Sustainable

Smart distrib**U**tion **S**ystem opera**T**ion for m**A**ximizing
the **IN**tegration of renew**ABLE** generation

PROJECT BOOK

This project has received funding from the European Union's Seventh Framework Programme for research technological development and demonstration under grant agreement no 308755.

SHARING KNOWLEDGE

EEGI
EUROPEAN ELECTRICITY GRID INITIATIVE

SuSTAINABLE project was awarded with the EEGI Support label, following the assessment of the GRID+ experts group.

EEGI (European Electricity Grid Initiative) is one of the European Industrial Initiatives under the Strategic Energy Technologies Plan (SET-PLAN) and proposes a 9 year European research, development and demonstration (R&D) programme to accelerate innovation and the development of the electricity networks of the future in Europe.

Throughout the course of the project, 3 physical meetings occurred with the project partners SiNGULAR and IGREENGrid, which served to monitor the proposed activities and continue advancing the mutual project knowledge to achieve a permanent and stable work, contributing thus to the European Family of Projects and creating added value inside the European Energy R&D activities.

SuSTAINABLE
www.sustainableproject.eu

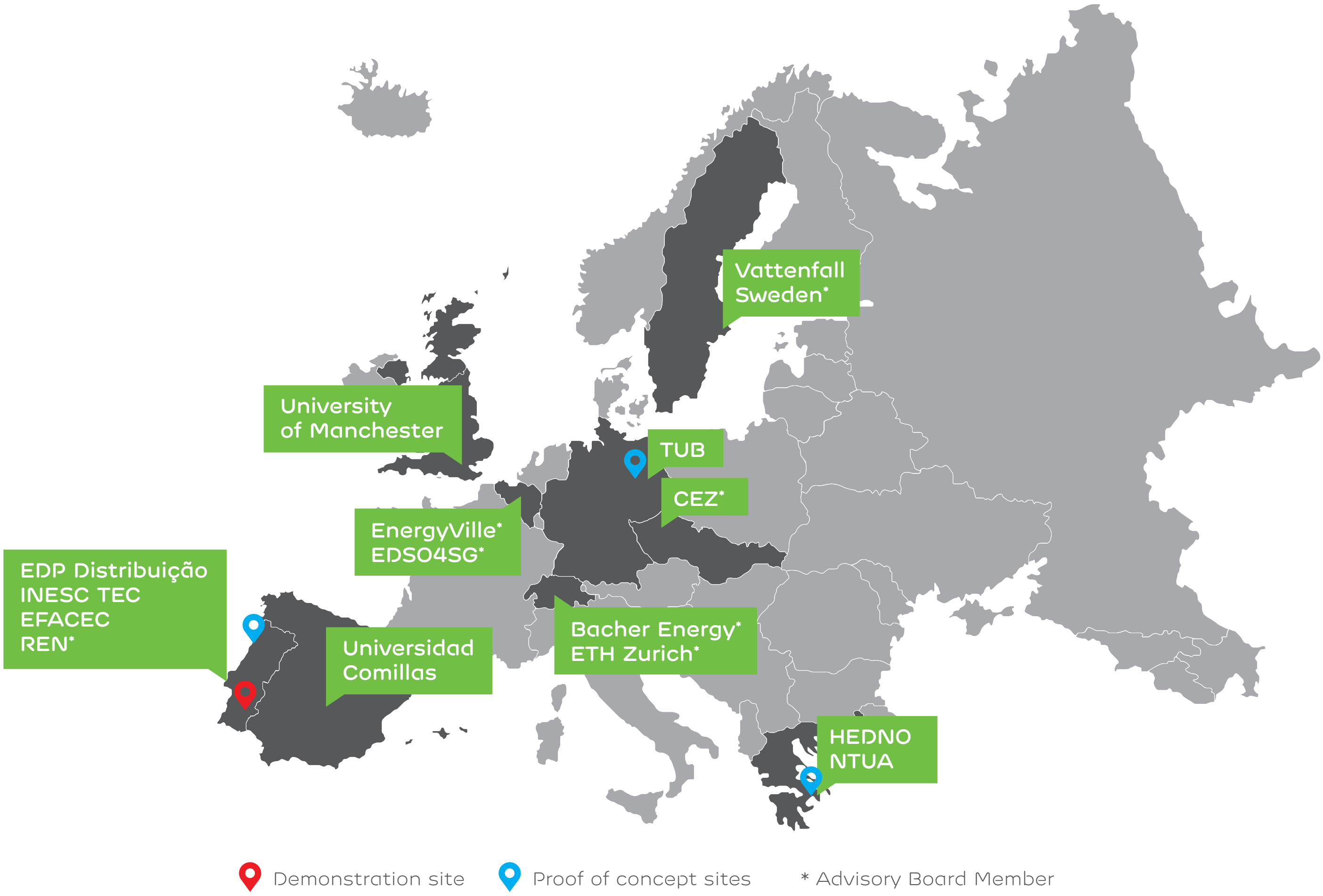
SiNGULAR
www.singular-fp7.eu

IGREENGrid
www.igreengrid-fp7.eu

Integration of variable distributed resources in distribution networks.

- **Project Duration**
  January 2013 – March 2016
- **Project Budget**
  5.73 M€
- **EC Funding by**
  3.87 M€
- **Consortium**
  8 partners from 5 different member states

THE CONSORTIUM



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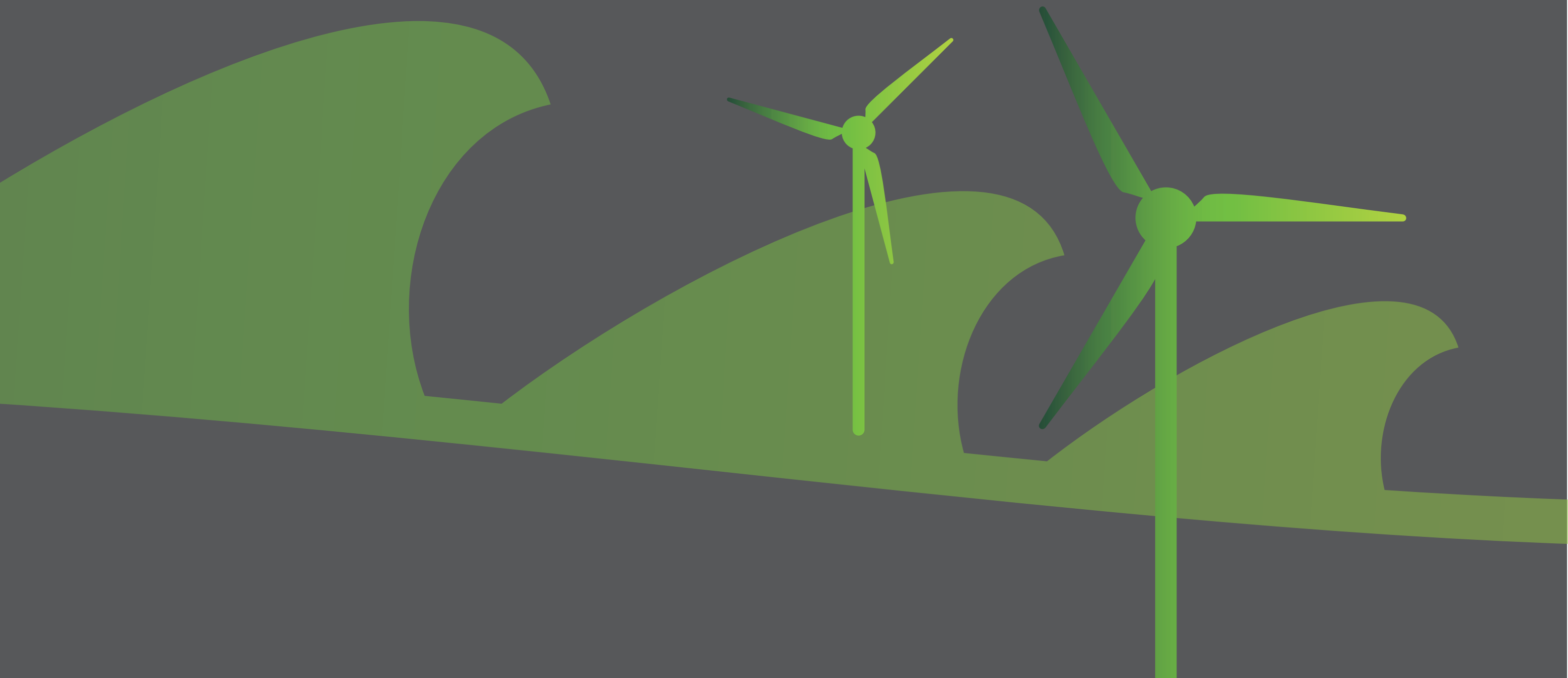
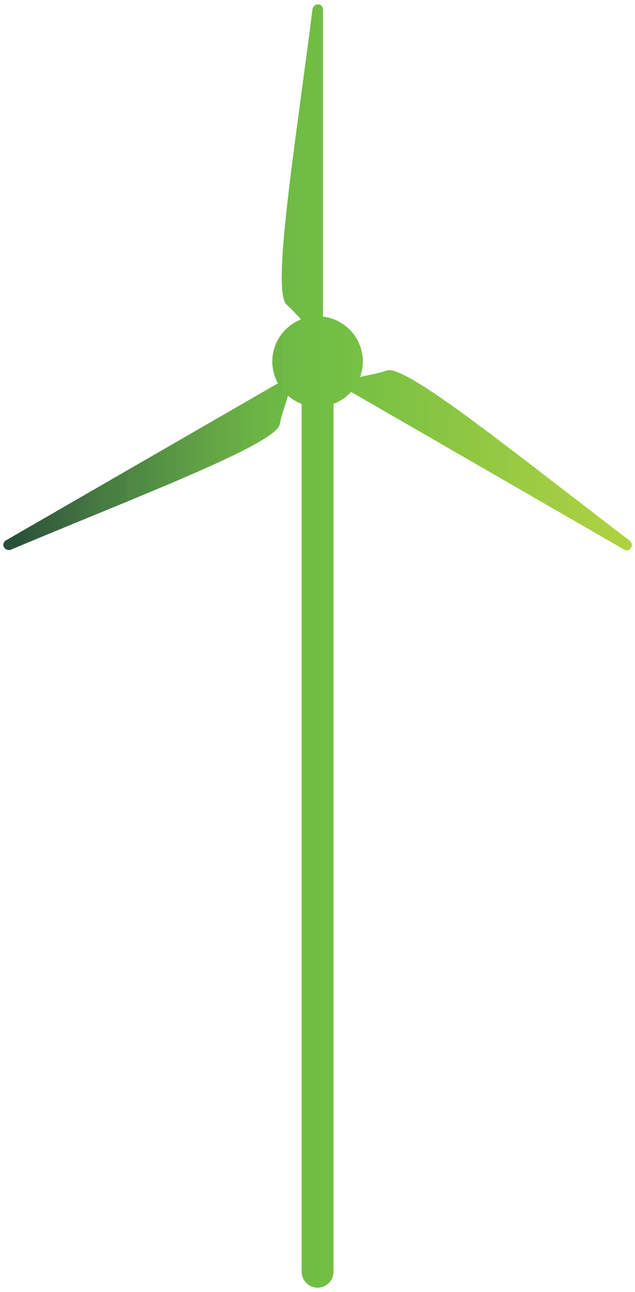


LIST OF ABBREVIATIONS

AI - Artificial Intelligence
AM - Asset Management
AMI - Advanced Metering Infrastructure
AMM - Advanced Metering Management
ANM - Active Network Management
ANN - Artificial Neural Network
CHP - Combined Heat and Power
DMS - Distribution Management System
DRD - Dynamic Response of Demand
DSE - Distribution State Estimation
DSM - Demand Side Management
DSO - Distribution System Operator
DTC - Distribution Transformer Controller
EC - European Commission
EI - Energy Intelligence
ERP - Enterprise Resource Planning
EU - European Union
FL - Flexible Loads
GIS - Geographic Information System
HAN - Home Area Network
JRC - Joint Research Centre
KPI - Key Performance Indicator
KPI - Key Performance Indicators
LV - Low Voltage
MCS - Monte Carlo Simulation
MV - Medium Voltage
NPV - Net Present Value
OLTC - On Load Tap Changers
OMS - Order Management System
OPF - Optimum Power Flow
PQ - Power Quality
QoS - Quality of Supply
R&D - Research and Development
RES - Renewable Energy Sources
RMS - Root Mean Square
SF - Sub Functionality
TSO - Transmission System Operator
VPP - Virtual Power Plant



01 EXECUTIVE SUMMARY

Distribution Grids are in a disruptive change coming from the current world macroeconomic context, needing alternative types of energy generation, combined with improvements in reliability and security of supply while inducing competitiveness in markets and a genuine paradigm change on consumer behaviour towards the energy system of the future. This new paradigm rests on a more efficient use of energy, thereby resulting in benefits for whole value chain, in particular for consumers.

It was the aim of SuSTAINABLE to address these challenges as an R&D European project, funded under the 7th Framework Programme of the European Commission. The project, with a duration of 39 months, was coordinated by the Portuguese distribution system operator EDP Distribuição and 8 partners from 5 different member states.

This document presents an insight into SuSTAINABLE, namely the work and approaches that were developed throughout the project, its results and the future ahead that it helped to shape.

02 CHALLENGES

INCREASING PENETRATION OF DECENTRALISED GENERATION

Distribution Grids are changing from passive to fully active, shifting towards smarter and more efficient operation of distribution power systems, challenged by Distributed Generation (DG) and significant changes in the electrical power system, at many levels, from planning to operation.

MAIN TECHNICAL CHALLENGES TO INCREASED DG PENETRATION

NETWORK VOLTAGE CHANGES

The voltage effect in particular is a key factor that can limit the amount of DG capacity to be connected to the distribution system, especially in rural networks.

POWER QUALITY ISSUES

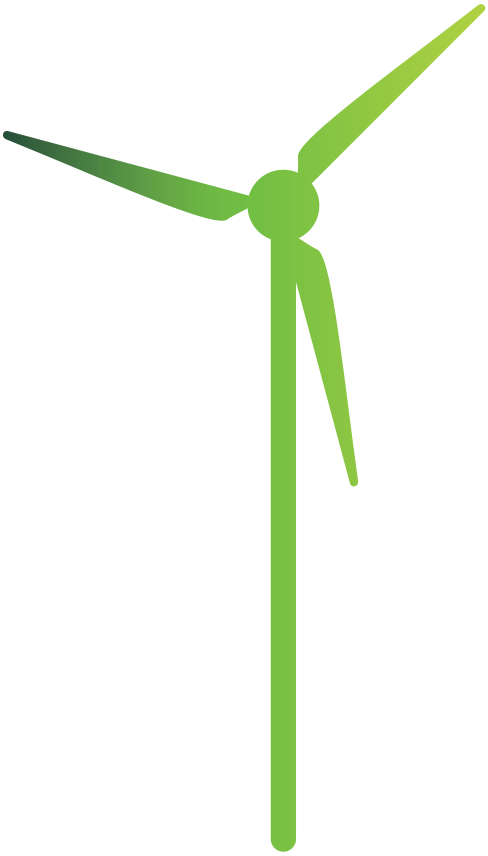
Two main aspects are usually considered: transient voltage variations and voltage harmonic distortion. Depending on several issues such as capacity, location, etc. the effect of DG on the network can be either positive or negative.

CONGESTION PROBLEMS

In some scenarios, DG may alter branch flows significantly, which may pose additional problems in terms of managing energy flows. This may ultimately cause branch overload, especially in the case of high levels of renewable-based DG integration, which may inject large amounts of energy into the distribution system.

PROTECTION ISSUES

Several different aspects can be considered here and need to be carefully addressed: protection of the generation equipment from internal faults; protection of the faulted distribution network from fault currents supplied by DG; anti-islanding or loss-of-mains protection (islanded operation of DG is likely to be allowed in the future as DG penetration increases) and impact of DG on existing distribution system protection.



03

SUSTAINABLE APPROACH

3.1 SCOPE AND OBJECTIVES

Following the pathway to the development of integrated distribution energy networks, SuSTAINABLE developed and demonstrated a new operation paradigm, leveraging information from smart meters and short-term localized forecasts of RES and consumption in order to manage distribution systems in a more efficient and cost-effective way, thus enabling a large-scale deployment of intermittent renewable based DG.

As depicted in Figure 1, SuSTAINABLE concept is based on a cloud-like principle, where the distribution system operator (DSO):

FIGURE 1 | Main inputs and outputs for the SuSTAINABLE concept.

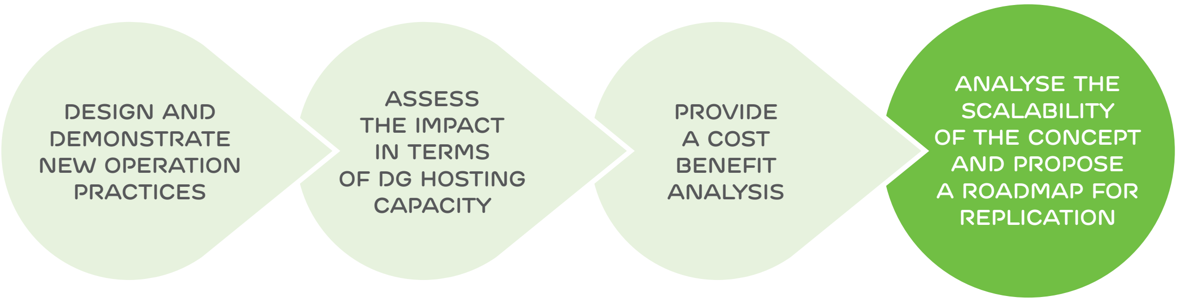
- Collects information from a smart metering infrastructure, other distributed sensors and communications from external partners

- Processes the information using tools such as distribution state-estimation, forecasting tools, data mining, and decision-making applications, being part of this information processed in a distributed way on data concentration devices located in the electrical distribution network

- Communicates settings to power quality mitigation devices, protection relays and actuators, distribution components (e.g. on-line tap changers (OLTC), reactive power compensation devices), and distributed flexible resources

- Assesses its market strategy as a provider of ancillary and balancing services

IMPROVING THE FLEXIBILITY AND RELIABILITY OF THE SYSTEM



3.2 SYSTEM ARCHITECTURE

The main aim of the proposed control architecture for the SuSTAINABLE project is to enable a coordinated and efficient control of the whole electrical distribution system, taking advantage of its own resources in order to overcome technical problems that may arise in operation especially in scenarios with high integration of Renewable Energy Sources (RES).

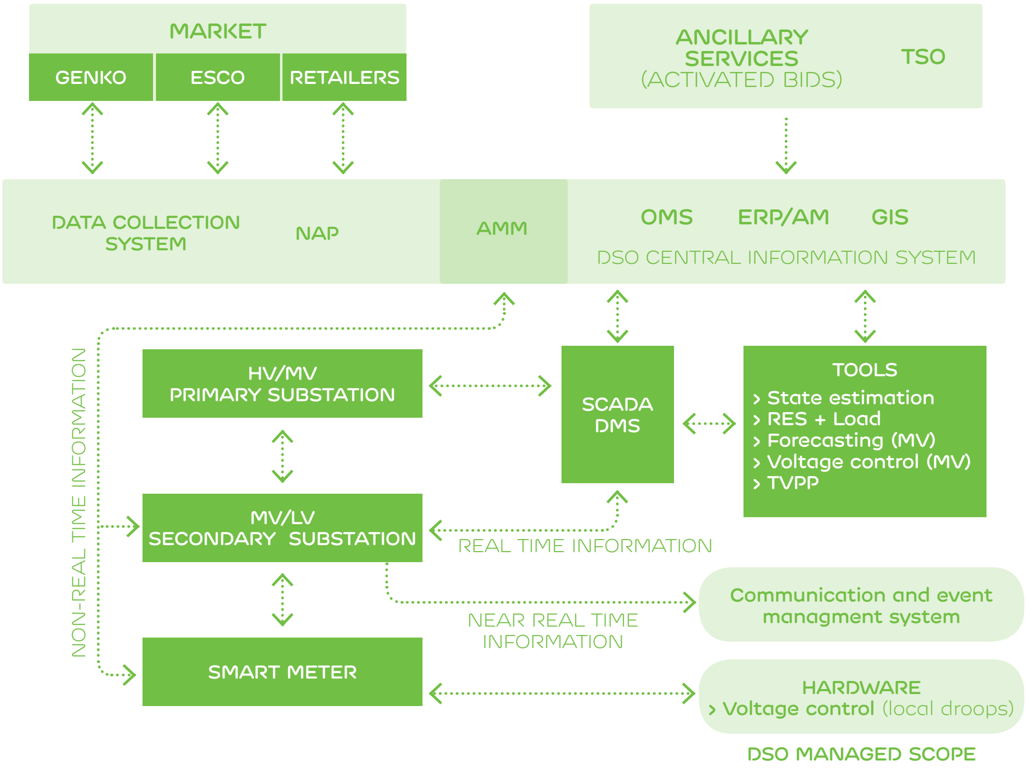


FIGURE 2 | SuSTAINABLE reference architecture.

A general framework for the data flow model of the SuSTAINABLE concept is presented in Figure 2. This framework comprises two different types of information: commercial (related to billing information) and technical (related to operational information).

At the top level is the DSO Central Information System, which includes Advanced Metering Management (AMM), Enterprise Resource Planning (ERP) / Asset Management (AM), Order Management System (OMS) and Geographic Information Systems (GIS). All the billing information from the customers down to the LV level, transmitted by the Advance Metering Infrastructure (AMI), must be processed in an AMM module located at the central information system level.

Finally, the DSO can be a market facilitator that collects all the commercial and technical data and provides this information to the market agents via DSO Central Information System. The DSO also facilitates the DSO/TSO cooperation. Ancillary services activated bids are communicated by the TSO and must also be taken into account since it is not realistic that they will communicate directly with each SCADA/DMS.

3.3 FUNCTIONALITIES

3.3.1 ESTIMATION AND FORECASTING

› ADVANCED LOCAL FORECASTING TOOLS TO PREDICT RES

The roll-out of the smart grid technology provides additional capabilities for monitoring and controlling of the distribution grid. Within the SuSTAINABLE project, a solar power forecasting system was developed and it is running operationally for 39 MV/LV secondary substations in Évora, Portugal. The architecture of the forecasting system is depicted in Figure 3. It uses different types of statistical models that combine information from weather predictions and time-series data collected by smart meters / data loggers geographically distributed in space.

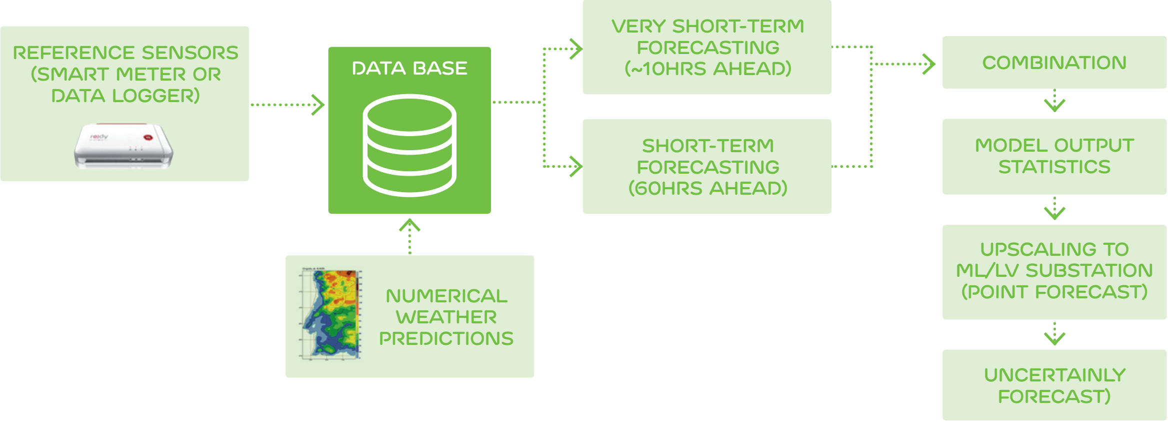


FIGURE 3 | Architecture of the SuSTAINABLE solar power forecasting system.

THE FORECASTING SYSTEM HAS THE FOLLOWING FEATURES:

- Generates forecasts (Figure 4), for the next 60 hours with time resolutions ranging between 15 and 60 minutes
- Combines past observations of time-series distributed in space in order to capture the effect of cloud movement in solar generation
- Its parameters are time-adaptive and cope with time-varying operating conditions
- It is scalable to compute the total solar power in each secondary substation
- Has data quality control and pre-processing modules that generate alerts in case of communication failure or when the protection system of the PV installation is trigged

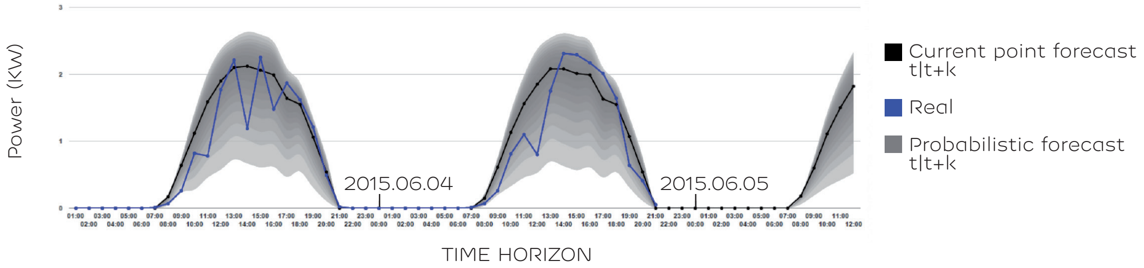


FIGURE 4 | Example of a point and uncertainty forecast.

Accurate prediction of the load plays an indispensable role in power system planning and electricity market analysis. In SuSTAINABLE project, a pioneering Artificial Neural Network (ANN) based approach was developed to estimate percentage of different load categories and distinguish controllable load from the total demand at bulk supply point at any given time based on RMS voltage, real and reactive power measurements at the substation, as shown in Figure 5. Load compositions obtained by the AI tool are compared with the validation data and used for load characteristics estimation and validation.

The estimated controllable and uncontrollable load percentages are also compared with the targets in the validation process. Moreover, the probability distribution and the confidence levels of load participation estimation errors are obtained. This module could be integrated with the total demand forecasting tool, which will provide prediction of load compositions and their controllability and eventually facilitate effective demand side management (DSM).

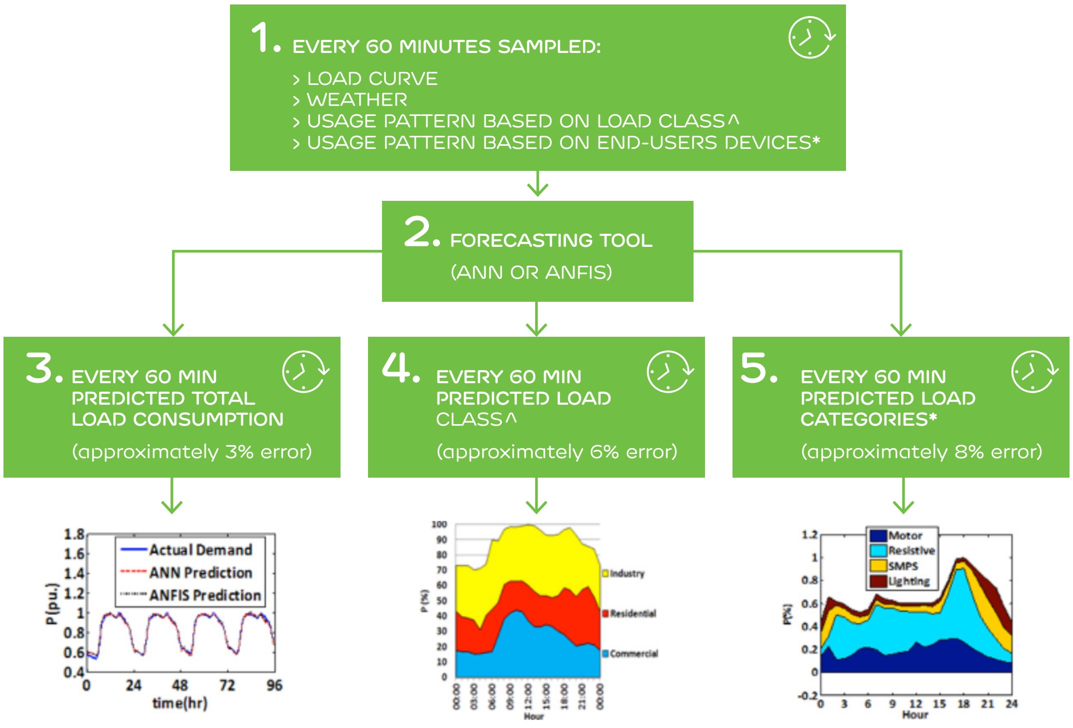


FIGURE 5 | Methodology for load forecasting.

Furthermore, an approach for prediction of dynamic response of the demand (DRD) was developed at distribution network buses by taking into account daily variation in demand composition and generic dynamic responses of different types of load.

With established dynamic signatures of different load categories and load compositions at different times of the day, Monte Carlo Simulation (MCS) is used to predict probabilistic real and reactive power responses, including ranges of variation of these responses at given time of the day. In this project, a DSM example is given to illustrate the change to DRD when control action is taken.

› ADVANCED LOCAL DISTRIBUTION GRID MONITORING/STATE ESTIMATION

The main objective of the state estimation functionality is to find the values for a set of variables (states) that adjust in a more adequate way to a set of network values (measurements) that is available in real-time.

3.3.2 NETWORK OPERATION

› ADVANCED COORDINATED VOLTAGE CONTROL

Large-scale integration of DER, and especially variable RES, brings significant challenges to grid operation that require new approaches and tools for distribution system management with voltage control being one of the most demanding tasks. Within the SuSTAINABLE concept, advanced voltage control involves a coordinated management of the several DER connected at the MV and LV levels in order to ensure a smooth and efficient operation of the distribution system as a whole.

The proposed methodology exploits two different levels of control encompassing both the MV and LV levels, as shown in Figure 6.

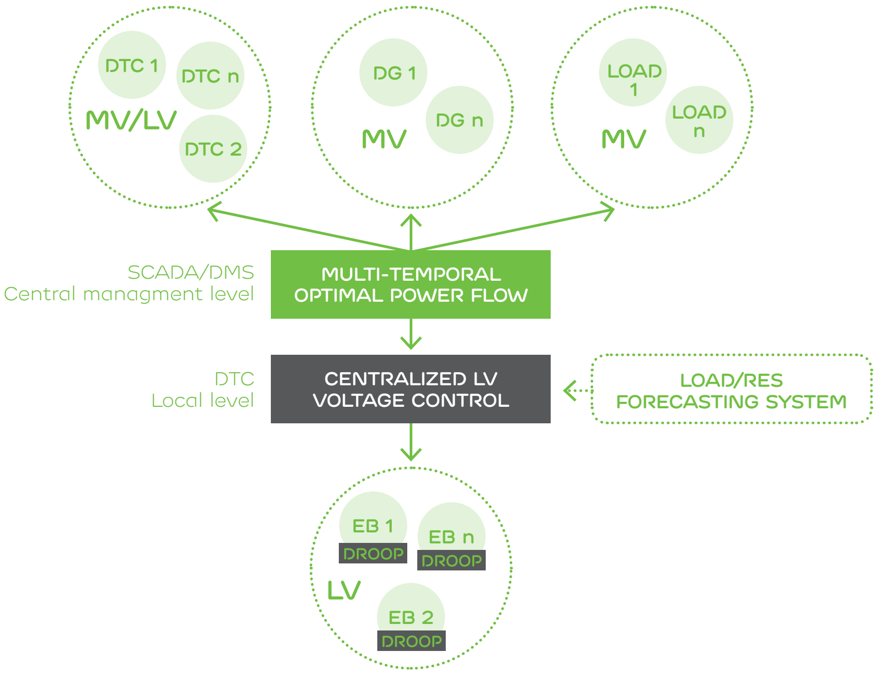


FIGURE 6 | Framework of the voltage vontrol system in SuSTAINABLE.

A multi-temporal OPF operation at the level of the HV/MV primary substation level is responsible for controlling MV network operation.

THE APPROACH WORKS IN 2 TIME-FRAMES:

D-1 ANALYSIS

The multi-temporal OPF produces a set of control actions for the next day by MV network node (DTC) with the objective of maximizing the integration of energy from variable RES subject to a set of technical constraints.

6-LEAD-TIMES AHEAD ANALYSIS

the same multi-temporal OPF developed for the day-ahead analysis is used in order to adjust the control actions previously identified with the objective of minimizing the deviations in a sliding window of 6 hours-ahead.

› TECHNICAL VIRTUAL POWER PLANT (TVPP) CONCEPT

An important functionality of the SuSTAINABLE concept is the Virtual Power Plant (VPP).

The VPP is a novel market player that aggregates and schedules distributed energy resources (DER) according to contracts established with them. These resources comprise renewable generation, storage, and load. The VPP's aggregation function is very important for the participation of DER in the electricity market. This is because distributed resources are often too small in size for direct market participation. This is covered by the commercial role of the VPP. However, the extensive proliferation of DER in distribution networks can lead to network security problems, which is one of the main challenges tackled by the SuSTAINABLE concept. The utilization of DER for flexibility services that support network security is therefore of interest. The activation of such services requires the close coordination between the system operators and the technical role of the VPP.

A valuable and new function of the VPP that was developed is the support in congestion management in the distribution network.

The VPP can support the DSO with the relief of network congestion by re-adjusting the schedules of its units.

The flowchart that indicates the series of steps and the interactions between the different actors in the day-ahead operation is shown in Figure 7.

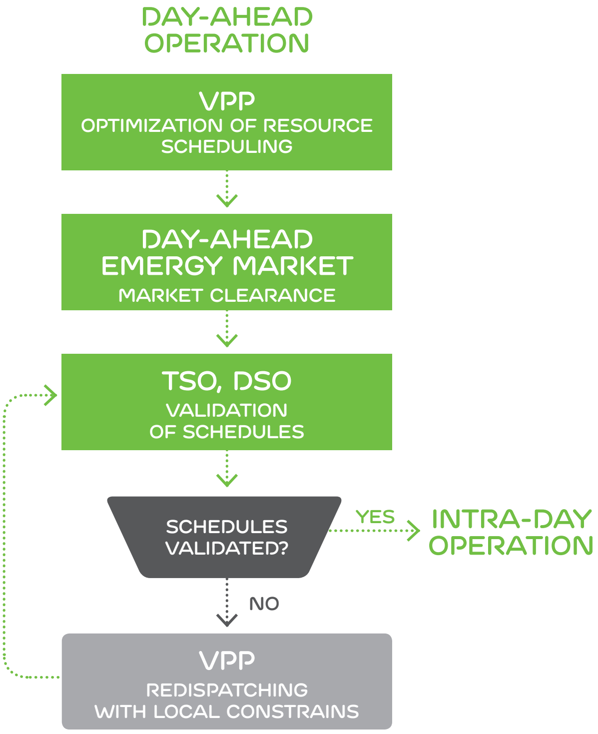


FIGURE 7 | Flowchart of the day-ahead operation.

In particular, after the VPP's internal optimal dispatching, its aggregated bid is sent to the day-ahead energy market. After receiving all the bids, the market is cleared and the schedules of the different resources are then sent to the TSO and DSO for their technical validation. Regarding the distribution network, if the DSO detects congestion on a feeder the VPP's congestion support function can be employed. The VPP receives local constraint information by the DSO and re-dispatches the schedules of its resources to address the congestion. During this re-dispatching, its aggregated bid stays firm to avoid intra-day imbalances. The accepted schedules can then be followed in the intra-day operation.

HV-MV SUBTRANSMISSION NETWORK 110KV

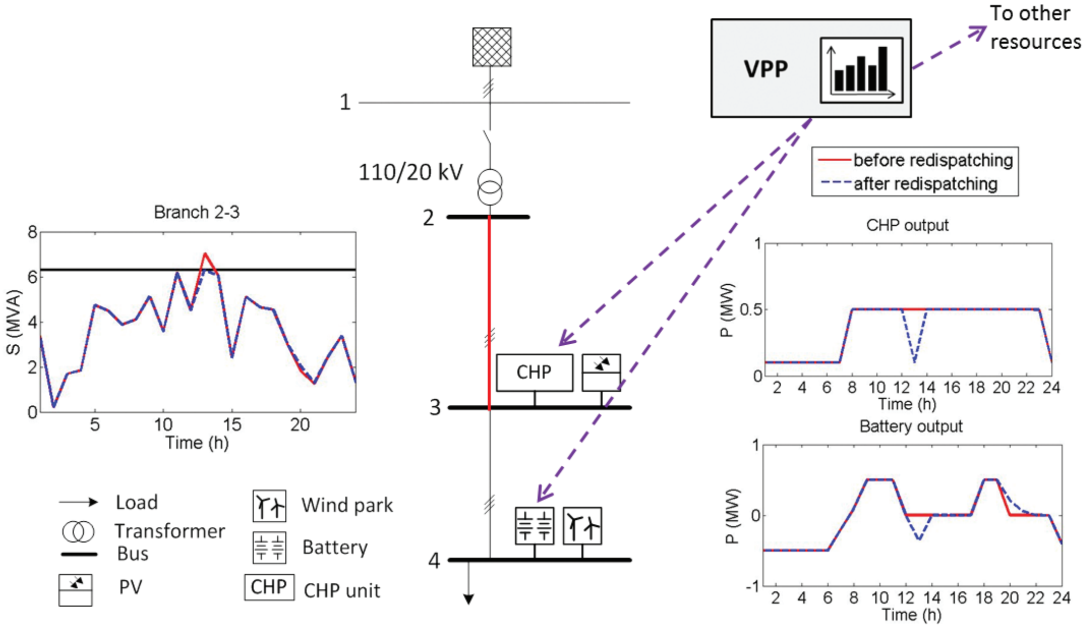


FIGURE 8 | Example of VPP's re-dispatching to relieve congestion over branch 2-3 at 13:00h.

An illustrative example of the re-dispatching of the VPP's units is shown in Figure 8. In particular, congestion is detected on branch 2-3 due to upstream power flow at 13:00 h. By employing the VPP's congestion support service, the units of the VPP on buses 3 and 4 are controlled. In particular, the battery starts charging and the CHP unit reduces its generation output in order to lower their contribution to the power flow over the overloaded line. The units of the VPP located on other feeders are accordingly modifying their schedules to maintain the VPP's aggregated energy market bid. In this way, the generation of the resources is not curtailed, but it is reallocated following a market-oriented approach.

› PROVISION OF DIFFERENTIATED QUALITY OF SUPPLY (QOS)

The role of VPP, presented in the previous section, is extended to support and enhance system security upon request for certain areas of the networks at certain times of operation. A method to temporally control interruptive loads from the VPP is developed without predefining control strategies or using indications, such as market prices, to decide on the best control strategy. To illustrate the general concept of the QoS in different zones including QoS temporal and spatial threshold variations, Figure 9 is presented.

THE DSO IN THIS EXAMPLE PROVIDES 3 LEVELS OF QUALITY IN EACH OF THE 3 ZONES

HPG
High Power Quality

MPG
Moderate Power Quality

LPG
Low Power Quality

For a certain observation period (day, month, year etc.) and due to different uncertainties (DG penetration, loading levels, faults probabilities,…) in different zones the QoS can vary between different levels, for example Zone A shows higher variation in QoS, where zones B and C show less variation (the red solid circle shows the current QoS level, the dotted circles show the levels that were recorded through the study period).

Also, different types of loads can show different levels of variation in requirements and QoS phenomena's thresholds.

The scheme of differentiated QoS developed in SuSTAINABLE can benefit both DSO and customers in terms of more effective way of operating the network while fulfilling different customers' requirements.

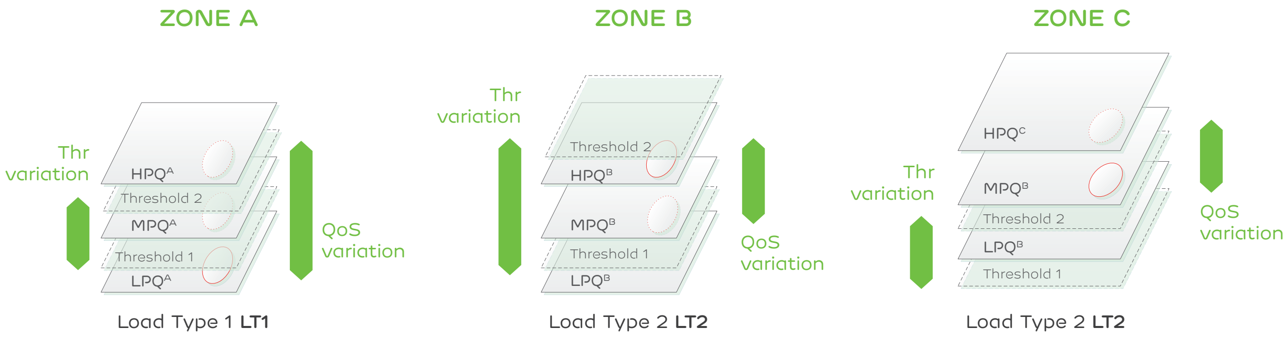


FIGURE 9 | Differentiated QoS example.

The expected benefits associated with the concept of provision of different levels of QoS to different zones (group of customers) can be summarized in Figure 10.

Savings in the mitigation costs due to the share of costs between costumers

Possibility to invest in more expensive, **but efficient**, QoS improvement solution wich are not affordable to individual costumers

Increasing adoption of the mechanism by the costumers due to decreasing mitigation costs

Benefits to the network: reduction of loses, restore balance between phases, voltage support

New mechanisms for demand side managment

FIGURE 10 | Provision of differentiated QoS: expected impacts.

3.3.3 NETWORK PLANNING

› NETWORK REINFORCEMENT PLANNING CONSIDERING DER MANAGEMENT

Under the SuSTAINABLE concept, managing the DER within the power distribution network may enable removing technical violations, namely nodal under or overvoltage and branch overloads, that would otherwise require new investments to be made in network reinforcement. In order to quantify the potential for investment deferral, two planning models were developed, model 1 and model 2.

MODEL 1

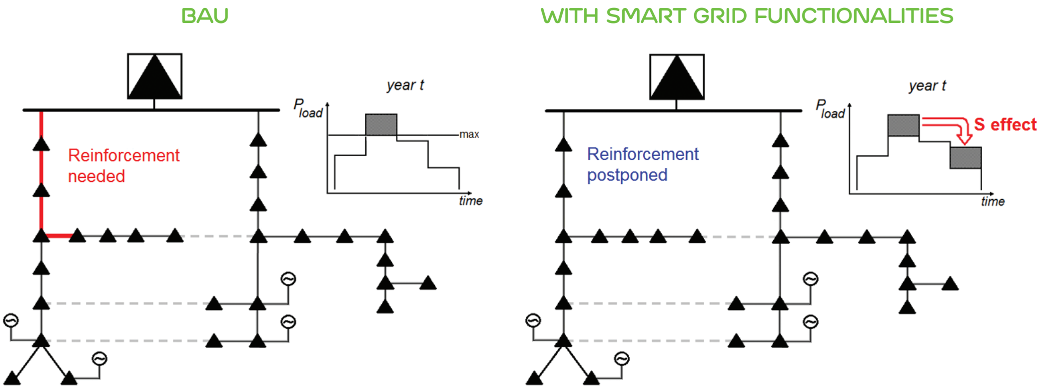
Determines the location, the size and the time period of new network components in order to meet the load growth demand and to host large shares of RES over the planning period.

The planning tool consists of two successive optimization procedures. In the first level, an optimization algorithm based on a problem specific Genetic Algorithm is used to define the siting and sizing of new distribution lines and substations. In the second level, a heuristic approach is employed to determine the period of commissioning of the selected investments on new network components. The planning tool incorporates the active network management (ANM) of the renewable generation by controlling the output active and reactive power of the DG units.

MODEL 2

Uses a multi-temporal OPF for simulating the daily operation of the future power distribution system including the DER, so as to obtain the corresponding schedules of investment and decision parameters (active power losses, energy costs), while enforcing the technical constraints for voltage and branch flows.

At the MV level, the model accounts for the profiles of the distributed generation (DG) in the grid, as well as the available distributed storage devices (DSD) and flexible loads (FL) that can be used for solving technical problems and thus may have an impact on the planning process. At the LV level (MV/LV secondary substations), simplified models are used for the load, microgeneration, solar PV and FL connected at the MV/LV substation level. Net Present Value (NPV) analysis is used for calculating the corresponding costs.


BAU

WITH SMART GRID FUNCTIONALITIES

FIGURE 11 | Potential for network reinforcement deferral under the SuSTAINABLE concept.

Both models have been tested using real power distribution networks, including the distribution networks of the Greek island of Rhodes (Model 1) and the Portuguese city of Évora and its suburban area (Model 2). In the case of Model 1, the results demonstrate that the active management of the renewable generation can lead to a decrease in the investment costs of distribution lines and substations. In regards to Model 2, the results show that using the distributed flexibility provided by DSD can bring about an increase of RES penetration while, at the same time, avoiding investments in network reinforcement.

› POWER QUALITY PLANNING FOR FLEXIBLE DISTRIBUTION SYSTEMS

In SuSTAINABLE, power quality planning focuses on optimising the QoS mitigation infrastructure based on customer requirements and presence of stochastic and intermittent power electronics interfaced DG in the network. Power quality (PQ) phenomena including voltage sags, harmonics and unbalance in distribution networks are considered for PQ planning, as these phenomena would most likely result in PQ interruption to equipment or industrial processes and thus cause massive financial loss to both utilities and customers in distribution networks. Methodologies and indices are investigated for evaluating the severity of various PQ phenomena. Several new PQ gap indices were proposed to evaluate the satisfaction levels of the received PQ performance compared to the customer specified thresholds, aiming to enable the provision of differentiated PQ levels in different zones of the network. Based on these indices, temporal and spatial analysis of PQ performance was performed on a large-scale generic distribution network with the presence of stochastic and intermittent power electronics interfaced DGs. In the harmonic investigation of the LV distribution network, a new modelling methodology for tracking losses and other network impacts is developed. Based on this method, an incentive scheme is proposed to promote harmonic compensation by distributed energy resources.

A range of PQ mitigating solutions was investigated to insure cost-effective management of PQ in the network. Flexible ac transmission system (FACTS) devices and network/plant based mitigation techniques were tested as the potential solutions to the PQ problems at hand. The effectiveness of these mitigation techniques were discussed based on the aforementioned severity indices and further tested in generic distribution network. An optimisation methodology was proposed for optimal, cost-effective, PQ mitigation in the network with the focus on the type of mitigating solutions and the optimal level of the mitigation. In this methodology,

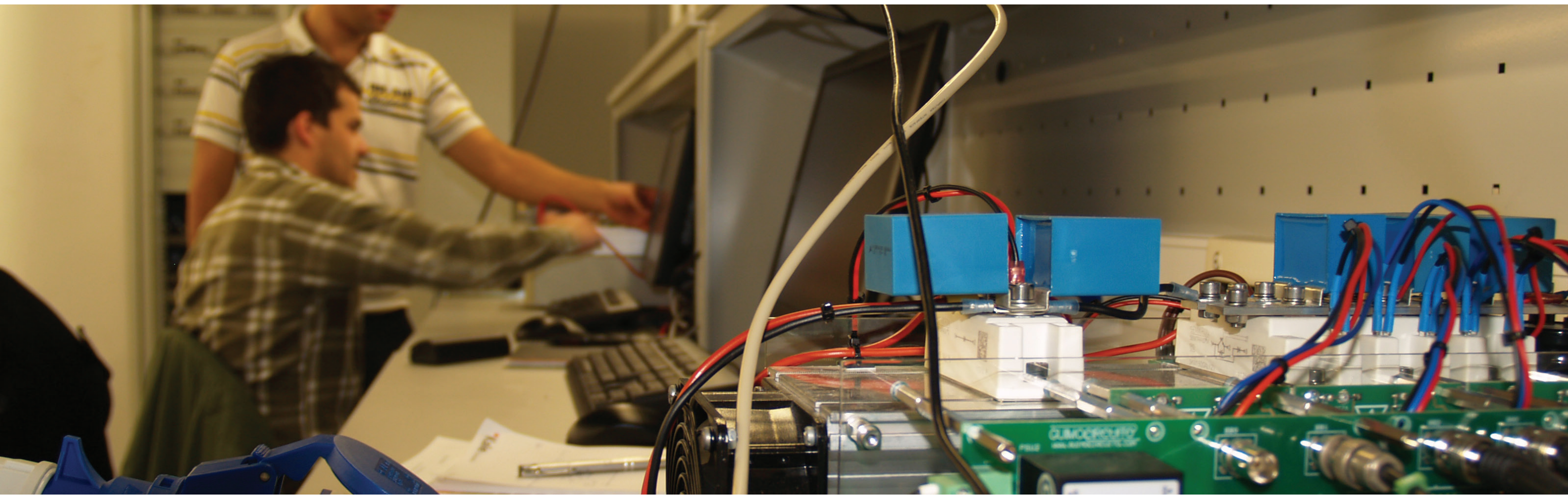
greedy algorithm is applied to search the optimal mitigation scheme in order to enable the provision of differentiated PQ levels. Taking the new gap indices as the objective functions of the proposed optimisation methodology, the mitigation strategy is optimised to meet the zonally specified thresholds. The optimality and robustness of the obtained solutions were validated through extensive simulations in DigSILENT/PowerFactory, and heatmaps are applied to present the significant PQ improvement as a result of the application of the optimal mitigation strategy obtained by the proposed methodology.

This project also investigates the economic assessment of PQ mitigation at planning level, by considering the benefits during the entire life span of the deployed solution. Since the upfront investment made for a mitigation solution pays back its returns only during the life span duration, the methodology calculates the net present value of future benefits, as well as the net present value of future maintenance, which brings the investment cost and its benefit to a common ground/level of comparison with planning or deployment year as the reference.

› PLANNING OF ADVANCED SYSTEM PROTECTIONS

The presence of high levels of distributed energy resources (DER) on the network are changing the passive nature of the network at a MV level. In the event of a short circuit on one network node, all DER will contribute to the overall fault current. However, distribution network's protection systems are designed considering the classical view of the distribution network as comprising only passive loads. To tackle this issue, the functionality of Advanced System Protections Systems was developed and implemented on the Sustainable project, dealing with the foreseeable problems arising from the contribution for the fault current provided by the DER. Therefore, this functionality calculates and sets the adequate protection parameters on the relays, according to the operational conditions and the short-circuit characteristics that DG introduces on the feeder.

Several conditions are considered for the calculations of the protection settings. For each condition, the SSC is able to decide on the most adequate setting group to be used within a real-time protection scheme and automatically send the control signal for this selection.



THE ENVISAGED PROTECTION CHALLENGES ASSESSED ON THE PROJECT WERE:

- PROTECTION BLINDING
- SYMPATHETIC TRIPPING
- FAILED AUTO-RECLOSING
- LOSS-OF-MAINS PROTECTION
- FAULT RIDE-THROUGH

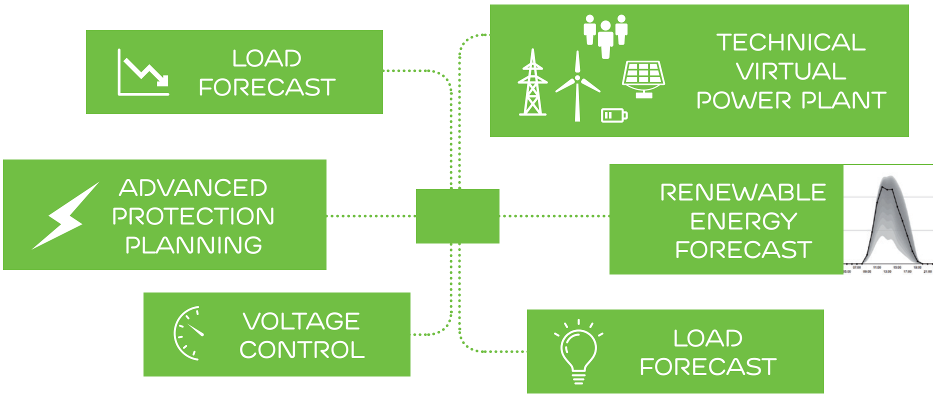
The proposed model aims at improving the selectivity of protection relays, by performing dynamic tuning of their protection setting, enhancing the role and performance of DG. Nuisance tripping will be minimized, limiting the impact of adjacent feeder faults.

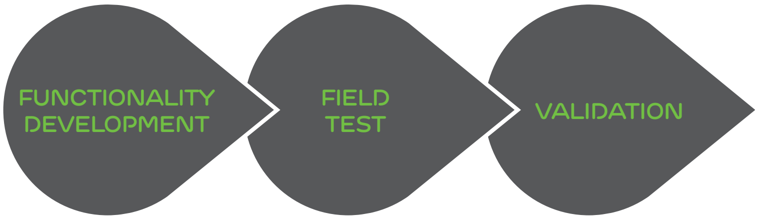
3.4 STUDIES AND DEMONSTRATIONS

3.4.1 SUSTAINABLE DEMO SITE – ÉVORA, PORTUGAL

The purpose of the proof of concept is to validate the developed functionalities in real conditions, using data collected from the network (sometimes, in real time), resorting to already installed equipment or equipment installed specifically for SuSTAINABLE demonstration purposes.

The field demonstration is one of the most differentiating components of the project, due to the significant development in software, equipment installation and configuration, and mostly, the effort to follow the proposed architecture, even in live conditions in the field. The validation activities will not only allow better understanding the behaviour of sustainable concepts in a live application, but will also provide inputs for data processing and KPI calculation.





› SF1 – LOAD FORECAST

The first smart-grid infrastructure installation in Portugal took place in Évora, with more than 35 000 smart meters installed, allowing access to more detailed information of the network, with special emphasis on the LV network.

The specific purpose of the demonstration is to forecast active power values for Casinha feeder, for a period that can range from 30 minutes to 24 hours. For this, real data was collected from the network and, together with weather data, was used to perform forecasts according to the algorithm developed within the project.

As mentioned before, SF1 demonstration requires both network and weather values. Weather data for Évora region including wind, humidity and temperature values, is provided twice a day.

Since network and weather data are located in different servers, it was necessary to build data extractors in order to collect this data and place it in the same FTP server. The network data is updated every 30 minutes, while weather data is, as mentioned, update twice a day.

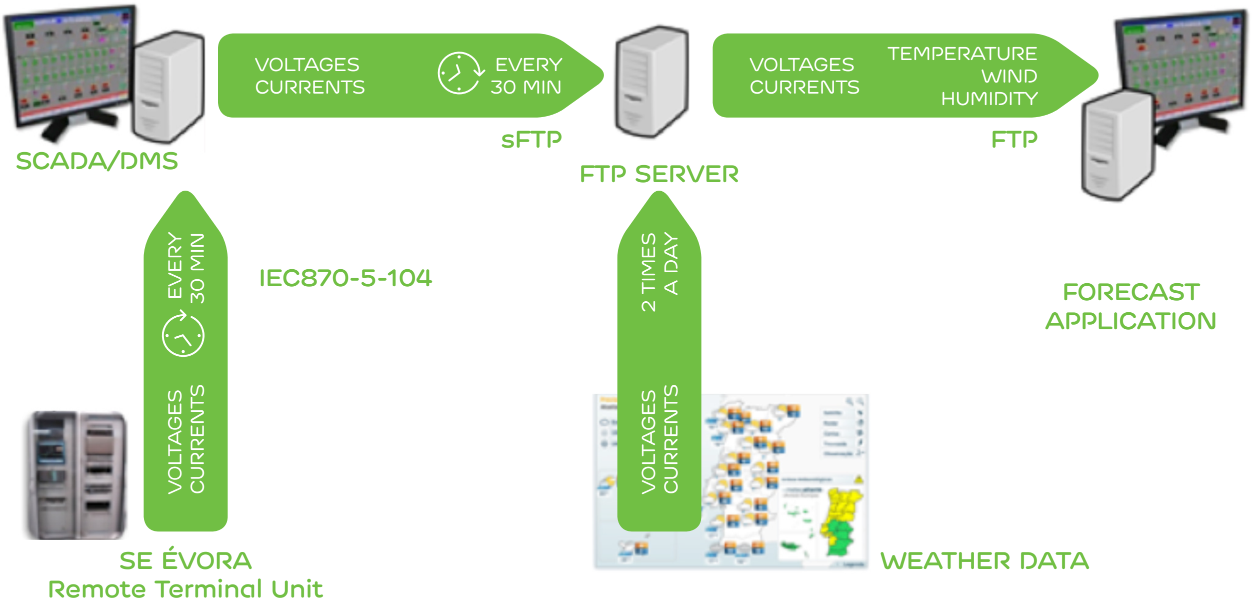


FIGURE 12 | SF1 demonstration architecture.

A specific software interface was developed in order to validate this functionality. It allows users to easily obtain forecast values, compare them with real power values and assess forecast error values, change forecast horizon.

› SF2 – RENEWABLE ENERGY FORECAST

The purpose of SF2 functionality and demonstration is to perform renewable energy forecasts at LV point level and secondary substation level. Since the only available renewable technology generation in Évora region is PV (at LV level), the demonstration focused in this specific technology.

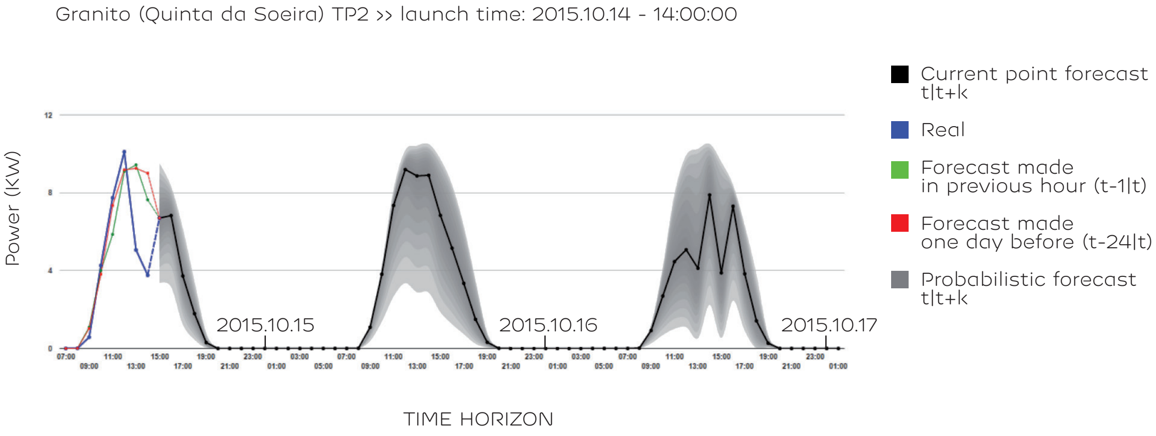


FIGURE 13 | Production forecasting of a renewable prosumer.

SF2 requires information at the LV level, namely, the energy produced by micro generators. Collecting this information for billing purposes is one of the roles of EDP Distribuição as the main Portuguese DSO. However, the frequency of data collection is not sufficient to produce forecasts with the quality that is necessary under the SuSTAINABLE project, which is focused on short-term forecasts. Therefore, it was necessary to install prototype monitoring equipment in a subset of micro generators. Criteria such as quality of historical information and geographical dispersion were taken into account. The participation of the customers was entirely voluntary and the scope of the project and of the demonstration was previously explained to them.

After the criteria analysis and customer survey, a group of 41 micro generators was obtained. These micro generators are spread throughout 27 secondary substations.

Visits were scheduled to each one of the customer's houses in order to install the monitoring equipment and to retrieve a protocol signed by the client that states the consent to provide microgeneration data for the purposes of this project.

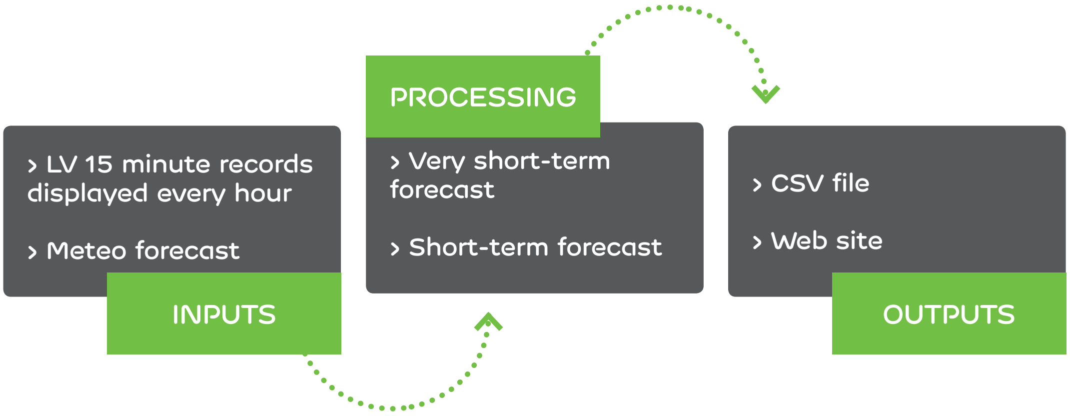


FIGURE 14 | Simplified block diagram of SF2 demonstration.

THE EQUIPMENT THAT IS INSTALLED AT THE CUSTOMERS' HOUSES CONSISTS OF:

POWER METER to measure the produced power	ELECTRONIC GATEWAY	3G ROUTER with SIM card to send the data to a central system

At the moment, every hour, information collected from the power meter is sent to an FTP server. The following information is provided:

Timestamp	Gateway identification	Energy measurements for each 15 minutes

The SF2 application uses this information, together with weather data, to process the forecasts according to the algorithm developed within the project.

The forecast results are available in csv files, via ftp, and via web site. A simplified block diagram is presented in Figure 14. This information in csv can be integrated in other corporate systems bringing added value to the analysis and decision making process.

Within this framework a web application was developed, containing graphical information for the forecast values allowing the user several customisation options.

› SF3 – STATE ESTIMATION

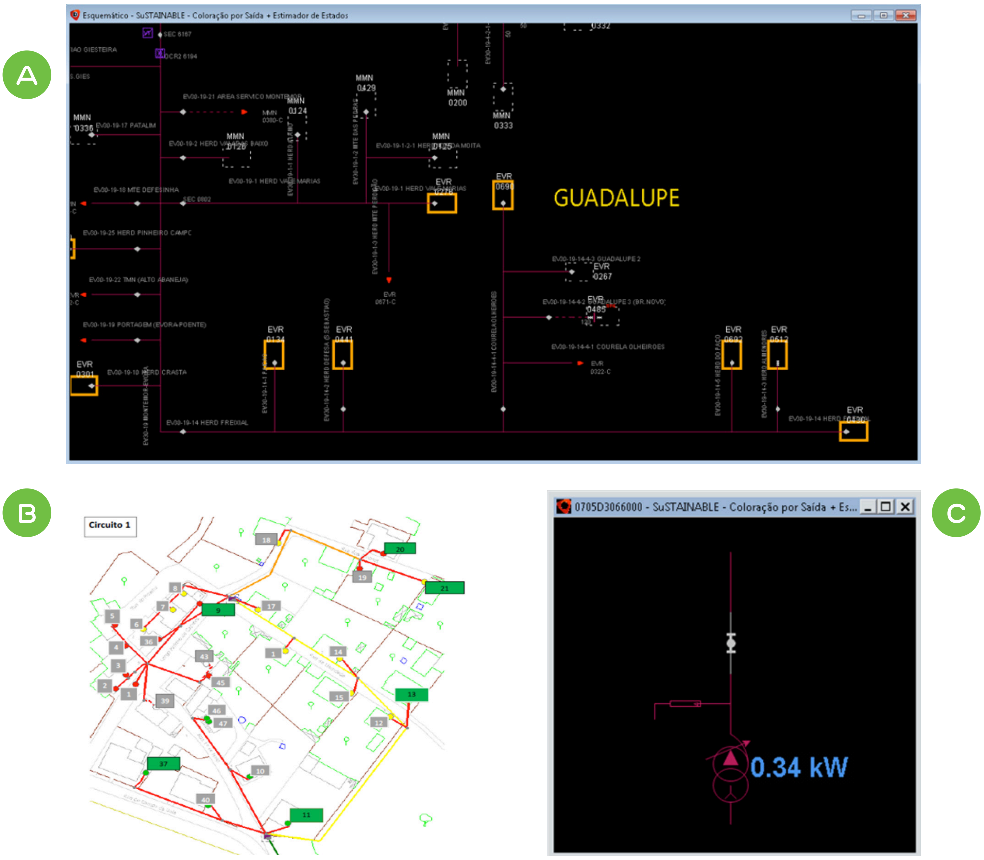


FIGURE 15 | LV Network and respective SCADA representation for the state estimation functionality: Ⓐ Guadalupe area SCADA representation Ⓑ Guadalupe LV network and selected customers for real time data collection Ⓒ Detail of a point and instant power

The purpose of SF3 functionality and demonstration is to perform state estimation at MV level, but with an innovative feature: the estimator is able to determine MV measurements by incorporating measurements collected at LV level (as long as they belong to the same LV network), through the use of an auto-encoder. LV historical data is used for model training and pseudo-measurements generation. Real data from a subset of smart-meters is necessary every time a state estimation is performed. For the purposes of this functionality, it was necessary to select a MV network and, within this feeder, a LV network for the provision of LV measurements.

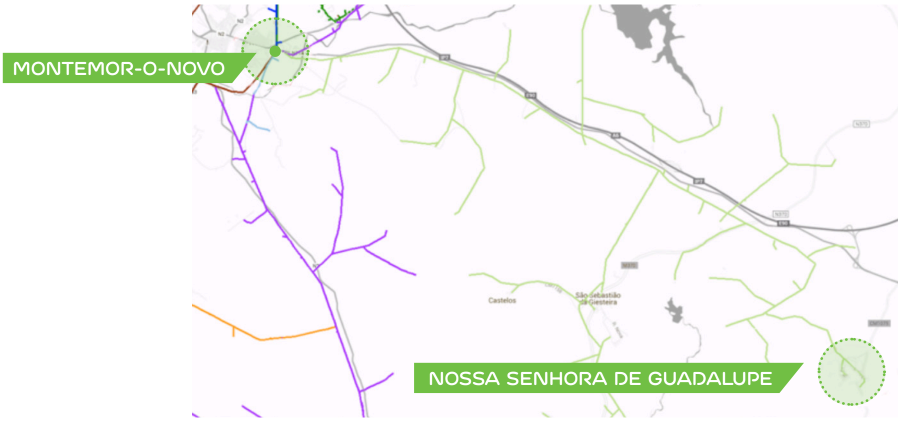


FIGURE 16 | Geographical location of primary and secondary substation for SF3.

The selected substation is Montemor's primary substation, and the selected LV network is located in Guadalupe village. The secondary substation located in Guadalupe contains 40 customers whose historical data is being used to the generation of pseudo-measurements. From these 40, 6 meters are monitored in real time whenever the estimator is executed. The 40 meters have PLC PRIME communication and the specific meters installed according to the solution indicated have GPRS communication.

FIGURE 17 | LV network from Guadalupe secondary substation

The system installed at Montemor primary substation includes a Workstation that can be used to visualize the network state using synoptic diagrams that have been specially built for this purpose. This workstation also offers an application with a Graphical User interface that is used to control and display results of Power functions. Figure 17 shows the snapshot of the LV network from Guadalupe secondary substation.

› SF4 – VOLTAGE CONTROL

The purpose of SF4 functionality is to assure voltage values remain within regulatory limits, by making use of the several DER spread throughout the network. Control schemes at primary substation level, secondary substation level, and LV level are foreseen in this functionality. The demonstration of this functionality will focus on the voltage control of a LV network.

SF4 requires resource controllability, and, as of today, there aren't any resources for the DSO to control in the MV/LV secondary substation and at the LV level. Also, the inverters that are present at the micro generators installations cannot be controlled, due to technical and regulatory reasons. Therefore, it became necessary to install resources that could be controlled. In order to obtain physical space for this purpose, an official protocol was stablished between EDP and local government authorities that allowed the use of a government building that is used only for material storage and sporadic local events.

Within these installations, the following resources were installed:

- **30 UNITS OF 250 WP SOLAR PANELS**
  corresponding to a total installed capacity of 7,5kW
- **64 UNITS OF 12V 12AH BATTERIES**
  corresponding to a nominal capacity of 4,6kWh (2 sets of 4,6kWh)

It is also important to state that this infrastructure was set up in a way that could assure that, in total, there are 4 controllable resources: 2 sets of 4,6 kWh in terms of batteries, and 2 sets of PV of 3,75 kW. Following the SuSTAINABLE architecture, each DER contains a prototype inverter that is controlled by a smart meter. The smart-meter then communicates with the secondary substation controller.

The smart-meters communicate with the DTC installed in the secondary substation, in which the voltage control algorithm is embedded. The smart meters in the SuSTAINABLE facilities are connected to the inverters via a local interface: the HAN interface. This interface is present in all of EDP's smart meters and allows the smart meter to serve as a gateway to the customer's house.

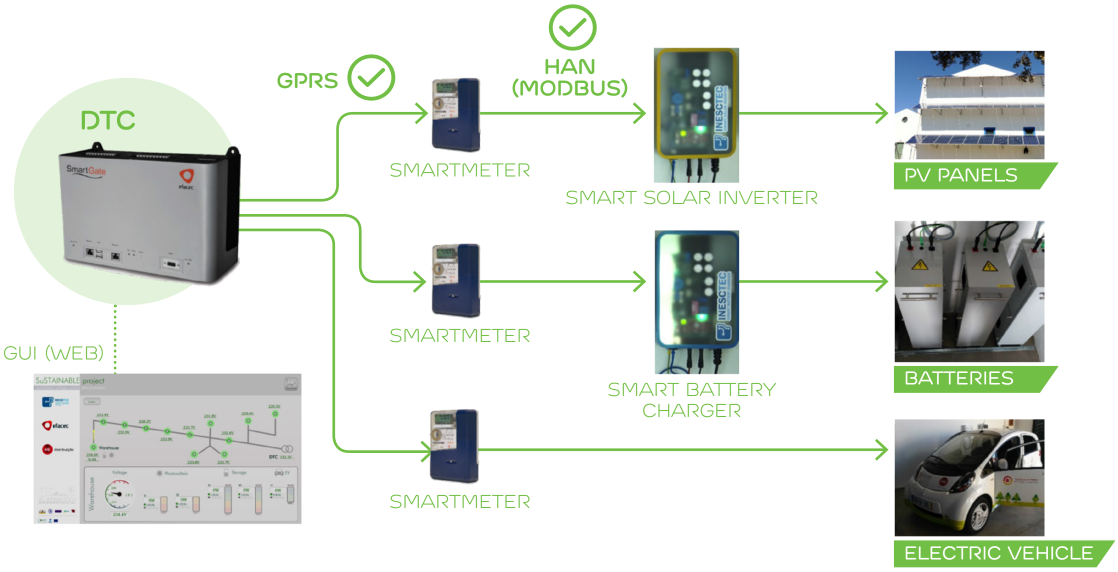


FIGURE 18 | Demonstrator setup for voltage control in Graça do Divor.

Two different prototype inverters have been developed by INESC to be used in the demonstration of the SF4 functionality:

- SMART SOLAR INVERTER FOR INTERFACING PV GENERATION
- SMART BATTERY CHARGER FOR INTERFACING BATTERY STORAGE UNITS

As previously explained, the inverters have active power/voltage droop control embedded in their hardware for local voltage control purposes.

To interact with the LV controllable resources (batteries and solar inverters), the user must access to the DTC HMI web interface. A set of modules are available for visualization and control the smart meters data.

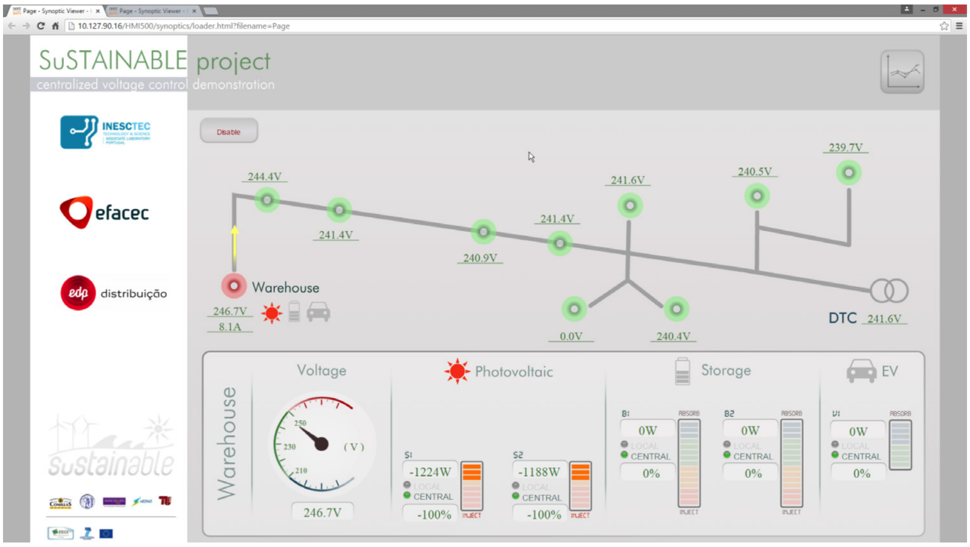


FIGURE 19 | Synoptic screen of SF4 software interface.

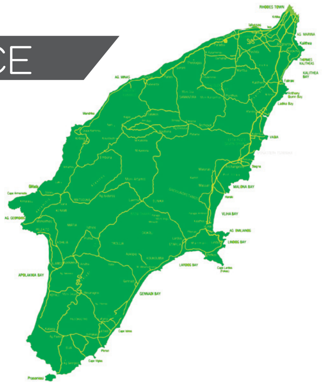
3.4.2 SUSTAINABLE DEMO SITE - RHODES, GREECE

RHODES ISLAND is located in the southern east part of Greece and is a relatively large island with a population of 160,000 inhabitants.

It has a thermal installed capacity of 233 MW with eleven generation engines, with a peak power consumption of around 200 MW. It has a HV transmission network of 150 kV and a distribution network with forty seven MV distribution lines at 15 kV and 20 kV voltage levels. There are currently 5 Wind Farms (WFs) with installed capacity of 49 MW and an increasing number of PVs with a current total capacity of 19.4 MW.

Rhodes has a summer peaking system. The ratio between minimum and maximum load is high with minimum around 40MW, while maxima often exceed 180MW. Thus, the RES production can reach hourly very high penetration levels exceeding 35%

RHODES, GREECE



THE FOLLOWING FUNCTIONALITIES WERE DEMONSTRATED USING THE RHODES SYSTEM AS REFERENCE:

FORECASTING TOOLS

At the frame of SUSTAINABLE project, a load forecasting system and a RES forecasting systems were developed by ICCS/NTUA. Specifically, the load forecasting system is applied to estimate the load of an HV/MV substation located at the Rhodes power system.

The substation is connected with two wind farms and several PV installations. In order to estimate the load that flows through the substation feeders, the load forecasting system uses the solar power and the wind power predictions providing by the RES forecasting system created by ICCS/NTUA.

ADVANCED VOLTAGE CONTROL

Advanced coordinated voltage control, which is one of the main functionalities developed within SuSTAINABLE project, plays a crucial role in controlling the MV network regulation resources, taking advantage of the capabilities offered by other functionalities developed within the project. The developed tool approaches the issue of network optimal operation mainly from a DSO perspective, taking however into account the impact on DG station operation.

The coordinated control concept defines an optimal day-ahead scheduling in a distribution network, in order to minimize an objective function that may comprise several objectives beyond voltage regulation (losses, tap wear, overall power factor etc.).The algorithm takes into consideration all network devices and systems that contribute to voltage regulation.

The algorithm was evaluated in 3 different real networks in Rhodes, characterized by different load and RES penetration levels, as well as feeder characteristics. One study case feeder corresponds to challenging conditions of significant length, relatively low load and high RES penetration levels. The second feeder is highly loaded, with a moderate RES capacity, while the third case corresponds to the simultaneous application of optimal control to both previous feeders.

The exploitation of storage systems and their effect on the calculated KPIs and the overall distribution network operation were also analysed. Storage is known to be a valuable tool in networks congested by DG, its effectiveness depending mainly on the sizing, installation position and management policy. In this study, results have been presented, assuming an indicative (rather than optimal) sizing and allocation of storage devices.

As a general conclusion it can be stated that optimal control leads to a significant improvement concerning voltage regulation, energy losses and the other optimization targets. The extent of this improvement depends on the availability and characteristics of the controllable network devices, particularly DER. It is obvious that if a network with insufficient DG units is examined, control effectiveness will be very reduced. Other controllable devices such as OLTCs or shunt capacitors also play a significant role. The loading level of the feeder is also a crucial parameter. The higher it is, the more controllable units will be required to achieve a notable result, as it is evident by the reduced performance of the algorithm when applied to the case study 2 feeders.

ADVANCED SYSTEM PROTECTION STRATEGIES

The protection problems described are evaluated through a series of simulation tests. Specifically, the test-bed of ICCS was utilized to investigate the protection blinding and sympathetic tripping occurrence in modern distribution networks with large DG penetration, conducting several HIL secondary tests. Moreover, the passive islanding detection methods were assessed under various operating conditions of the examined network, making use of a simulation scheme built by ICCS in the Simulink platform.

Protection blinding and Sympathetic tripping were studied both in a theoretical level but also in Hardware in the Loop (HIL) tests, where real relays were connected to simulated distribution networks. The model of the distribution network under examination was designed in the RSCAD/RTDS environment, and used in a series of simulations. It represents a simplified single-phase configuration of the Greek island Rhodes HV/MV Substation "Gennadi". Moreover, the Automatic reclosing (auto-reclosing), as an effective fault clearing technique, was analyzed. A classification of islanding detection methods was presented. The conducted simulation cases focus on the two most common passive anti-islanding techniques, namely the ROCOF and VS techniques, which are widely applied to industry facilities.

To conclude, the adaptive protection algorithm that was developed and validated in ICCS-NTUA laboratory, proved to be an adequate solution for solving protection issues caused by the integration of DG units in the distribution network. By changing the relays setting groups (according to the topology of the network) the problems of Protection blinding and Sympathetic tripping were encountered.

PLANNING METHODOLOGIES

The network reinforcement planning tool that was developed for ICCS in SuSTAINABLE is applied to the Rhodes distribution network. The developed multi-stage power distribution planning (PDP) framework considers the active management of the distributed flexibility and it is applied to MV distribution networks with high penetration of renewable energy sources (RES).

Two 20kV distribution feeders of the Rhodes distribution network were analyzed to validate the effectiveness of the developed planning tool for real world distribution networks. The results highlighted the positive effects of the management of the renewable generation on both investment and operational costs. The results demonstrate that by incorporating the active management of the renewable generation the investment costs on distribution lines and substations can be decreased by 2% to 35%. Furthermore, by controlling the active and reactive power of the RES a reduction of 2%–6% to the total annual energy losses is achieved and the hosting capacity of the network can be increased by 15%–60%.

3.5 STUDIES AND DEMONSTRATIONS

3.5.1 SCALABILITY AND REPLICABILITY OF RESULTS

A key contribution of the SUSTAINABLE project is to identify scaling-up and replication rules and methods of the functionalities implemented in Portugal, Greece, UK and Germany.

In the present methodology, first the local implementation conditions for each country have been analysed. Four different types of conditions have been considered: geographical, technological, regulatory, and stakeholders. Then, the macro-scale replication of the functionalities developed in the project has been assessed. This has been performed by analysing the most important barriers identified through the previously mentioned questionnaire and determining their relevance and potential impact of the macro-scale replication of the SuSTAINABLE concept. The summary of this analysis is presented in the following table.

FUNCTIONALITY	PORTUGAL	GREECE	UK	GERMANY
SF1: RES Forecasting	above average	average	bellow average	average
SF2: Load Forecasting	average	bellow average	average	above average
SF3: Monitoring/State Estimation	above average	average	bellow average	average
SF4: Coordinated Voltage Control	average	bellow average	bellow average	above average
SF5: TVPP as a support for DSO/TSO	above average	above average	bellow average	bellow average
SF6: Provision of Differentiated QoS	above average	average	bellow average	bellow average
SF7: Flexibility Based Reinforcement planning	above average	average	average	average
SF8: Power Quality Planning	above average	average	bellow average	average
SF9: Advanced Protection Planning	above average	bellow average	average	above average

TABLE 1 | Relative impact of the implementation barriers of the SuSTAINABLE functionalities by country.

3.5.2 COST BENEFIT ANALYSIS

In SUSTAINABLE project the cost benefit methodology is based on the guidelines defined by the European Commission (EC) and the Joint Research Centre (JRC). In brief, the methodology is based on the evaluation of a set of KPIs to consider all relevant variables that can affect the cost benefit evaluation. In particular, three functionalities were analysed in detail in the different SUSTAINABLE demos, trying to quantify costs and benefits:

1
Prediction tools

2
Network automation

3
Voltage control

1

Prediction tools

The results from the impact of RES forecasting tools on the market highlight that the main benefits are obtained from the reduction of the ancillary services cost, where a reduction of 38% in the forecasting error implies a reduction of 34% of this cost.

On the other hand, the impact of thermal costs and CO^2 emissions is very small (lower than 1%), meaning that most changes are associated to generation operation rather than to the market structure.

This functionality provides higher benefits for large RES generation, implying that the more renewable energy sources into the system, the higher the necessity of this functionality. In Portugal, as the increase of demand cannot be covered only by the increase of RES penetration, all costs increase.

On the contrary, in Greece, with an aggressive RES penetration scenario, the ancillary service costs experience a huge increase, which can be effectively mitigated thanks to forecasting tools, as shown in the analysis.

2

Network automation

The impact of automation in the distribution grids shows that there is a major improvement of the continuity of supply for low automation degrees.

In particular, a 7% automation degree is identified as optimal in Évora, while in Rhodes the optimum is 3%.

The type of network, larger and more rural, as well as the lower demand in Rhodes network, make the cost benefit analysis only positive for very low automation degrees. On the contrary, in Portugal, even up to 40% automation degrees lead to a positive cost benefit analysis, with respect to the baseline scenario.

The sensitivity analyses show that the impact of failure rates on the continuity of supply indices[1] is linear, identifying the slopes which relate the failure rate decrease with the continuity of supply index improvement. The regulatory threshold used to set which faults are computed when evaluating the continuity of supply indices has an effect in the frequency of interruptions, but affects neither the duration of interruptions, nor the cost benefit analysis.

3

Voltage control

Regarding coordinated voltage control, prediction tools are shown to have an impact on the improvement of voltage control. In particular, the impact of underestimating or overestimating DG is similar (see Figure 20), although the drivers for these costs can be rather different.

Communication systems are also identified as relevant to reduce systems costs further, highlighting the value of controlling every minute.

With the employment of prediction tools and communication systems, there is usually a trade-off between voltage deviation costs and curtailment. However, concerning DG penetration, all benefits decrease for high DG penetration; meaning that the more DG into the system, the more costly that coordinated voltage control will be.

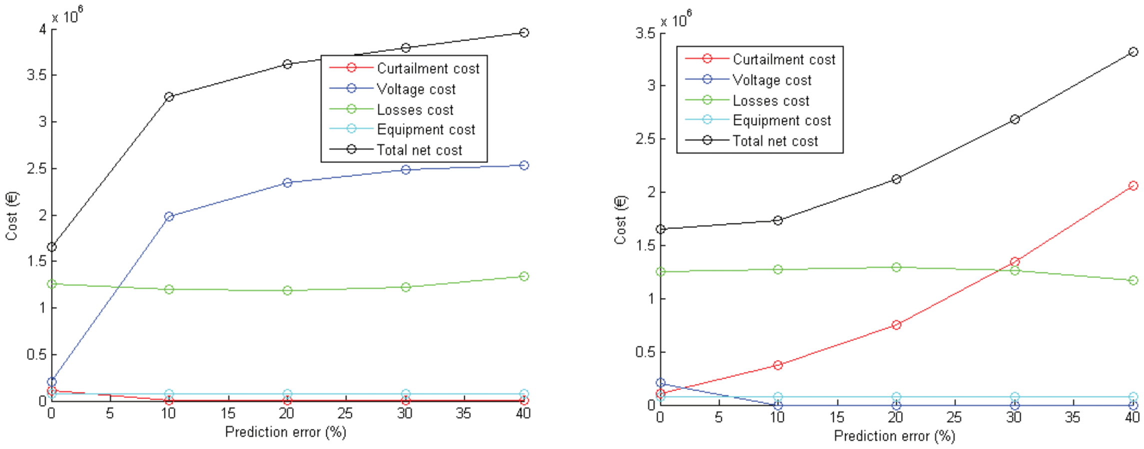


FIGURE 20 | Sensitivity to prediction error. In the case of underestimating (left) and overestimating (right) DG demand, by controlling every minute using the absolute set-points in a day with fluctuations.

Finally, the cost-benefit analysis carried out shows that smart grid solutions may lead to a reduction of total net costs, depending on their particular implementation. In the cases investigated, the selection of the adequate prediction error and automation degree targets is critical to be able to integrate renewable energy sources in a cost efficient way.

Overall, this points out the necessity of very carefully analysing smart grid solutions and technical characteristics of each distribution network to identify the best opportunities.

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[1] Continuity of supply indices measure the duration and frequency of interruptions.

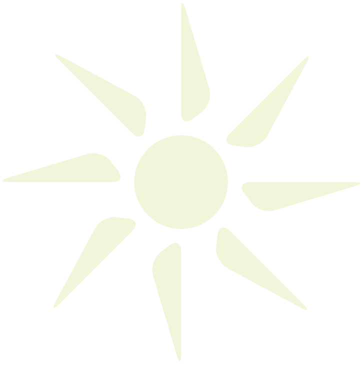
3.6 ROADMAP

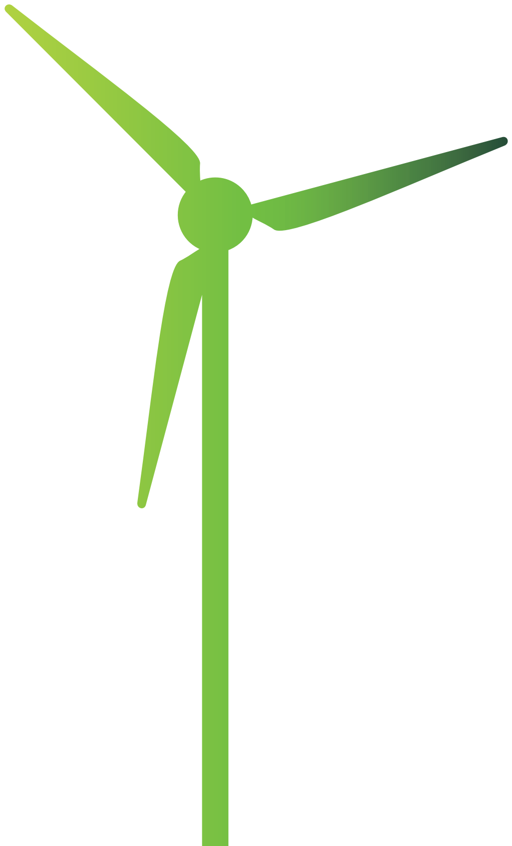
The transformation is underway and the 2015 Paris agreement enforces the shift of paradigm confirming "the irreversible transition to a low carbon, safer and healthier world" where power sector should play a crucial role. To pave this way, some barriers related to regulation and adoption of new market models still need to be overcome while new technological functionalities emerge to guarantee the evolution into a more reliable, efficient and flexible smart grid.

Concerning technological tools, many developments are emerging providing to network increased levels of predictability, controllability and observability over the growing number of resources connected to distribution network mainly in low and medium voltage. In this process, DSOs are positioning themselves as technological enablers leveraging the ability to become local system operators and moving from the traditional "Connect and Forget" concept towards a "Connect and Manage" one.

Therefore, the roadmap for deployment of SuSTAINABLE concept across Europe may essentially depend on factors beyond technology development, considering they are becoming more reliable and economically feasible. Several conditions such as level of DER penetration, regulation framework (e.g. existence of government decision about smart meters' rollout, incentives for innovation promotion, possibility of curtailment), technical conditions of network and social aspects such as consumer engagement and trust in DSOs, need to be addressed and will lead to different speeds of deployment of such concept among different European countries:

With all of these changes, we deeply believe for the next decades in a world powered essentially by renewables connected in distribution network where DSOs will play a key role in this SuSTAINABLE transformation of power sector.





04

CONCLUSIONS

In 2014, 56% of electricity in the EU came from low carbon sources and the share of RES in the power mix became the largest source of low carbon electricity in the EU, comprising 28% of total power generation. Furthermore and according to Energy Intelligence, New Energy Top 100 Green Utilities, six European companies ranked in top ten in 2015 (Acciona, Iberdrola, EDP, Enel, EDF and Dong Energy) which highlights the focus of Europe organizations towards this target.

Most of these new generators are being connected to distribution networks, which is likely to be continued and reinforced in the coming years in Europe. For example, in countries of SuSTAINABLE demo-sites, it is forecasted that energy from PV generators may double in Portugal (from 443 GW.h in 2014 to approximately 1.000 GW.h in 2020) and in Greece, it is expected a huge increase in Wind Energy (from 2.982 GW.h in 2014 to around 20.000 GW.h in 2020). This new paradigm points out the importance of technological developments addressed in SuSTAINABLE regarding the maximization of integration of renewable energy in distribution network.

However, this integration must be done in a cost-effective way for the electric system, ensuring at the same time high levels of quality of service, which brings to DSOs new challenges and need of a more active grid management. By managing their network with more advanced ICT tools, DSOs have begun to deal in a smarter way with certain grid issues such as network congestion or voltage constraints.

Regarding some tools addressed by SuSTAINABLE, a higher accuracy of renewables forecasting will affect positively the reduction of ancillary service costs and will give DSOs the ability to guarantee high standards of quality of service. Another tool such as voltage control, by acting over DER through a centralised voltage control system or even locally, will have a positive impact of avoiding overvoltage in distribution network and guarantee at the same time the reduction of the amount of energy curtailed and the increase of DG hosting capacity.

However, to achieve this transformation and consequent benefits on a large scale, national legislation and energy regulation must be adapted to make sure that this new technological developments can introduce its full potential by allowing the emergence of new market structures and at the same time by creating incentives for innovative grid projects.

This should be, in fact, the major transformation required to achieve the targets announced by EU and enhance the beneficial impacts of SuSTAINABLE on EU landscape.

In conclusion, the level of impacts of SuSTAINABLE, over the different countries of EU, will heavily depend on the regulatory framework and political decisions. If it ensures an adequate regulatory framework, we will witness in the short-medium term the implementation of this novel operation paradigm to manage distribution systems in a more efficient and cost-effective way, enabling a large-scale deployment of variable distributed generation,

WELCOME TO THE FUTURE...

SuSTAINABLE DELIVERABLES

NUMBER	NAME
D1.1	Project Quality Plan
D1.2	First Technical Progress Report and Financial Report
D1.3	Second Technical Progress Report and Financial Report
D1.4	Final Report
D2.1	Survey Results Regarding State of the Art Technologies and Control Methodologies
D2.2	SuSTAINABLE Validation Scenarios Definition
D2.3	Overall SuSTAINABLE Architecture
D2.4	KPI Assessment Methodology
D3.1	Methodologies for Load Prediction
D3.2	Description of Pre-prototype for Local RES Prediction
D3.3	Distribution Network State Estimators
D3.4	Description of Pre-Prototype of the Multi-temporal Operational Management Tool for the MV/LV Distribution Grid
D3.5	TVPP Simulation Model with Integrated Operation for Distribution/Transmission Co-coordinative Action
D3.6	Methodology for Provision of Differentiated QoS
D4.1	Multi-objective Methodology for Network Reinforcement under the SuSTAINABLE Concept
D4.2	Methodology for Optimizing QoS Mitigation Infrastructure Based on Differentiated Customer Requirements in Distribution Networks with Maximised Integration of DG
D4.3	Protections Strategies for Distribution Grids with Large Scale Integration of DG Units
D5.1	Evaluation of Forecasting Techniques in the Greek Site
D5.2	Evaluation of the Operation Methodologies
D5.3	Evaluation of the Planning Methodologies
D6.1	Guidelines for Validation Activities
D6.2	Description of Tools Integration on Existing Infrastructure
D6.3	Final Detail Impact Assessment Report
D7.1	Cost and Benefit Analysis in the SuSTAINABLE Demos
D7.2	Regulation for Smart Distribution Grids with Active DER Integration
D7.3	Economical Interactions of Entities Controlled by VPP for Providing Potential Services to Enhance the Operation of Distribution Networks
D8.1	Definition of Scalability and Replaceability of the SuSTAINABLE Concept in a Micro-Scale Perspective
D8.2	Scaling-up and Replication Rules Considering the Requirements and Local Conditions of Demo Sites
D8.3	Roadmap and Proposals of the SuSTAINABLE Concept in an Effective Macro-scale Replication
D9.1	Dissemination and Communication Plan
D9.2	Website for the Project
D9.3	First Global Stakeholders Workshop and Conferences
D9.4	Second Global Stakeholders Workshop and Conferences
D9.5	Final Convention
D9.6	Modalities for Interaction During the Course of the Project
D9.7	Short General Description of Use Cases and Process for Demonstration of the Proposed Solutions
D9.8	Short Report on Exchanged Experiences on Demonstrations and Validation of the Proposed Solutions

SuSTAINABLE PUBLICATIONS, ARTICLES AND CONFERENCE PAPERS

CONFERENCE PAPERS:

1. A. Madureira, R.J. Bessa, L. Seca, J. Pereira, A.A. Messias, D.A. Lopes, P.G. Matos, **"Advanced System Architecture and Algorithms for Smart Distribution Grids: The SuSTAINABLE Approach"**, in 23th International Conference on Electricity Distribution, Lyon, June, 2015

2. A.Madureira, L. Seca, J. Peças Lopes, P. G. Matos, N. Silva, **"Maximizing the Integration of Distributed Generation in Smart Grids Distribution Systems"**, CIGRÉ, Lisbon, April 2013

3. R.J. Bessa, A. Trindade, A. Monteiro, Cátia S.P. Silva, V. Miranda, **"Solar power forecasting in smart grids using distributed information"**, in Proc. of the 18th Power Systems Computation Conference (PSCC 2014), Wroclaw, Poland, August 2014.

4. R.J. Bessa, **"Solar power forecasting for smart grids considering ICT constraints"**, in Proc. of the 4th International Workshop on Integration of Solar Power into Power Systems, Berlin, Germany, Nov. 2014.

5. Y. Xu and J. V. Milanovi**c**, **"Framework for Load Composition Forecasting at Bulk Supply Point"**, in Proc. 13th Int. Conf. on Probabilistic Methods Applied to Power Systems (PMAPS), Durham, UK, 2014.

6. Sami Abdelrahman, Huilian Liao, Jia Yu and Jovica V. Milanovic, **"Probabilistic assessment of the impact of distributed generation and non-linear load on harmonic propagation in power systems"**, in Proc. 18th Power Systems Computation Conference (PSCC), Wroclaw, Poland, 2014

7. Sami Abdelrahman, Huilian Liao and Jovica V. Milanovic, **"The Effect of Temporal and Spatial Variation of Harmonic Sources on Annual Harmonic Performance of Distribution Networks"**, in Proc. 5th IEEE PES Innovative Smart Grid Technologies Europe (ISGT), Istanbul, Turkey, 2014

8. Y. Xu and J. V. Milanovic, **"On accuracy of demand forecasting using artificial intelligence based methods"**, in Proc. 5th IEEE PES Innovative Smart Grid Tehnologies Europe (ISGT), Istanbul, Turkey, 2014

9. Y. Xu and J. V. Milanovic, **"Estimation of percentage of controllable load in total demand at bulk supply point"**, in Proc. 9th Mediterranean Conference on Power Generation, Transmission Distribution and Energy Conversion (MEDPOWER), Athens, Greece, 2014

10. Y. Xu and J. V. Milanovic, **"Artificial intelligence based methodology for load disaggregation at bulk supply point"**, IEEE Trans. on Power Systems (Digital Object Identifier: 10.1109/TPWRS.2014.2337872

11. V. A. Papaspiliotopoulos, D. E. Karalexis, and G. N. Korres, **"Description, Setting and Secondary Testing of a digital protective relaying system"**, in Proc. 12th International Conference on Developments in Power System Protection (DPSP'14), Copenhagen, Denmark.

12. T. C. Xygkis, G. D. Karlis, I. K. Siderakis, and G. N. Korres, **"Use of Near Real-Time and Delayed Smart Meter Data for Distribution System Load and State Estimation"**, in Proc. 9th Mediterranean Conference on Power Generation, Transmission Distribution and Energy Conversion (MedPower'14), Athens, Greece, 2014.

13. V. A. Papaspiliotopoulos, T. S. Kurashvili, G. N. Korres, **"Optimal Coordination of Directional Overcurrent Relays for Distribution Systems with Distributed Generation based on a Hybrid PSO-LP Algorithm"**, in Proc. 9th Mediterranean Conference on Power Generation, Transmission Distribution and Energy Conversion (MedPower'14), Athens, Greece, 2014

14. V. A. Papaspiliotopoulos, V. A. Kleftakis, P. C. Kotsampopoulos, G. N. Korres, and N. D. Hatziargyriou, **"Hardware-In-the-Loop Simulation of Protection Blinding and Sympathetic Tripping Phenomena in Modern Distribution Grids"**, in Proc. 9th Mediterranean Conference on Power Generation, Transmission Distribution and Energy Conversion (MedPower'14), Athens, Greece, 2014.

15. N. Hatziargyriou, A. Dimeas, K. Kaousias, S. Kokkinelis, G. Korres, P. Kourelis, G. Mparbayiannis, S. Papathanassiou and E. Stavropoulou **"SuSTAINABLE – Smart Distribution System OperaTion for MAximizing the INtegration of RenewABLE Generation"**, International Conference on Deregulated Electricity Market issues in South Eastern Europe (DEMSEE 2014), Nicosia, Cyprus, 2014.

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16. R.J. Bessa, A. Trindade, V. Miranda, **"Spatial–temporal solar power forecasting for Smart Grids"**, IEEE Transactions on Industrial Informatics, vol. 11, no. 1, pp. 232-241, Feb. 2015.

17. J. V. Milanovic and Y. Xu, **"Framework for estimation and prediction of dynamic response of aggregate load"**, IEEE Trans. on Power Systems (Digital Object Identifier: 10.1109/TPWRS.2014.2343691

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Sustainable

Smart distrib**U**tion **S**ystem opera**T**ion for m**A**ximizing
the **IN**tegration of renew**ABLE** generation