricity system more flexible within affordable capital and operational costs:
  - In Central Western Europe (CWE), PFC and DLR reduce implementation costs and time compared with conventional assets. A PFC smart controller at the Belgian border could reduce system costs by € 50 million (€ 250 million if fully deployed in CWE). Broad DLR deployment in CWE would reduce system operational costs by € 125 million.
  - Analysis of the Spanish system indicates that FACTS (Flexible AC Transmission Systems) devices can eliminate re-dispatching of more than 550 GWh/year, which represents 4.5 % of the total energy currently re-dispatched in Spain. For the tested DLR system, the potential avoided re-dispatch would amount to approximately 650 GWh.

Overall:

- New offshore network capacity that interconnects national networks allows local surpluses of wind power to be used elsewhere, reserve power to be held, and potentially cheap, zero carbon power to be used instead of more expensive higher-carbon fossil fuel plants.
- The CO_2 reduction benefits arising from a reversal of the merit order of fossil-fuelled generation are significant.
- A realistic scenario for increased hydro capacity in Norway combined with interconnections to UK, Germany and the Netherlands will decrease the total power generation costs by approximately € 518 million/year and eliminate 10 million tonnes of CO_2 emissions.
- Hydro capacity in Switzerland and Austria can also be integrated as a source of renewable energy for CWE. This will make the system more stable as a highly flexible source of balancing power and will also decrease CO_2 emissions. However, an essential prerequisite is the installation of sufficient transmission capacity between Germany, Austria and Switzerland.

3. TSO DEPLOYMENT OF R&D

TWENTIES was a demonstration project and almost all of the technologies proven in this project have been installed. For instance, DLRs and the DLR forecasts are currently in use in Belgium while Overhead Line Controllers and Real-Time Thermal Rating have been applied in Spain. The HWRT controller has been installed in two Danish offshore wind farms to increase the system security.

The knowledge and information concerning the feasibility of HVDC grids is being utilised as a part of the current HVDC interconnector projects between France and Spain (INELFE) as well as between France and Italy (Piémont–Savoie project). The results of TWENTIES also showed that additional R&D effort was needed on specific issues such as interoperability in multivendor multi-terminal HVDC grids. Indeed, while efficient and secure operation of HVDC networks could be demonstrated, technical specifications and standards must be established in a multivendor context to ensure good performance in transient regimes and to prevent adverse interactions between terminals and devices. The BEST PATHS project currently underway will tackle some of these issues.

The TWENTIES project was completed in 2013. Therefore, the results have not yet been deployed on a large-scale with the exception of the prototypes developed, installed and demonstrated within the project. Nonetheless, TWENTIES has demonstrated technologies that will undoubtedly help all stakeholders to deal with the increase of wind power generation.

4. LESSONS LEARNT THROUGH R&D DEPLOYMENT AND DISSEMINATION

In order to successfully convert R&D results into applications, it has been crucial to involve control centre engineers from the very beginning. It has also been beneficial to work with manufacturers to expand the tests beyond site acceptance tests and debug and optimise the products for use in daily operations. The following actions have proven to be very helpful:

- Inviting participation from the very beginning of those units responsible for operating and maintaining equipment (future users)
- Closely following up on project progress
- Working hard with main actors to establish robust methodologies for cost-benefit analyses

Also, it is important to keep in mind that deployment of new technologies requires the agreement of many different parties. As an interesting side-effect, much expertise is gained by collaborating closely with both vendors and operating personnel.

Finally, one of the key lessons learnt is the importance of organising an effective R&D dissemination strategy for external stakeholders. Indeed, TWENTIES produced significant results that can benefit all actors.

A cost-benefit analysis was performed for the electrical system as a whole, but not under any particular TSO business perspective. It is also important to ensure that deployment of new technology does not undermine reliability and security standards.

The main barrier or obstacle in this project was the lack of a regulatory framework encompassing both the costs and benefits (cost savings) of the new technologies for the system. For example, since regulations usually reward TSOs for CAPEX (Capital expenditures) while incentivising the reduction of OPEX (Operation expenditures), technologies that decrease CAPEX while increasing OPEX might not be economically interesting, thus preventing wider acceptance.

The knowledge learned through this project was disseminated to stakeholders by publishing the results in scientific journals and reports, and discussing it at conferences and dedicated events. Furthermore, all deliverables are available at the project website www.twenties-project.eu.

WINDGRID

WINDGRID

Brief description:
Windgrid focused on preparing the European electricity network for large-scale integration of wind farms. It involved the design, development and validation of new tools and devices for planning, controlling and operating power systems in a competitive market.

Start/End: 2006/2009 **Budget:** € 4.3 million **Funding scheme:** Granted by 6th Framework Programme

Consortium:

TSOs: REE (ES), REN (PT)

Others: DELOITTE, S.L. (ES), Gamesa Wind Engineering, APS (DK), Institut für solare Energieversorgungstechnik e. V. (DE), Windenergie S.R.O. (CZ), Iberdrola Energias Renovables II S.A.U (ES), ENERCON GmbH (DE), KORONA INZENIRING D.D. (SI).

Website: –

Cordis: cordis.europa.eu/project/rcn/86435_en.html

1. RATIONALE

In 2010, the European Union set a target 12 % market share for renewable energy from total primary energy consumption. At first glance, wind farms appear to be an efficient solution for this task. However, due to its volatility and sensitivity to voltage dips and other factors, large-scale wind energy has also jeopardised the security of electricity supply.

An integrated approach was used to solve these problems wherein technical and regulatory solutions were to be defined as standardised guidelines. Wind farm clusters lead to the establishment of a new type of control centre, the Wind Farm Cluster Management System (WCMS). The WCMS aggregates operational data, creates the necessary schedules, facilitates energy and power control, as well as providing reactive power. This enables wind farms to perform closer to conventional power plants. The WCMS concept addresses the problems relating to wind volatility.

This project summary reflects feedback received from REE and REN.

2. Main R&D project results

The WINDGRID project helps to provide the European electricity network with appropriate solutions for dealing with the increasing penetration of wind farms of the future.

WINDGRID provided new tools and devices for planning, controlling and operating power systems in a competitive market. These were designed, developed and validated to address the large-scale integration of wind farms in the European electricity network.

The project was completed by the end of 2009 and the main results can be summarized as follows:

- Implementation, integration and testing of an effective Wind Farm Cluster Management System, proving that is possible to do it efficiently and independent from whatever manufacturer and the operator.
- Implementation, integration and testing of Security Analysis Tools needed to integrate as much wind energy as possible within security conditions.
- Define a methodology and guidelines to elaborate a Grid Code in a System with a massive penetration of wind energy.
- Define a methodology and guidelines to set the Technical Requirements that wind generators should fulfil in a system with a massive penetration of wind energy without undermining the system security.
- Test in real facilities different Control Strategies, some of them really innovative, that could be used to upgrade the services that wind generators provide to the System, proving their effectiveness and its contribution to market competition.

Regarding this last point, WINDGRID project has been a project strongly oriented to full scale demo activities in order to prove in real facilities and under real life conditions the proposed solutions. The main conclusions and results of these tests, carried out in Spain and Portugal, were the following:

- Capability of setting an active power limit for a wind farm cluster in real-time.
- Possibility of controlling the maximum output of the plant; this accounted for different means of control such as reactive power, constant tangent phi, constant reactive power and an innovative solution based on voltage setpoint at transmission level (150 kV).
- Protocol was made compatible from control centre to turbine level and loop controls are allowed in real-time to allow direct controlling.

The economic benefits of the project are that, by avoiding overloads and having better control of the voltage profile, wind power penetration can be optimized (i.e. minimizing wind power curtailment) allowing thus an efficient dispatching management of the system; and also that, thanks to the ability of wind farms to provide such services, the hosting capacity for this technology can be higher without compromising system security.

3. TSO deployment of R&D

The responses received indicate that results from WINDGRID have already been applied by TSO REN at their control centre. The compatible protocol — ICCP — allows the Control Centre to be linked to the Renewable Control Centre so that setpoints can be transmitted. Thus, the active power output can be limited to the individual wind farms. It is also possible to define setpoints for reactive power output (tangent phi).

Currently, the main challenge is the regulatory framework, since curtailment and voltage control have yet to be defined in the grid codes.

The project results provide TSOs with the following:

- Real-time capability of setting an active power limit for wind farm clusters
- Ability to control maximum plant output by through reactive power via constant tangent phi, constant reactive power or, innovatively, constant voltage at 150 kV
- Monitor in real time that penetration levels are compatible with system security criteria

4. LESSONS LEARNT THROUGH R&D DEPLOYMENT AND DISSEMINATION

The main conclusion was that through the implementation of the appropriate tools, wind farms can provide system services with high impact at system level and this brings, in turn, more opportunities for increasing the wind power penetration levels and hosting capacity.

Project participants have done the following to disseminate the project results:

- Published articles on project results in prestigious energy and engineering magazines.
- Presented project to International Council on Large Electric Systems (CIGRE), Union for the Co-ordination of Transmission of Electricity (UCTE), European Transmission System Operators (ETSOs) and other relevant associations.
- Presented the project at prestigious energy workshops and events.

The final workshop was held in Lisbon. TSO REN also presented some of their test cases for demonstration purposes.

ABBREVIATIONS

AC	Alternating current
ANEMOS PLUS	"Advanced Tools for the Management of Electricity Grids with Large-Scale Wind Generation" project
BEST PATHS	"Beyond State-of-the-art Technologies for re-Powering AC corridors and multi-Terminal HVDC Systems" project
CAPEX	Capital expenditure
CBA	Cost-benefit analysis
CO_2	Carbon dioxide
CWE	Central Western Europe
DC	Direct Current
DLR	Dynamic line rating
EENS	Expected Energy Not Supplied
EMS	Energy management system
ENTSO-E	European Network of Transmission System Operators for Electricity
ETN	European Transmission Network
EU	European Union
EV	Electric Vehicles
EWIS	"European Wind Integration Study" project
FACTS	Flexible AC Transmission System
HVDC	High Voltage Direct Current
HWRT	High Wind Ride Through
ICOEUR	"Intelligent Coordination of Operation and Emergency Control of EU and Russian Power Grids" project
IT	Information Technology
iTESLA	"Innovative Tools for Electrical System Security within Large Areas" project
MERGE	"Mobile Energy Resources in Grids of Electricity" project
OPEX	Operating expense
OPTIMATE	"Model for pan-European Electricity Market" project
PEGASE	"Pan-European Grid Advanced Simulation and state Estimation" project
PFC	Power Flow Controlling
R&D	Research and Development
REALISEGRID	"Research, methodologies and technologies for the effecive development of pan-European key grid infrastructure to support the achievement of reliable, competitive and sustainable electricity supply" project
RES	Renewable Energy Sources
TSO	Transmission System Operator
TWENTIES	"Transmission system operation with large penetration of Wind and other renewable Electricity sources in Networks by means of innovative Tools and Integrated Energy Solutions" project
UCTE	Co-ordination of Transmission of Electricity
VPP	Virtual Power Plant
WAMS	Wide-Area Monitoring Systems
WINDGRID	"Wind on the grid: an integrated approach" project
WCMS	Wind Farm Cluster Management System

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NOTE

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