Generalized Operational FLEXibility for Integrating Renewables in the Distribution Grid (GOFLEX)

D4.1 Distribution Observability and Management System (DOMS): Requirements

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Executive Summary

This document represents the 4.1 deliverable of Work Package (WP)4. WP4 is responsible for developing a Distribution and Observability System (DOMS) to help the grid operators with better grid management. The document details the functional and data requirements and specifies the inter-dependencies with other WPs for DOMS to be successfully implemented.

Document History

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1	5 April 2017	For internal review	Seshu Tirupathi	
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1.2	25 April 2017	Final submission	Seshu Tirupathi	

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List of Acronyms and Abbreviations

Abbreviation	Definition
DOMS	Distribution Observability and Management System
WP	Work Package
API	Application Programming Interface
DSO	Distribution Service Operator
ATP	Automatic Trading Platform
FOA	Flex Offer Agent
GIS	Geographic Information System
FOSS	University of Cyprus
ESR	L'Energie De Sion Region SA
PCC	Point of Common Coupling

1 Introduction

1.1 Purpose

WP4 of the GOFLEX project concentrates on estimation and short term predictions of the state of the grid assets which help the grid operators exploit energy flexibility in order to manage the grid better (ex. managing or reducing peaks). This document elaborates on the requirements (functional and non-functional), dependencies on other partners/WPs and other logistics for the successful implementation of WP4.

1.2 Related Documents

Dependencies on other WPs for the observability system of WP4 to be developed are mentioned in this document. The dependencies can be functional (ex. Application Programming Interface (APIs)) or non-functional (ex. data management) and the direction of the dependency is clearly stated in this document. These dependencies must have a symmetrical mention in the requirements document of the corresponding WPs respectively. The related documents to this report are D2.1, D5.1 and D6.1.

1.3 Document Structure

The rest of the document is organized as follows: In Section 2, the objectives of WP4 are described. Section 3 and Section 4 cover the requirements that are provided for and expected from other WPs respectively. Section 5 and Section 6 summarize Sections 3 and 4 by providing tables for the functional and non-functional requirements respectively. Section 7 provides details on the architectural requirements and considerations to implement the objectives of WP4. The implementation plan for this WP is described in Section 8 followed by conclusions in Section 9.

2 Work Package Description

As stated in the proposal, WP4 will develop the solution for observability of the distribution system, specifically estimation and short-term prediction of the state of the grid assets, based on physical network models and energy data and forecasting services available from the cloud-based service platform (cf. WP5). The solution will serve the purposes of the distribution grid operator of detecting/predicting grid congestion and informing market requests for the energy flexibility available through demand response:

- Improve observability in the distribution grid by further developing tools based on power systems state estimation to combine physical network models with all available sensor data and localised energy forecasts and produce estimates of current state of grid assets.
- Provide short-term prediction of the condition of the distribution grid by further developing stochastic power flow simulators based on physical network models and localised energy forecasts.
- Estimate likelihood of grid congestions through the design of statistical analysis methods that compare the probabilistic predictions of the grid conditions with the operating limits.

A solution to estimate the aggregated effect of operational flexibility across the distribution grid, to inform requests from the DSO for purchasing demand-response offers.

3 Provided to other work packages / components

DOMS is primarily responsible for short term predictions of the grid assets for Distribution System Operators (DSO). In addition, anicallary computations based on the state of the grid required by other WPs are also provided in this WP. The functions and data that WP4 provides to other work packages are as follows:

3.1 Functionality

- WP2/3 (Automatic Trading Platform (ATP)):
    - Provide grid context to the trading interfaces: Query prosumers that are relevant with respect to a grid topology element. For example. list the prosumers connected to a primary substation.
    - Send predictions of “desired” energy at grid asset and proposed price to FOA at regular intervals of 15 min – 1 hour (depending on market resolution) for the next 24 – 48 hours (this can be configured).
    - Receive feedback on submitted bid.
    - Send fractional/relative energy losses between two points of interest in the grid on request.
- WP7/WP8/WP9: Provide support for trading for flexibility to serve DSO purposes
    - Register grid locations and states of interest for monitoring. Example states are: Active power, reactive power, voltage, frequency, etc. Examples of grid locations are: transformer, substation feeder, power line, service territory, etc.
    - Register preference levels of grid states. Examples of levels are: threshold for “normal”, “undesired”, “congestion” for active power at a point in the grid
    - Registration operation will be provided through cloud service API, no Graphical User Interface (GUI) is required.
    - Estimate current value of state at desired grid locations
    - Estimate short-term predictions of state at desired grid locations
    - Estimate likelihood of state variables being within preference levels.

  - Register economical parameters for acquiring flexibility. Examples of such factors are: €/kwh for each preference level of grid state, cost of energy loss/MWh etc.
  - Generate bid for buying flexibility based on short-term predictions of state (and provided economic factors, by sending desired energy change (increase or decrease) and price to Flex Offer Agent (FOA), which will then generate a flex-offer based on this information.

3.2 Data

Functions provided by WP4 to other WPs produces data that is utilized for internal computations of the other WPs. The data provided by WP4 to other WPs is mentioned below:

To DSO:

- Actual value of the state variables registered from DSO, at intervals of 15-min to 1 hour (depending on market resolution and available data).
- Forecasted value of the state variables registered by the DSO, at intervals of 15-min to 1 hour and over the next 24 hours.
- Likelihood estimates of state being within desired preference levels over the forecasting horizon. These will be provided in the form of probability values.
- The data will be made available through cloud service APIs. A visualization of such quantities may be provided if demo sites would require GUI. This can be provided using the same platform as ATP.. Such dependency is detailed in section 4.1.

To FOA:

- Desired increase/decrease of energy at grid asset, with associated price that DSO is willing to pay for providing such amount of flexibility. Both delta energy (in kWh) and price (€/kWh) will be provided in 15 min – 1 hour interval for the next 24 hours and refreshed every 15 min – 1 hour.

To ATP:

- Prosumer identifiers that are relevant with respect to a grid topology element, e.g. list of prosumers whose flexibility can contribute to increase/decrease load at a substation or transformer.

- Relative/fractional energy loss between two points in the grid to help ATP compute the transmission losses via the service platform.

4 Depends on other work packages / components

WP4 also has functional and data dependencies on other WPs. Functions and data that WP4 requires from other work packages are as follows:

4.1 Functionality

- ATP
  - Receive bid for buying flexibility at point in the grid: The communication format will have to be determined, but DOMS being a cloud service, it will be required that FOA initiates/subscribes to a DOMS service for receiving
  - FOA sends feedback on submitted bid.
  - Visualization of state forecasts, actuals and flexibility
- Cloud service platform (WP5)
  - Query metadata of registered prosumers (Geographic Information System (GIS) location, grid connectivity).
  - Query available sensor data available at prosumer and grid locations.
  - Register energy forecasting model for a grid location. Receive energy forecasts at 15 min – 1 hour intervals for next 24 hours, updated every 15 min – 1 hour.
- DSO
  - API to upload grid asset information, registration of grid assets and states of interest, registration of preference levels and cost/economic parameters.

4.2 Data

- Metering data for grid states for which DSO has interest in trading flexibility. Data are required for a historical period of at least 2 years and at a time resolution of 15 min – 1 hour. Examples are: voltage at a substation feeder head, power load of substation or transformer, energy generation or demand over the service territory, etc.
- Metering data from prosumers that are relevant to grid states of interest, in the form of energy demand, distributed generation (where ap-

plicable) and flexible demand (e.g. electrical water heater consumption). Data are required for a historical period of at least 2 years and at a time resolution of 15 min – 1 hour, where this is available

- Grid topology data: Metadata about grid assets for interest in flexibility (substation, transformers, feeders etc.) and connectivity of prosumers with respect to such grid assets. Essential data are GIS coordinates of assets, interconnectivity (e.g. one-line diagram). Where available, power-flow models involving such grid assets would be also useful, including electrical parameters (line impedances, transformer parameters, capacitors, etc.)
- Energy forecast data for registered grid assets of interest for flexibility.

5 Functional Requirements

The functional requirements mentioned in Section 3 can be broken down into simple modular tasks. The requirements to perform these tasks are mentioned in Table 1.

Table 1 Functional requirements

Requirement Number	Requirement Description
F4.2.1	A cloud hosted distribution observability management system to represent the state of the grid assets.
F4.2.2	Module to produce pseudo-measurements through extrapolation or machine learning algorithms using historical data to maximize observability of distribution grid.
F4.2.3	API to register grid locations (ex. transformer, power line etc.) and states of interest (ex. active power, reactive power etc.) for monitoring.
F4.2.4	Module to compute current value of state at desired grid locations.
F4.2.5	Module for short term predictions of state at desired grid locations.
F4.2.6	Module to compute fractional transmission losses between two points in the grid.
F4.2.7	A Transmission API to send the fractional transmission losses and costs per unit energy loss between requested points in the grid.
F4.3.1	Module to register the preference levels of state variables.
F4.3.2	Module for computing likelihood estimates of state variables within the registered preference levels.
F4.4.1	Module to ingest energy forecasts, measurements and other sensor data.
F4.5.1	A Grid Context Trading API to send the state of the grid to the trading interfaces at the required spatial and temporal scale.
F4.5.2	A Grid Forecast Trading API to send the relevant prosumer information and bids to the trading interfaces at the required spatial and temporal scale.
F4.5.3	Framework to register the economical parameters for acquiring flexibility.
F4.5.4	Computational framework to generate bids for buying flexibility.
F4.5.5	A Feedback API to receive information of completed bids from FOA.

6 Non-functional requirements

Data requirements mentioned in Section 3.2 and Section 4.2 are summarized in Table 2.

Table 2 Non-functional requirements

Requirement Number	Requirement Description
NF4.4.1	Historical data storage of the state variables registered from DSO.
NF4.4.2	Storage of forecasted values of the state variables registered by the DSO.
NF4.4.3	List of prosumers and prosumer identifiers relevant to a given grid required for load management at a sub-station.
NF4.4.4	Metering data for grid states that are included for trading flexibility. Minimum requirement of 2 years of historical data.
NF4.4.5	Metering data from prosumers that are relevant to grid states of interest.
NF4.4.6	Metadata about grid assets and connectivity. Essential data are coordinates of assets and interconnectivity.
NF4.4.7	Energy forecast data storage for registered grid assets.
NF4.4.8	Economical parameters and state variable preference levels required by bid generation module.

7 Architectural considerations / assumptions

DOMS software developed in this WP will reside on a cloud system. Draft of the pseudo-architecture of the observability system and interactions with other solutions is shown in Fig. 1. DOMS and the service platform reside on the cloud and the remaining services that DOMS interact with are on premise. Initial registration of state variables, economic parameters etc. are executed by DSO directly or through FOA. Interface API of DOMS is used for all further interactions with DSO (through FOA). Relevant prosumer identifiers for a given state and location is provided to ATP through this interface as well. There is a two way interaction between DOMS and cloud service platform for information retrieval regarding forecasts at a given location and the data required for DOMS computations.

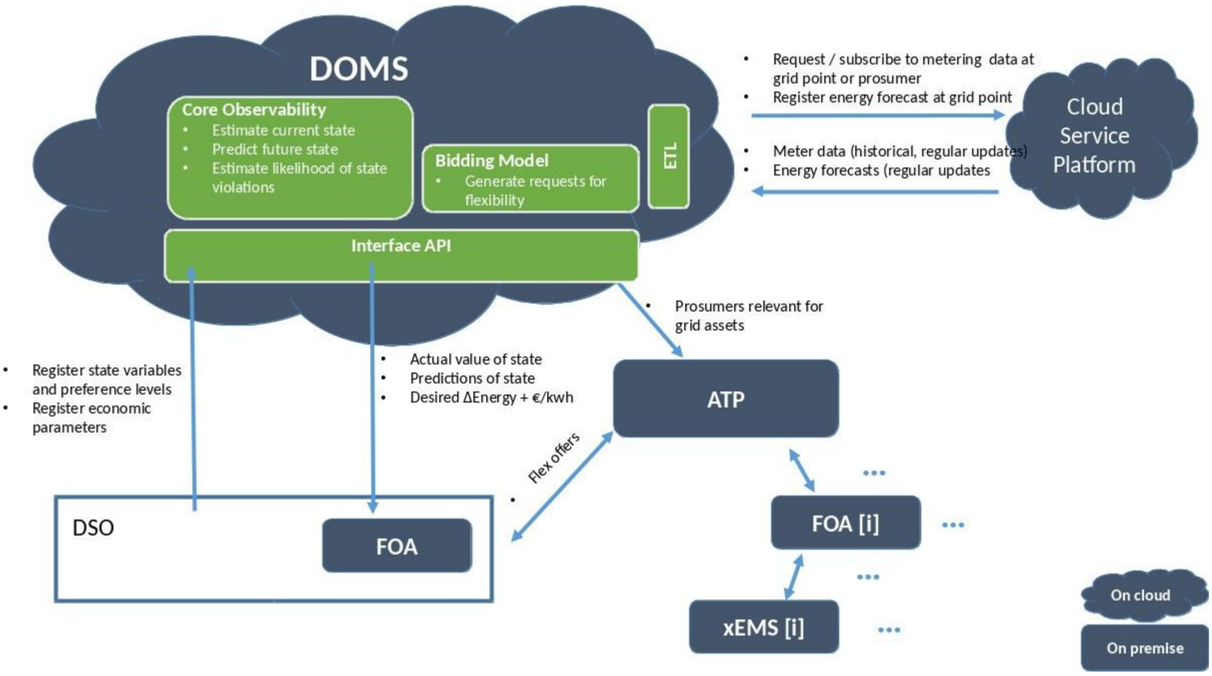

Figure 1: Architecture of DOMS Framework

8 Implementation Plan

Requirements outlined above will be implemented in a phased project. We note here the prioritization of requirements through the project phases.

8.1 Prototype

Initial DOMS model is developed using synthetic data with unit test framework set up to ensure that the implementation is accurate and robust (F4.2.1, F4.2.2). Stochastic aspects of DOMS are then developed (F4.3.1, F4.3.2). The system is then expanded to include static data from the test sites (F4.2.4). This is followed by creating a capability to include real time observations, forecasts and other sensor data residing in the cloud platform (F4.4.1). Machine learning algorithms are then developed to improve the model to account for missing observations (F4.2.3).

8.2 Full Version

In Core functionalities of state estimation and stochastic power flow prediction developed in the prototype are tested with real time data from the test sites through the cloud platform to produce the current value and future predicted values of the state respectively at the given grid location (F4.2.5, F4.2.6). The system is then integrated with the trading platform by providing an API to send and receive energy and bid information (F4.5.3, F4.5.4, F4.5.5).

8.3 Final Version

The final version of DOMS is fully integrated with the GOFLEX solution and the core components have been improved and finalized based on previous simulation/laboratory tests and on performance in demonstration tests covered by the use cases. The final version includes documentation required for configuring and integrating DOMS, and guidelines for using its interfaces. Final performance analysis against specified metrics and KPIs of DOMS core functionalities are also reported.

DOMS output and resolution could be impacted with the spatial and temporal resolution of the historical and real-time observations for the three test cases. There are small changes that need to be accommodated for the initial configuration of the system to ensure data consistency. However, DOMS framework in itself is relatively robust to the three test cases. DOMS requirements for the three test cases are given in Table 3.

Table 3 Specific DOMS instance requirements for the three test cases

Description	FOSS	ESR	SWW
Objectives	**Campus:** Advanced forecasting of renewable generation for day ahead production and use of storage systems to improve power quality issues and improve operational capabilities through ancillary services to the grid operators (such as voltage regulation, frequency support) **Within Cyprus:** Avoid congestions due to distributed energy resources	Optimization of the balance for ESR to reduce corrective costs (one day ahead planning to reduce intraday correction costs) Use DSM to reduce peak loads on the distribution grid, thus reducing the need of upgrading the infrastructure in an area where decentralized PV production is increasing.	Flexibility for load curtailment or load shedding to improve operational capabilities and avoid congestions.
State Variables	**Campus:** Power quality at point of common coupling with the EAC. **Within Cyprus:** Load/Voltages at sub-station/feeder head.	Total energy in the service territory.	Total energy in the service territory.
WP4 Minimum Requirements	**Campus:** Historical and real time data at PCC Prosumer connectivity to point of interest Metering data from storage system **Within Cyprus:** Historical and real time data at substation/ feeder head. Prosumer connectivity to point of interest For both cases: - Metering infrastructure at	Energy demand and generation data for the service territory. Prosumer data: Energy demand, PV generation.	Energy demand and generation data for the service territory. Prosumer data: Energy demand, PV generation.

	each separate building (average monthly consumption values) - Analytical energy measurements from the current PV generation installations - Data from sensors (solar irradiance, ambient and PV panel temperature, wind speed and direction, etc.) at PV installation		
Time	30 minutes interval	15 minutes – 1 hour interval	15 minutes – 1 hour interval

8.4 Performance Indicators

The performance of WP4 is tracked by quantifiable metrics through the implementation of the three phases of the project (prototype - final version). As outlined in the proposal document, GOFLEX project aims to demonstrate its potential for positive impact on the EU power network, electrical consumers and grid operators by allowing integration of large scale of distributed energy resources into the grid and providing a framework for trading of demand response resources. WP4 contributes to the following subset of impacts within this scope of the overall GOFLEX project:

- IM1 - The EU power network will be capable of integrating large share of renewables exceeding 50% by 2030, in particular variable energy sources, in a stable and secure way
- IM2 - Competitive demand response schemes for the benefit of the grid and the consumers.
- IM3 - Validated contributions for improved stability and flexibility in the distribution grid, avoid congestion; enabling near real-time pan European energy balancing market.

These impacts are realized by checking the performance of the relevant indicators for WP4. The relevant indicators and the description of the methods to measure these indicators are given in Table 4.

Table 4 Requirements description and supporting methodology that can be performed to measure the KPIs of WP4

Impact #	Performance Indicator	Functional and Non-functional requirements	Methodology
IM1	Capable of integrating large share of renewables : Safe increase of installed capacity (MW) with respect to initial capacity margins with no available demand response	F4.2.5, F4.2.6, F4.4.1	Estimate current share of renewables Identify methodology to quantify capacity margin (power flow models, meter data) Identify methodology to predict effect of flexibility on capacity margin
IM2	Benefit for DSO : reduced cost of congestion avoidance	F4.2.5, F4.2.6, F4.3.1, F4.3.2, NF4.4.8	Financial benefit evaluation of the deferral of investments for grid reinforcement through trading for flexibility in order to regulate voltage and active / reactive power profiles.
IM3	Grid state observability: near -real time (5min) and forecast (forecast 30min up to 24-48 hrs) Likelihood of Prediction of congestion (voltage/power-flow limit violation)	F4.3.1, F4.2.5, F4.2.6, F4.4.1	Certain parameters will be observed: active power (production/ consumption), reactive power, voltage magnitude, current, frequency (at the PCC of the microgrid with the main grid). Measure likelihood of observing and predicting congestion in the short-term.

9 Conclusion

The report provides the requirements for the implementation of WP4. In addition, the requirements of WP4 from other WPs and vice versa are described in detail to successfully implement the complete system of GOFLEX that can be tested on the three test sites described in WP7-WP9.