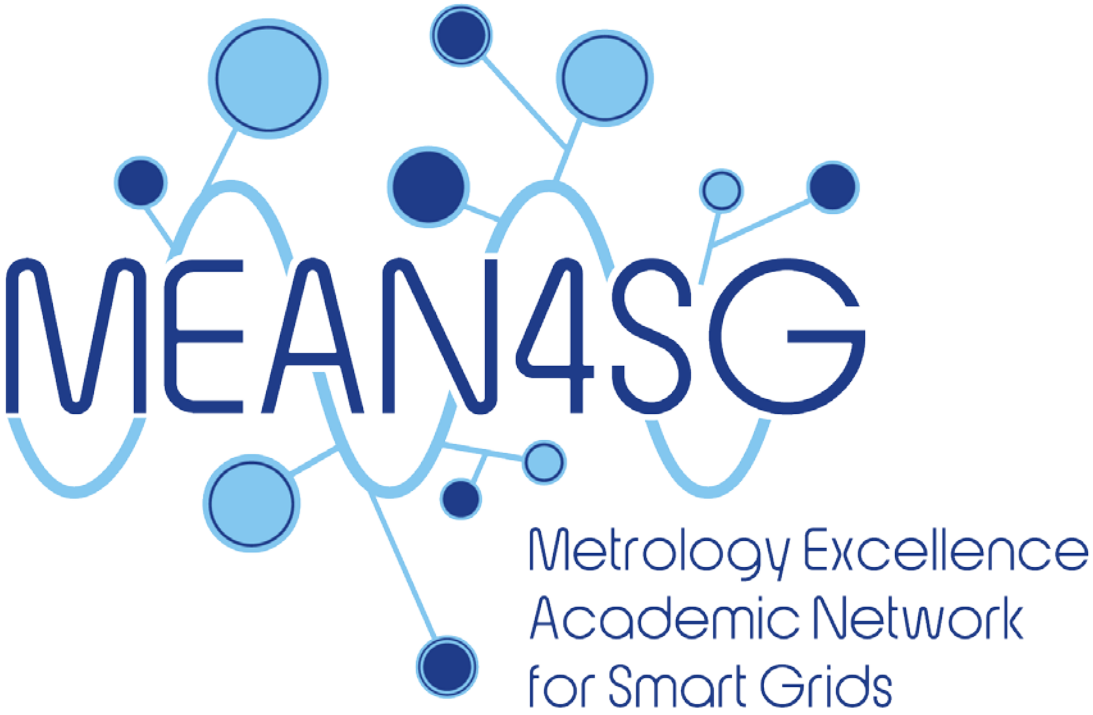

WP4 Final research report

Deliverable D4.2

WP4. Smart Grids: Modelling and Management.

Metrology Excellence Academic Network for Smart Grids

Grant agreement: 676042

From March 2016 to February 2020

Prepared by: ENEL GTG

Date: 18/02/2020

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DELIVERABLE FACTSHEET

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APPROVALS

	Company
Author/s	ENEL GTG, CIRCE
Task Leader	T4.1, T4.3 (ENEL/ENEL GTG); T4.2 (CIRCE)
WP Leader	ENEL GTG

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ABBREVIATIONS

ANOVA: Analysis of Variance

CA: Consortium Agreement

DoA: Description of Action

EC: European Commission

ESR: Early Stage Researcher

GA: Grant Agreement

IPR: Intellectual Property Right

LV: Low Voltage

MEAN4SG: Metrology Excellence Academic Network for Smart Grids

MV: Medium Voltage

PCDP: Personal Career Development Plan

PLC: Power Line Communication

PST: Personal Supervisory Team

REnS: Renewable Energy Sources

RVCs: Rapid Voltage Changes

SB: Supervisory Board

TC: Training Committee

WD: Wavelet Decomposition

WP: Work Package

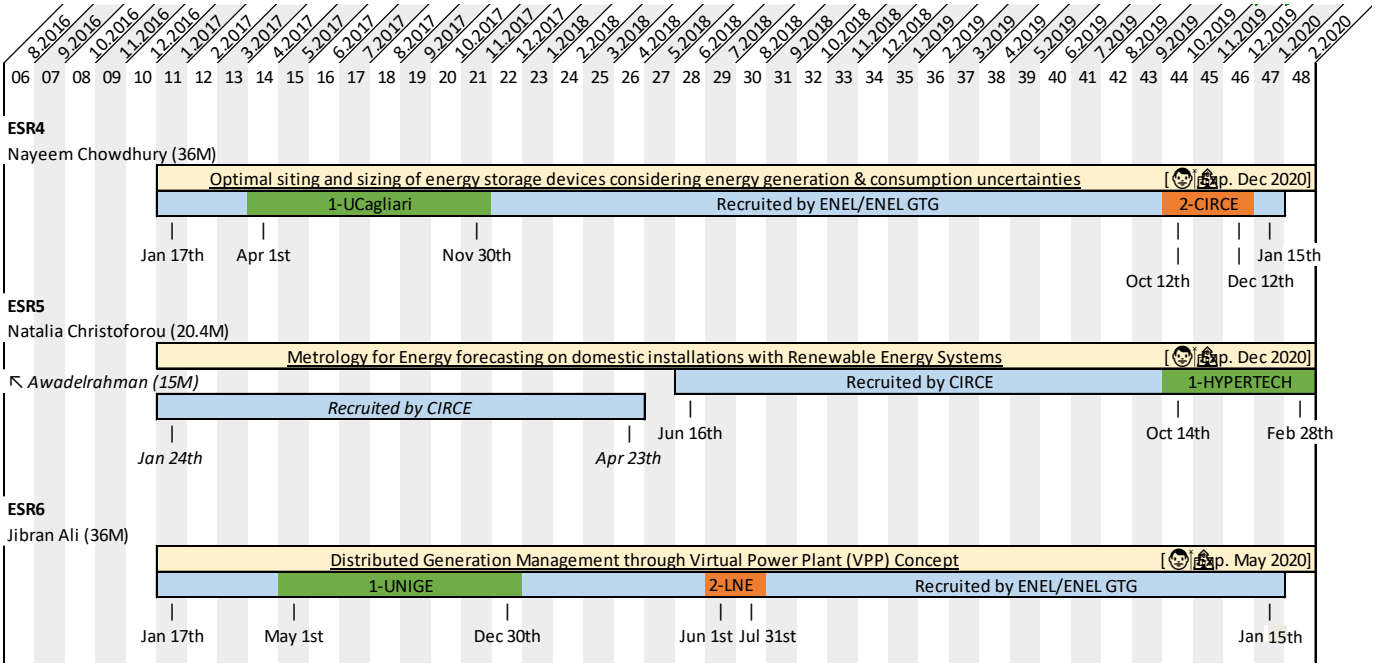
EXECUTIVE SUMMARY

This document presents the progress of the research activity in

WP4 Smart Grids: Modelling and Management.

There are three tasks defined in the MEAN4SG's DoA within the Grant Agreement in this Work Package based on Modelling and Management of Smart Grids: a) Development of an integrated model of electric systems, b) Metrology for energy forecasting in domestic installations with RES, and c) Development and validation of Distributed Generation Management at customer sites for service provision through Virtual Power Plant concept.

The development of these tasks corresponds to the topics treated through 3 doctoral theses performed by Early Stage Researchers (ESR) 4, 5 and 6



This WP addresses the modelling and management of distributed generation and demand systems. First the focus is put on the metrology for energy forecasting on domestic installations with RE systems. Lately, the integration of those units within the whole electric system is considered. The understanding of small generation and demand units and their interaction with energy and services markets will potentially balance demand side with supply side more effectively on Smart Grids and will also reduce undesirable peaks of consumption making the whole system more efficient. Besides, the integration of the large discrete data available from advanced distributed sensing on complex electric models is essential for strengthening Smart Grids operability on future electrical grid deployments.

Task 4.1 Development of an integrated model of electric systems

PhD title (ESR 4): *Optimal siting and sizing of energy storage devices considering energy generation and consumption uncertainties*

MEAN4SG beneficiary: ENEL/ENEL GTG

The research focused on the development of a methodology and a simulation and optimization tool for modelling the whole electric system following a holistic approach. Model development aims at overcoming the currently available modelling tools, lacking simulation capabilities that consider local markets at distribution level and the potential behaviour of new actors like active storage systems, loads, distributed generation and aggregators.

Task 4.2 Metrology for energy forecasting in domestic installations with RES

PhD title (ESR 5): *Metrology for Energy forecasting on domestic installations with Renewable Energy Systems*

MEAN4SG beneficiary: Fundación CIRCE

The implementation of a Non-Intrusive Load Monitoring algorithm that meets the majority (if not all) of the following requirements: accuracy (80-90%), no training (not significant occupant effort for the algorithm), near real time capability, scalability (run online and respond to events as they happen), and ability to work with all types of appliances (on-off, finite state, permanent consumers, or variable-power).

The main focus of this research is to monitor the energy consumption and by providing direct feedback, such as real-time appliance level consumption information, to the consumers, we can achieve significant reduction of energy wastage.

Task 4.3 Development and validation of Distributed Generation Management at customer sites for service provision through Virtual Power Plant concept

PhD title (ESR 6): *Distributed Generation Management through Virtual Power Plant (VPP) Concept*

MEAN4SG beneficiary: ENEL/ENEL GTG

The main objective is to develop replicable solutions for optimal management of distributed energy resources at customer sites, coordinated with larger generation assets, enabling the provision of energy services to the ancillary services market, following a Virtual Power Plant (VPP) concept.

The solutions will be scalable and applicable to different and heterogeneous contexts, from a geographical, social and economic point of view and will demonstrate the whole energy services value chain.

The goal is to acquire expertise in this area, and then to apply the experience in the services related to energy management. Thus, the research focuses on the development of replicable solutions for optimal management of distributed energy resources, coordinated with larger generation assets, enabling the provision of energy services to the ancillary services market (in particular for reactive power service provision), following a Virtual Power Plant (VPP) concept.

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1 TASK 4.1 DEVELOPMENT OF AN INTEGRATED MODEL OF ELECTRIC SYSTEMS (ESR04)

1.1 Summary

The current framework in energy market and electric network are fostering alteration from centralized to decentralized production. For this reason, it will require a unique adaptation of the electric network, especially the distribution network. This adaptation indicates the shift of a passive distribution network to an active network. The planning for investment decisions follow-on in the evolution of the distribution grid are multi-layered, long-lasting, and have a substantial influence on the end-user experience. However, these investments are challenging due to inherent uncertainties in the future evolution of load, generation, and technology. The necessity for the distribution grid to become active from a passive network mainly compelled by the integration of weather-dependent distributed energy resources (DER).

For the system operator to plan for a cost-effective and intelligent network, it is essential to include optimization and innovative solution into consideration. New innovative solutions such as energy storage could play a vital role in avoiding expensive investment decisions.

1.2 Background and organisation of the project

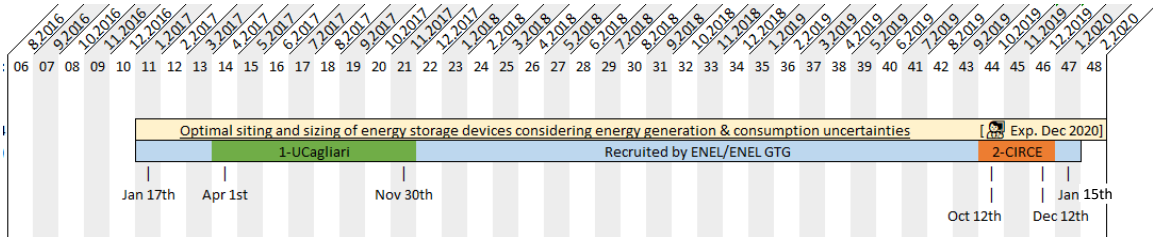
1.2.1 ESR04 Factsheet

Thesis title: *Optimal siting and sizing of energy storage devices considering energy generation and consumption uncertainties*

Research fellow: Nayeem Chowdhury
Current position: Innovation Engineer at EirGrid (Ireland)
Contact beyond the project: linkedin.com/in/nayeem-chowdhury

Recruitment organisation within MEAN4SG: ENEL/ENEL GTG
Secondment organisations:

(1) University of Cagliari
(2) CIRCE



Main Contribution to MEAN4SG:

Development of a methodology and a simulation and optimization tool for modelling the whole electric system following a holistic approach. Model development aims at overcoming the currently available modelling tools, lacking simulation capabilities that take into account local markets at distribution level and the potential behaviour of new actors like active storage systems, loads, distributed generation and aggregators.

Link to presentation: https://youtu.be/b6qE1vdxK-k

1.2.2 Background

Optimization plays a vital role in the operation and planning of electric power systems. From real-time to long-term planning, the most critical power system decisions are supported by a variety of different optimization problems. In dealing with the uncertainty that affects these decisions, today's power system operators usually exploit deterministic optimization models that aim to maintain the reliability of the system and minimize costs. While this approach is valid, it can be expected that the development of new techniques in the area of optimization under uncertainty could yield substantial benefits to this practice. This is the challenge that motivates this Thesis. More precisely, this Thesis proposes models and algorithms to address critical optimization problems in electric power system operations by considering uncertainty through an emerging technique such as Robust Optimization.

OPF is a type of optimization problems where active and reactive power of devices connected to the electric grid can be optimized to minimize a cost function considering the physical constraint of the network. It is a suitable tool to model the operation and planning of distribution systems that contain active elements such as storage and demand response. Due to the high dimension of the distribution network characteristics, alternating current (AC) OPF is the most suitable method. In this thesis, convex relaxations have been chosen to guarantee a low calculation burden and globally optimal solutions. This thesis has emphasized on the development of operations and planning methods to incorporate new challenges in planning and operations for smart grids.

1.2.3 Objectives

The targets have been to take a closer look at aspects related energy network and market in Italy and in Europe. The task covered different aspects:

- Overview of the regulatory framework in Italy and Europe.
- Identification of technologies enabling reactive power provision: capability and related costs.
- Quantification of possible market opportunities related to the reactive power provision services.
- Identification of potential technologies to improve the capability of conventional power plant in terms of reactive power provision.
- Development of a simulation tool to identify potential flexibility and market participation approach of the active distribution network.
- **Development a simulation tool** for finding an optimal location for energy storage in the electric network.
- Validate the developed optimization tool with real network information.

1.3 Research line of the fellow

1.3.1 Research tasks, activities to attain the project goals

During the first year of the project, the fellow has done an exhaustive literature survey regarding the integrated grid modeling, flexibility assessment methodology of power system and energy storage system.

In the same way, the fellow has contributed to the development of the **simulation tool** which is suitable to assess the impacts of future changes in market structures and regulations on electric system management. The simulation tool has been tested by simulating different market models with different DG penetration. The fellow also validated the tool by fixing bugs and understand the compatibility of different system environments. The result of this task has been included in an article which has been developing for publication.

The fellow was also involved in an energy storage project which is perfectly aligned with the future task. The project deals with a methodology to deploy storage system considering multiple conflicting criteria. The unique method has been developed to provide aid to the decision-maker to plan distributed resources under smart grid framework. The proposed approach has been submitted for publication.

Moreover, an optimization tool for energy storage siting and sizing has been developed during the second and third year of the project. The optimization tool finds the best location to install energy storage devices considering the network and economic constraints. In order to have an accurate model, AC OPF has been adopted to simulate the network. However, AC OPF is nonlinear in nature and inclusion of temporal variables such as storage can make the whole model intractable. In order to overcome these issues, second-order cone relaxation techniques have been adopted and linearize the nonlinear constraints. The tool considers uncertainty in the model using Robust Optimization.

The exploitation of budgeted uncertainty sets allowed to have the flexibility to change the robustness of the model that eventually provides a comprehensive scenario of the results. A substantial reduction of the annual operational costs can be observed with the ESS inclusion in the deterministic case and much more in the uncertain cases. The results demonstrate that not only the storage helps to reduce the operational cost, for relieving even the worst-case and reducing, even more, the resort to load shedding and to the generation curtailment, but also that, with the assumed hypotheses, the ESS CAPEX can be amortized in the ten years of their life duration.

Two conference papers and one journal paper have been published out of this research.

1.3.2 Recruitment and Training Overview

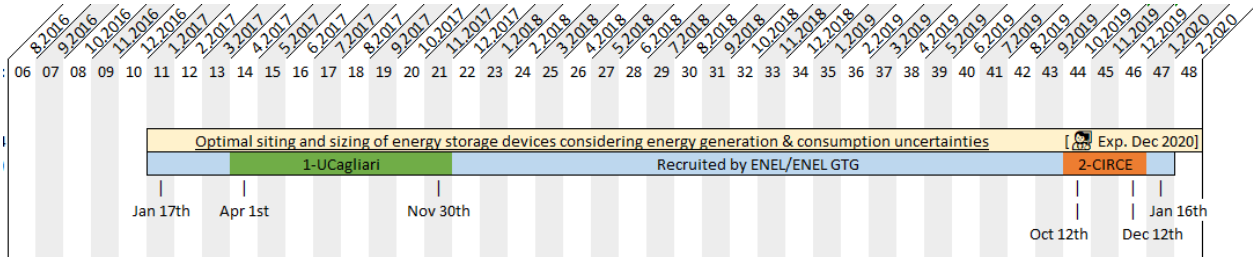


Figure 1 ESR04 recruitment timeline

Recruitment Organisation

Nayeem Chowdhury has been recruited by ENEL/ENEL GTG in a total duration of 36 months, from 17.01.2017 until 15.01.2020. During his training he has acquired skills in the **Development of an integrated model of electric system**, corresponding to the dedicated task 4.1 within the project framework.

Nayeem successfully ended his 3 years of activity highlighting some technical discussion and identifying the potential tool for developing the research projects, as well as planning the research activities and necessary lessons for acquiring relevant skills.

In this sense, the main facilities and skills used to validate scientific results have been both the real network data and critical analysis from experts.

Secondment organisations

In total, Nayeem has collaborated at the heart of two secondment organisations within his research during MEAN4SG project.

Table 1 Secondments performed by ESR04

Information about secondments for ESR04				
Fellow	**Secondment Organization**	**Start Date**	**End Date**	**Duration (months)**
Nayeem Chowdhury (ESR04)	University of Cagliari	1.04.2017	30.11.2017	8
Nayeem Chowdhury (ESR04)	CIRCE	12.10.2019	12.12.2019	2

During his **first secondment at the University of Cagliari**, Nayeem was cooperating in the identification of methods to develop the tool and validate the developed tool with real network information, supported by the real network data and critical analysis from experts. In this sense:

- The distribution system has been simulated in a simplified but representative way, considering participation of distributed generation and customers through local markets, integrated with equivalent transmission network and market models.
- A multi-criteria analysis for energy storage deployment under smart grid framework has been performed and applied to a typical rural network.
- Writing a paper on multi-criteria analysis for storage deployment (which is submitted to a journal for publication).
- Identify the bugs for WISE tool and check for compatibility.
- Develop a residential microgrid in Simulink and impact analysis on the network asset (Transformer).
- Simulate offer builder tool for different scenarios and help to prepare deliverables for WISE.

During his **second secondment at CIRCE**, Nayeem worked on the development of a database for the European Islands information in terms of energy, demography, amount of renewable energy, climate, etc. The information has been used to develop a set of KPIs to evaluate each island. The task will contribute to the Clean Energy for EU Islands Initiative by providing an Investment Planning Tool (IPT) that will be able to create action plans for the islands to generate their own sustainable and low-cost energy. Nayeem took advantage from relevant databases/websites and horizon 2020 reports.

Courses and summer schools organized in the framework of MEAN4SG

ESR04 has participated in most of the Specific Courses and Summer Schools organized in the framework of the project

- 1st MEAN4SG Specific Course: Hold in CIRCE, Zaragoza, Spain on 31/01/2017-02/02/2017, as a training activity within the ITN-ETN MEAN4SG project
- 1st MEAN4SG Summer School: Hold in the Van der Valk Hotel, Haarlem, The Netherlands, on 19-20/04/2017
- 2nd MEAN4SG Specific Course: Hold in the University of Strathclyde, Glasgow, UK, on 6-8/06/2017, as a training activity within the ITN-ETN MEAN4SG project
- 3rd MEAN4SG Specific Course: Hold in CIRCE, Zaragoza, Spain on 28-30/11/2017, as a training activity within the ITN-ETN MEAN4SG project
- 3rd MEAN4SG Summer School: Hold in ORMAZABAL, Boroa, Spain on 19-21/06/2018, as a training activity within the ITN-ETN MEAN4SG project

Other training events performed/promoted within MEAN4SG

Among the training events taken place and promoted within the project's framework, ESR04 did participate to the following:

- Researchers meet Innovators. Hold in Berlin, Germany on 11-12/07/2019, an organized by the Marie Curie Alumni Association aiming researchers and innovators to synergistically and successfully work together.
- Demo workshop about insulation diagnosis on MV grids for maintenance departments of utilities. Hold in LCOE, Madrid, Spain on 03/06/2019, as a training activity within the ITN-ETN MEAN4SG project
- Demonstration Workshop on Electric System Modelling, Development of an integrated model of electric systems and Development and validation of distributed generation management at customer sites for service provision through virtual power plant concept. Hold online by ENEL with special guests from the Universities of Cagliari and Genova on 10.10.2019, as a training activity within the ITN-ETN MEAN4SG project

During the workshop on Electric System Modelling and as a part of the organization, the fellow has presented the tool for energy storage planning and technique to consider the uncertainty in the model. The degree-awarding universities and the host institution presented the activities related to the research project. Apart from ESRs, the external audiences from universities were present at the workshop

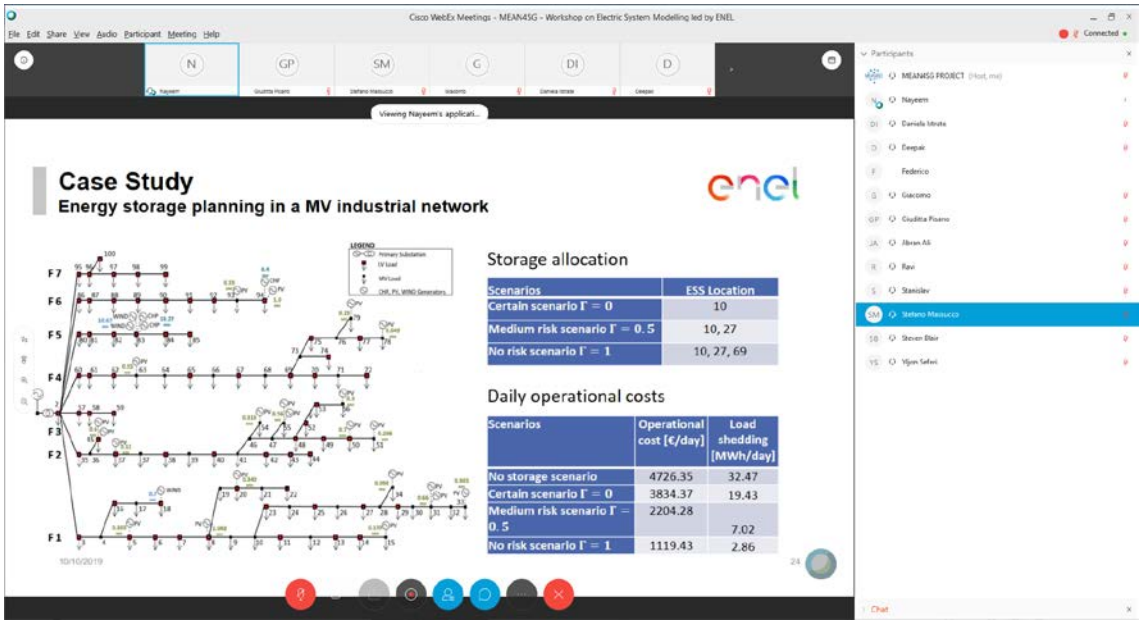


Figure 2 Presentation of Nayeem's results during the Workshop

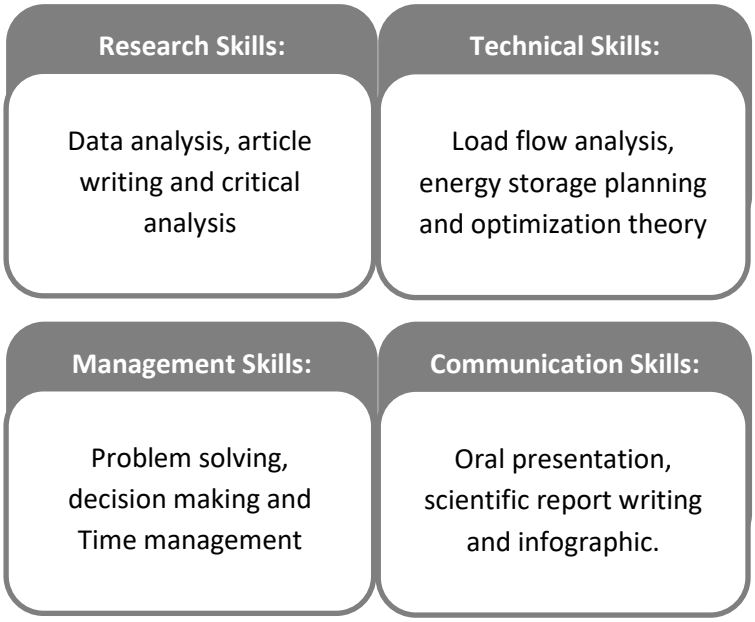
- Other conferences and events: CIRED 2017, EURAMET Workshop, MEDPOWER 2018, AEIT 2018, AEIT 2019, CIRED 2019.

Seminar Presentations

ERS04 did participate in the following seminar events proposed in the framework of the project:

- European Researcher's Night, 1st year PhD seminar
- CIRED'19. The Leading Forum where the Electricity Distribution Community meets. 3-6 June 2019. Paper Title: "Optimal location of energy storage systems with robust optimization"
- PhD Webinar. Workshop on Electric System Modelling led by ENEL: October, Thursday the 10th: Nayeem Choudhury [10:30] - Developing an optimization tool for locating and sizing of storage in the transmission systems in uncertain domain for the presence of wind, solar and active demand: [Link to the presentation https://youtu.be/b6qE1vdxK-k]

1.3.3 Skills learnt under MEAN4SG framework



1.4 Achievements

1.4.1 Research results

The main contribution of the ESR04 research activity have been the following:

- ✓ Answer to the Development of an optimization tool for energy storage planning by adopting optimization theory, dynamics of energy storage and load flow analysis. **Results: The tool efficiently decide the optimal location of energy storage device in the electric network.**
- ✓ 6 papers delivered

1.4.2 Thesis

- **Title**: Optimal siting and sizing of energy storage devices considering energy generation and consumption uncertainties
- **Defense date** (Upcoming): December 2nd , 2020
- **Defense place**: University of Cagliari
- **Doctoral school**: University of Cagliari
- **Thesis supervisor**: Giauditta Pisano

1.4.3 Publications

- Multi-Criteria Analysis for the Optimal Selection of Storage Projects in Smart Grids, Journal of Electric Power System Research.
- Troncia, M., Chowdhury, N., Pilo, F. (2018). A joint Multi Criteria - Cost Benefit Analysis for project selection on smart grids. In 2018 AEIT International Annual Conference (pp. 1–6).
- Nayeem Chowdhury, Fabrizio Pilo, Giuditta Pisano, and Matteo Troncia. "Optimal location of energy storage systems with robust optimization." CIRED 2019.
- Nayeem Chowdhury, Giuditta Pisano, and Fabrizio Pilo. "Energy Storage Placement in the Transmission Network: A Robust Optimization Approach." In *2019 AEIT International Annual Conference (AEIT)*, pp. 1-6. IEEE, 2019.
- Giuditta Pisano, Nayeem Chowdhury, Massimiliano Coppo, Nicola Natale, Giacomo Petretto, Gian Giuseppe Soma, Roberto Turri, Fabrizio Pilo. “Synthetic models of distribution networks based on open data and georeferenced information.” Energies 2019.
- Chowdhury, N.; Pilo, F.; Pisano, G. Optimal Energy Storage System Positioning and Sizing with Robust Optimization. Energies 2020, 13, 512

1.5 Networking and Exploitation Plan

1.5.1 Synergies with third parties

Nayeem had attended several workshops, conferences and business meetings where he could interact with important key actors in the field. Nowadays and thanks to these interactions, Nayeem is working as Innovation Engineer at EirGrid

Besides, Nayeem has identified potential ways of collaboration with other ESRs, notably:

- ESR-06 Jibran Ali (ENEL) | Distributed Generation Management through Virtual Power Plant (VPP) Concept, for which technical discussion on relevant research topics did take place

1.5.2 Exploitable foreground that can potentially derive from the ESR project

The main target audience of the research are the utility and market operators

In terms of relevant innovation activities carried out (prototypes, testing activities, standards) and new potential applications, products, services, reference materials, the developed tool can be used by the system operators for energy storage planning in the network considering technical and economic aspects.

Table 2 Exploitation Plan for ESR04

Exploitation Plan for ESR04					
Fellow	**Title**	**Direct Applications / Commercial use**		**Patent**	**Future Research Required**
Nayeem Chowdhury (ESR04)	Optimal siting and sizing of energy storage devices considering energy generation and consumption uncertainties	Yes	No	Possible	No

Details on how the detected patents could be developed are explained in its dedicated deliverable: "D8.2 Exploitation roadmap in consonance with the end user feedback"

2 TASK 4.2 METROLOGY FOR ENERGY FORECASTING IN DOMESTIC INSTALLATIONS WITH RES (ESR05)

2.1 Summary

The implementation of a Non-Intrusive Load Monitoring algorithm that meets the majority (if not all) of the following requirements: accuracy (80-90%), no training (not significant occupant effort for the algorithm), near real time capability, scalability (run online and respond to events as they happen), and ability to work with all types of appliances (on-off, finite state, permanent consumers, or variable-power).

Maximum energy savings can be achieved by real time information in the appliance level consumption as opposed to monthly bills or weekly advice on energy usage. On the utility side, providing much finer granularity of information will help to provide more precise demand response programs. Disaggregating the load information will enable the buildings energy management systems to better execute the energy conservation strategies (e.g. scheduling).

2.2 Background and organisation of the project

2.2.1 ESR05 Factsheet

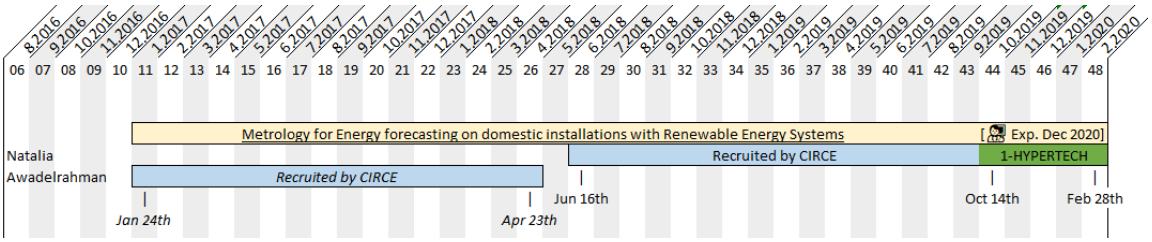
Thesis title: *Metrology for Energy forecasting on domestic installations with Renewable Energy Systems*

Research fellow: Natalia Christoforou
↖ Previously: Awadelrahman Mohamedelsadig Ali Ahmed
Current position: Engineer at Hypertech (TBC)
Contact beyond the project: linkedin.com/in/nataliachristoforou

Recruitment organisation within MEAN4SG: Fundación CIRCE

Secondment organisations:

(1) HYPERTECH



Main Contribution to MEAN4SG:

ESR05 Natalia pursues the research started previously by Awadelrahman aiming to contribute to the scope of MEAN4SG by monitoring the energy consumption and by providing direct feedback, such as real-time appliance level consumption information, to the consumers, we can achieve significant reduction of energy wastage.

2.2.2 Background

One of the world's most challenging issues nowadays is energy conservation. And, the reason why there is a notable concern regarding saving energy is the fact that lately there is observed an exponential increase in energy demands across the world. Moreover, while the energy consumption is rising, at the same time the availability of energy resources is decreasing. There is without a doubt, therefore, a need for adopting solutions in order to slow down energy wastage and optimally utilize available resources.

According to Eurostat, in 2017 in Europe, the building energy use accounted for 41.7% (27.2% households and 14.5% services) of total primary energy consumption. So, it is quite clear that reducing electricity consumption in buildings can lead to a considerable decline in energy wastage.

One way for conserving energy in buildings is curtailment (e.g. less heating/cooling on a daily basis). However, most consumers are inhibited from applying this technique because:

- to the majority of them, energy usage is an abstract concept,
- they are not aware of how much energy is consumed by the devices in their houses, and therefore they do not know which actions they should adopt for more beneficial energy conservation. Hence, if the household residents were familiar with how much the use of a specific appliance affects the total consumption.

Motivated by this, and in order to provide appliance-level energy data to residents, there is a notable development of the Appliance Load Monitoring (ALM) methods, which continuously monitor the energy consumption in a building, analyse the measured data, and present this information to the consumers.

As a matter of fact, in recent times we can see a growing interest in this research area, mainly inspired by the parallel advancements in sensing technology, data communication, and networks, artificial intelligence, and machine learning techniques.

According to, the two major approaches to ALM are the Intrusive Load Monitoring (ILM) and the Non-Intrusive Load Monitoring (NILM). ILM approaches require one or more than one sensor per appliance in order to perform load monitoring. NILM or energy disaggregation systems, on the other hand, acquire the total energy demand signal of the house at a single point, and decompose it into individual appliances, without needing extra submetering. Therefore, although the ILM method is more accurate in measuring appliance-specific energy consumption compared to NILM, its need for several measuring devices makes it expensive and hard to install, maintain, and expand.

In this sense, MEAN4SG project targets increasing the **energy efficiency** by providing detailed feedback information of the consumption.

2.2.3 Objectives

The **objectives** to be accomplished through this PhD thesis can be achieved via:

- Developing advanced energy disaggregation algorithms what is known as **Non-Intrusive Load Monitoring (NILM),** using only the smart meters measurements and mathematical modeling to give a breakdown of the energy consumption.
- The system should be generic and with less human intervention.
- System will be validated in real platform.

2.3 Research line of the fellow

2.3.1 Research tasks, activities to attain the project goals

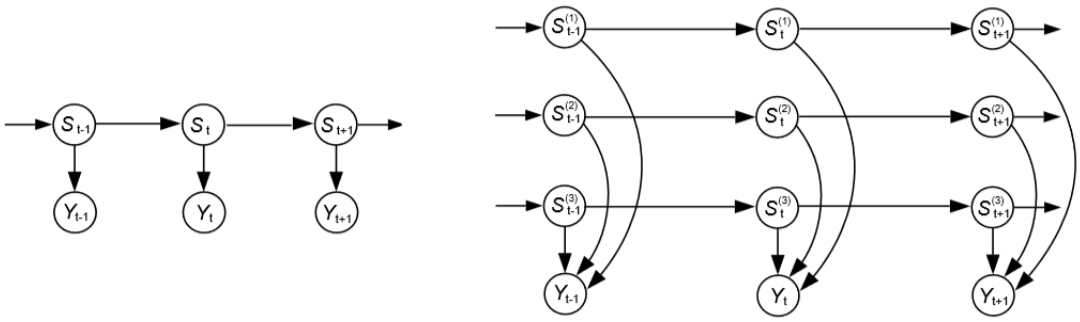
The regarding task within MEAN4SG project aims to increase the **energy efficiency** by providing detailed feedback information of the consumption.

In this sense, NILM has been proposed as a method to disaggregate the electrical load by examining the specific electric power consumption signature within the aggregate load data. The appliances depending on their operation states are categorized in 4 types:

1. Type-I: On/OFF state (e.g. toaster), the easiest to identify.
2. Type-II: Multi-State with finite number of states (e.g. Washing machine), having switching patterns makes it not difficult to identify.
3. Type-III: Continuously variable (e.g. dimmer light), very difficult to extract.
4. Type-IV: Permanent consumer devices (constant power, e.g. smoke detector).

To acquire the aggregated signal, the meters can be classified into two main classes based on the sampling rate, and it is agreed as a convention in NILM research, that the 1 Hz is the boundary between the low frequency data and the high frequency data. In section 5, examples of available datasets are discussed. But here it is important to point out the current smart meters in Spain have minimum integration time of 5 minutes (although the accessible is 15 minutes' rate) as *per a personal communication with Fernando Salzar, Arquitectura de Redes y Sistemas at Unión Fenosa.*

A NILM model includes an HMM model for each appliance when the in the states of appliances: mean value of each power level with its associated variance implies that the states are extracted through the GMM (Gaussian Mixture Models) clustering technique.



FHMM:

- The independent HMMs of the appliances evolve in parallel
- The sequence of observed output $\{Y\_t\}$ represents the aggregated hidden states
- The algorithm estimates the most probable sequence of hidden states that could have produced that output

The used dataset to achieve the project goals put in practice includes:

- 21 power meters, 2 water meters, and 2 natural gas meters
- Electricity, water, and natural gas measurements at one-minute intervals
- Weather data (hourly weather data that covers the same time period as the measurements)
- 1,051,200 readings for 2 years of continuous monitoring (from April 2012 to March 2014) per meter from a single household in Canada
- 11 measurement characteristics for each meter (voltage, current, real power, reactive power etc.)

Via Python, a Hmmlearn - built on scikit-learn, NumPy, SciPy, and matplotlib has been put in practice to measure the real power in several appliances such as refrigerators, clothes dryer, dishwasher or ovens, among others.

Therefore, there is no doubt that the model needs improvement. It is however planned to do that by using more features such as the reactive power, the power factor, and perhaps some other no power-related features like the user presence in the house, the hourly utilization of the appliances, the appliances dependencies, and the weather conditions.

2.3.2 Recruitment and Training Overview

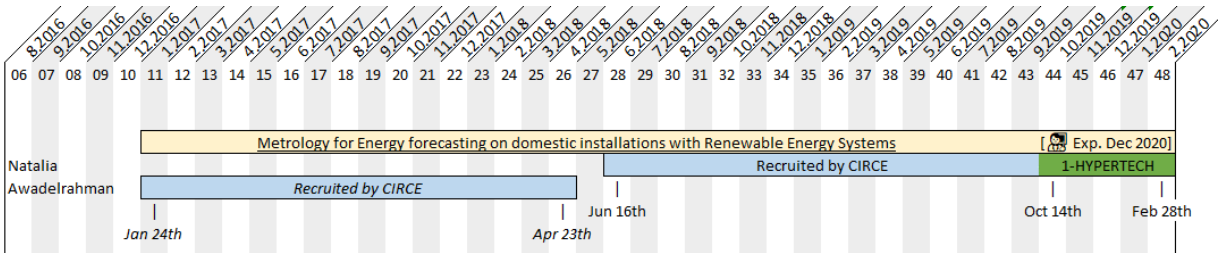


Figure 3 ESR05 recruitment timeline

Recruitment Organisation

Both Natalia and previously Awadelrahman have been recruited by Fundación CIRCE in a total duration of 35.4 months (15 months for Awadelrahman and 20.4 months for Natalia)

Both of them have received guidance from CIRCE and exchange of ideas in order to develop a NILM algorithm and acquired skills in **Metrology for Energy Forecasting in Domestic Installations with RES**, corresponding to the dedicated task 4.2 within the project framework.

Secondment organisations

Due to the unforeseen withdrawal from the previous ESR05 Awadelrahman, and the complete adaptation to Natalia within the project framework, it has been decided to take advantage from a single more longer non-academic secondment at the end of the recruitment, where Natalia not only could test the developments performed during her research, but to have further options to pursuing her research in a following contract with the seconded organization.

Table 3 Secondments performed by ESR05

Information about secondments for ESR05				
Fellow	**Secondment Organization**	**Start Date**	**End Date**	**Duration (months)**
Natalia Christoforou (ESR05)	HYPERTECH	14.10.2019	28.02.2020	4.5

During her **secondment at HYPERTECH**, Natalia could exchange knowledge and ideas in order to improve the accuracy of the developed NILM algorithm. Hypertech also provided aggregate meter readings as well as sub-metered readings for a number of appliances from several houses. These data will be used to evaluate the performance of the algorithm.

Moreover, there are thoughts of developing a mobile application or a web page where the results of the algorithm that is applied to a household will be displayed.

Within the Hypertech offices, energy consumption data from several households has been used to validate Natalia's scientific results.

Courses and summer schools organized in the framework of MEAN4SG

Occurred mainly during the first half of the project, former ESR05 Awadelrahman has participated in the 3 Specific Courses and 1 of the 3 Summer Schools organized in the framework of the project

- 1st MEAN4SG Specific Course: Hold in CIRCE, Zaragoza, Spain on 31/01/2017-02/02/2017, as a training activity within the ITN-ETN MEAN4SG project
- 1st MEAN4SG Summer School: Hold in the Van der Valk Hotel, Haarlem, The Netherlands, on 19-20/04/2017
- 2nd MEAN4SG Specific Course: Hold in the University of Strathclyde, Glasgow, UK, on 6-8/06/2017, as a training activity within the ITN-ETN MEAN4SG project
- 3rd MEAN4SG Specific Course: Hold in CIRCE, Zaragoza, Spain on 28-30/11/2017, as a training activity within the ITN-ETN MEAN4SG project
- 2nd MEAN4SG Summer School: Hold in the University of Strathclyde, Glasgow, UK, on 23-25/01/2018, as a training activity within the ITN-ETN MEAN4SG project,

Joining the project on 2017, June the 12th, last ESR05 Natalia did participate in the last Summer School organized in the project framework

- 3rd MEAN4SG Summer School: Hold in ORMAZABAL, Boroa, Spain on 19-21/06/2018, as a training activity within the ITN-ETN MEAN4SG project

Figure 4 Visit to the Ormazabal Installations during the 3rd MEAN4SG Summer School

Other training events performed/promoted within MEAN4SG

Among the training events taken place within the project's framework, ESR05 did participate to the following:

- Demo workshop about insulation diagnosis on MV grids for maintenance departments of utilities. Hold in LCOE, Madrid, Spain on 03/06/2019, as a training activity within the ITN-ETN MEAN4SG project
- Demonstration Workshop on Electric System Modelling, Development of an integrated model of electric systems and Development and validation of distributed generation management at customer sites for service provision through virtual power plant concept. Hold online by ENEL with special guests from the Universities of Cagliari and Genova on 10.10.2019, as a training activity within the ITN-ETN MEAN4SG project

Seminar Presentations

Not being able to conclude any consistent project results by the time, ERS05 was not able to participate in the seminar events proposed in the framework of the project.

However, in a later stage and once Natalia's results could have been tested within the secondment (Hypertech) facilities, bilateral conversations between the managers of the smart grid departments of both organisations (Fundación CIRCE and Hypertech) have taken place.

Two have been the goals of these bilateral conversation:

- From one side, exploring potential synergies to apply Natalia's research in a wider scope as well as developing side-projects taking advantage of the potentialities of both organizations.
- From the other side, establishing the script for the drafting of at least two (2) conference papers aiming to consolidate the research performed during her recruitment within MEAN4SG project.

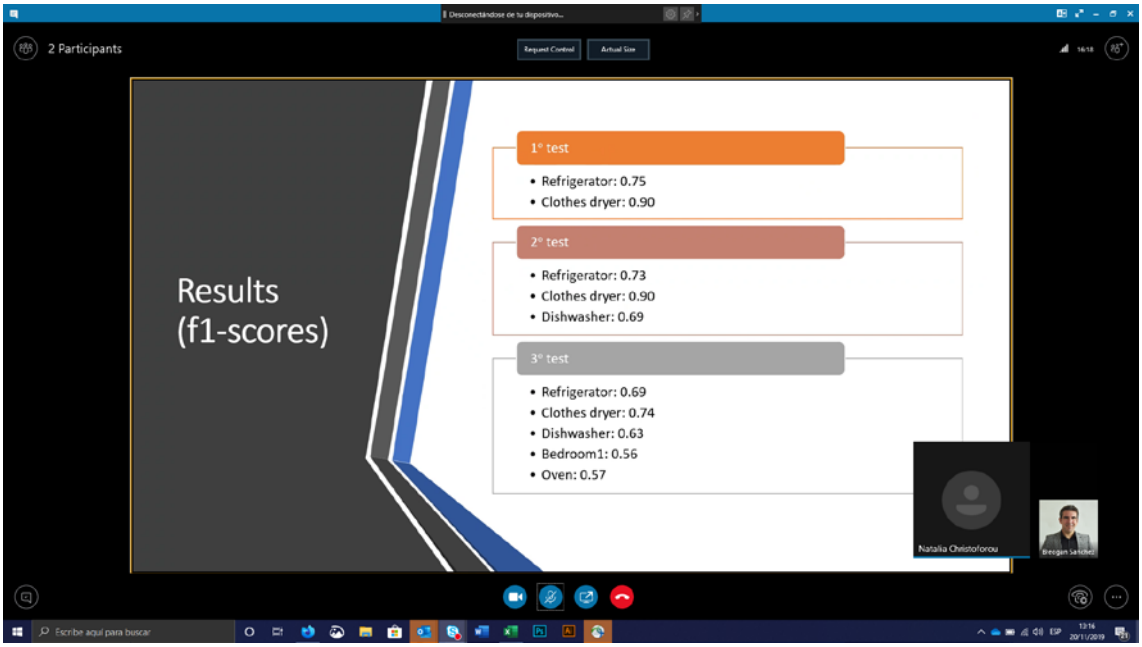


Figure 5 Screenshot from ESR05 presentation during bilateral conversation CIRCE-HYPERTECH – 20.11.2019 (13:00)

2.3.3 Skills learnt under MEAN4SG framework

Research Skills:	Technical Skills:
Finding information of the internet, Analysis of information from different sources	Advanced Machine Learning, Probabilistic Graphical Models

Management Skills:	Communication Skills:
Prioritizing tasks	Listening

2.4 Achievements

2.4.1 Research results

Energy conservation in residential buildings through power disaggregation has been an issue to be addressed. In this sense, providing information on individual appliances consumptions to residents can make them aware of their energy profile and thus influence them to change their consuming behaviour so that to reduce the amount of energy they consume.

- A Non-Intrusive Load Monitoring (NILM) method of disaggregation on which each appliance power demand has been modelled as a Hidden Markov Model (HMM). Based on these trained HMMs of the appliances, the total load disaggregation is modelled as a Factorial Hidden Markov Model (FHMM), and then the single most probable hidden state sequence across all appliances is inferred through the Viterbi algorithm.
- By working in the Literature review of NILM, Machine learning and Probabilistic graphical models, ESR05 did help the implementation of NILM, achieving its further development. At this stage, future research is needed to optimize it
- 2 conference papers (1 expected to be published on May 2020 / 1 in drafting mode)

2.4.2 Thesis

- **Title**: Metrology for Energy forecasting on domestic installations with Renewable Energy Systems
- **Defense date**: December 2020
- **Defense place**: University of Zaragoza, Spain
- **Doctoral school**: University of Zaragoza, Spain
- **Thesis supervisor**: Dr. Julio J. Melero

2.4.3 Publications

During the drafting of the current document, there is one (1) publication about to be submitted and another one (1) in drafting mode

<u>About to be presented (as per March 2020)</u>

- Natalia Christoforou 1, Jorge Bruna 1 and Julio J. Melero 1, "Power disaggregation on domestic environments using a Factorial Hidden Markov Model" in *Energies Journal*, 2020.

<u>In drafting mode</u>

A second publication together with Hypertech at the end of the secondment is foreseen in order to complete the previous and specially focused on Natalia's cooperation in Hypertech (after the

disposal of up to 10 homes for research purposes, real-life data or intervention among others…). A publication could be expected for mid-April.

2.5 Networking and Exploitation Plan

2.5.1 Synergies with third parties

In terms of networking and due to the advanced status of ESR05 research, it has been Natalia who have had a more active role regarding meeting actors from the Smart Grids field.

Natalia did participate in some events such as the 3rd Summer School and both workshops about insulation diagnosis on MV grids for maintenance departments of utilities, and on Electric System Modelling.

Besides, her 4.5 months cooperation at the heart of Hypertech provided Natalia a wide selection of important contacts to pursue and discuss her research as well as to optimize and implement the NILM algorithm.

Besides, Natalia has identified potential ways of collaboration with other ESRs, notably:

- ESR-04 Nayeem Chowdhury (ENEL) | Development of Integrated grid model of electric System. With Nayeem, Natalia combine her research results to further improve the efficiency of smart grids modelling.
- ESR-06 Jibran Ali (ENEL) | Distributed Generation Management through Virtual Power Plant (VPP) Concept. Natalia has spotted a common knowledge gathered from their research to achieve a higher level of energy management

2.5.2 Exploitable foreground that can potentially derive from the ESR project

The main target audience of the research are companies that provide Smart Energy solutions to consumers (the NILM algorithm gives consumers the ability to monitor how much energy consume each one of the appliances they use)

In terms of relevant innovation activities carried out (prototypes, testing activities, standards) and new potential applications, products, services, reference materials, it should be highlighted the development of a NILM algorithm that disaggregates which appliances are turned on from a metered/monitored power line.

Table 4 Exploitation Plan for ESR05

Exploitation Plan for ESR05					
Fellow	**Title**	**Direct Applications / Commercial use**		**Patent**	**Future Research Required**
Natalia Christoforou (ESR05)	Development of tools for accurate and reliable measurements of Power Quality (PQ) in Smart Grid	No	Yes	Possible	Yes

Details on how the detected patents could be developed are explained in its dedicated deliverable: "D8.2 Exploitation roadmap in consonance with the end user feedback"

3 TASK 4.3 DEVELOPMENT AND VALIDATION OF DISTRIBUTED GENERATION MANAGEMENT AT CUSTOMER SITES FOR SERVICE PROVISION THROUGH VIRTUAL POWER PLANT CONCEPT (ESR06)

3.1 Summary

The objective is the deployment of replicable solutions and of optimal management of Distributed Energy Resources (DER) in Low-Medium Voltage Network, for energy service provision to regulated and liberalized actors of power system, through the VPP concept, which aggregates DER through advanced ICT. The identified architecture is based on European Smart Grid Architecture Model (SGAM), and implement service definition, provision and validation, allowing customer active participation in the electric markets. Validation of architecture and algorithms in a real context is expected, together will best practices definition for VPP deployment.

Studies of aggregators, VPPs, Italian energy market, Transmission System Operator (TSO)-Distribution System Operator (DSO) interactions and the auxiliary services have been carried out. Detailed study of the architecture of VPP and the identification of simulation and hardware assets are in progress.

The focus is on DER aggregation. It is to ensure that TSO and DSO consider demand response providers and aggregators in a non-discriminatory fashion with respect to ancillary services and balancing provision. Development of aggregator platform, and simulating market and VPPs (with real VPPs and TSO/DSO markets).

For the Italian market, this opens up opportunities and flexibility for auxiliary services market. The Italian market comprises of Energy Market and Ancillary Service Market. However, to participate in this ancillary service market, the aggregator or the demand response provider has to comply with the Italian market regulation of production unit to supply greater than 10 MVA to be a relevant unit. Other requirements include the production unit to not include any intermittent renewable sources (at transmission side), specific consumption unit (only interruptible load), and not any unit at distribution side. At current, these DERs and specifically resources on distribution level are not allowed to participate in Italian energy market, but a degree of freedom can be left here with the fact that the regulation changes every year.

Like real power, reactive power management is necessary too (which is an important market for ancillary services). Reactive power exists in AC circuits when voltage and current are not in phase due to inductive or capacitive effects. This reactive power imbalance can have adverse effects on power system. For example, decrease of reactive power for a load causes voltage drop. For real power P, the voltage drop causes current to increase through the load, and this can damage the

load. If this voltage drop increases further, generators are tripped to ensure safety, and thus the situation becomes worse (with further voltage drop).

It focuses on the aspects of developing VPP for three levels:

1- Transmission, that could support TSO
2- Distribution, that acts as a management system for DERs to facilitate DSO
3- Business model for DSO support integrating changes at the substation level

All these models are simulated within the following software:

1- LabVIEW
2- DIgSILENT
3- MATLAB/Simulink
4- LabVIEW Real-Time
5- Matrikon OPC

The test cases were developed using the following aspects:

1- How to facilitate reactive power support to TSO and DSO
2- How to provide the frequency restoration services
3- How to improve power system protection

The test cases and the simulation results are validated within:

1- DIgSILENT
2- OPAL-RT
3- LabVIEW Real-Time

Everything is disseminated under the publications below. The researcher was successful in obtaining funding for EU ERIGrid project, for which he did the OPAL-RT based VPP validation.

3.2 Background and organisation of the project

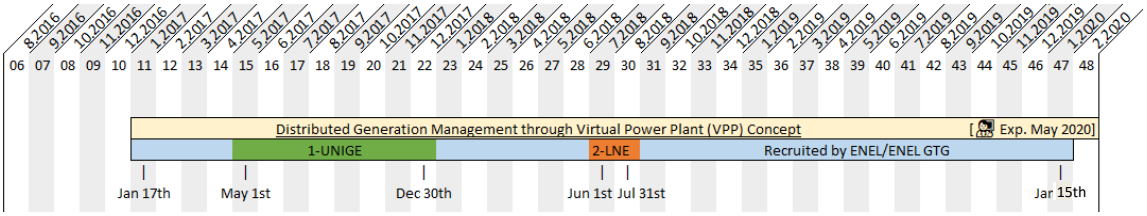
3.2.1 ESR06 Factsheet

Thesis title: *Distributed Generation Management through Virtual Power Plant (VPP) Concept*

Research fellow: Jibran Ali
Current position: Researcher at the heart of the North Carolina State University
Contact beyond the project: --

Recruitment organisation within MEAN4SG: ENEL/ENEL GTG
Secondment organisations:

(1) University of Genova
(2) LNE



Main Contribution to MEAN4SG:

Development of replicable solutions for optimal management of distributed energy resources, coordinated with larger generation assets, enabling the provision of energy services to the ancillary services market (in particular for reactive power service provision), following a Virtual Power Plant (VPP) concept.

Link to presentation: https://youtu.be/b6qE1vdxK-k

3.2.2 Background

Development of replicable solutions for optimal management of distributed energy resources at customer sites, coordinated with larger generation assets, enabling the provision of energy services to the ancillary services market, following a Virtual Power Plant (VPP) concept.

Solutions will be scalable and applicable to different and heterogeneous contexts, from a geographical, social and economic point of view and will demonstrate the whole energy services value chain.

Energy crisis is a global issue these days. Especially, developing countries are facing many problems in the area of energy systems. They suffer energy crisis which results in load shedding and high prices of electricity. Most of the problems can be solved by proper energy management, and this requires expertise in the area of Smart Grid.

The background covers the following aspects:

1- What is VPP? Why it is useful? And why the actors in power system requires such entity for the services?
2- What are the types of VPP? What are the market operators, consumers, and the producers? What is the future of VPP?
3- What are the individual components? What are the ways to model them?
4- What is the ICT interface amongst the components?
5- How to test this platform?

3.2.3 Objectives

The goal is to acquire expertise in this area, and then to apply the experience in the services related to energy management.

- Identification of interaction schemes that may allow customer active participation in the electric markets.
- Modelling of customer capabilities to interact with active demand response programs and development of predictive algorithms to estimate actual customer willingness/capabilities to offer flexibility on the market.
- Development of decision support system that identifies optimal customer's resources configuration/set-point and of an energy brokerage tool to allow VPP interaction with energy and services market.
- Development and integration of steady-state and real time tools in a distributed intelligence system to guarantee customer heat and power supply and to enable interaction with Virtual Power Plant centralized manager.
- Validation of the developed tools

The Virtual Power Plant (VPP), was studied, and the concept of aggregators was developed. There were use of the platforms for aggregator. The management of distributed energy resources were done for service provision and the aggregation involves DER through OPC communication. The models motivated the use of sub-systems for integration for VPP. It started with the need to model one ancillary service, and the reactive power was used for the case study.

3.3 Research line of the fellow

3.3.1 Research tasks, activities to attain the project goals

The below mentioned items represents those tasks being developed and aiming to attain the project goals:

- Study of Virtual Power Plant (VPP), and the concept of aggregators utilizing VPP, loads, and storage.
- Study of the platforms used for the function of aggregator. Deployment of replicable solutions and of optimal management of distributed energy resources in Low-Medium Voltage Network, for energy service provision to regulated and liberalized actors of power system, through the VPP concept, which aggregates DER through advanced ICT.
- Study of TSO and DSO, and the control of reactive power for voltage stability. The focus is on the current Italian market regulations, and focus on other possible emerging/future techniques.
- Proposal of architecture for the use of these reactive power compensation techniques for the conventional power plants.
- Study of development and implementation of a Virtual Power Plant (VPP) aiming both at the economic-energetic optimization and at service provisioning on the energy market. Study of the idea of full-scale demonstration and validation of VPP concept), and working for the accomplishments.
- Study of centralized management system to serve as a tool for VPP, and as an interaction platform for the aggregator.
- Study of real time simulation schemes for the use by SCADA and aggregator.
- Study of tools for VPP validation.
- Development of Virtual Power Plant (VPP), utilizing VPP, loads, and storage. Implementation of the platform for the function of aggregator.
- Development of SCADA system to serve as a tool for VPP, and as an interaction platform for the aggregator.
- Involvement in VPP component of energy storage system.
- Development of real time simulation schemes for the use by SCADA and aggregator.

- Development of tools for VPP validation.
- The progress is in line with the project goals and objectives.

3.3.2 Recruitment and Training Overview

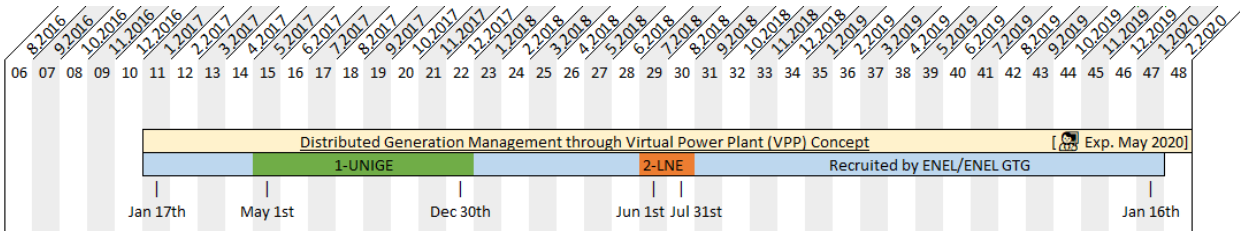


Figure 6 ESR06 recruitment timeline

Recruitment Organisation

Jibran Ali has been recruited by ENEL/ENEL GTG in a total duration of 36 months, from 17.01.2017 until 15.01.2020. During his training he has acquired skills in the **Development and validation of Distributed Generation Management at Customer sites for service provision through Virtual Power Plant Concept**, corresponding to the dedicated task 4.3 within the project framework.

Jibran successfully ended his 3 years of activity highlighting literature and study material for VPP, storage systems, and demand response as main interactions within ENEL/ENEL GTG. Besides, it is important the support for arrangements of required skills and defining tasks useful for completion of project. Training and supervision has always been supported.

In this sense, the main tools used to validate scientific results have been DIgSILENT and MATLAB/Simulink.

Secondment organisations

In total, Jibran has collaborated at the heart of two secondment organisations within his research during MEAN4SG project.

Table 5 Secondments performed by ESR06

Information about secondments for ESR06				
Fellow	**Secondment Organization**	**Start Date**	**End Date**	**Duration (months)**
Jibran Ali (ESR06)	University of Genova	1.05.2017	30.12.2017	8
Jibran Ali (ESR06)	LNE	1.06.2018	31.07.2018	2

During his **first secondment at the University of Genova**, Jibran's main interaction have been the simulations for a) material for VPP, storage systems, and demand response, b) support for arrangements of simulation platforms and trainings useful for completion of project, and c)

simulation and future activities which has been indicated and supported. Jibran did use DIgSILENT(version with OPC Support), MATLAB/Simulink, LabVIEW, and Matrikon OPC for the abovementioned analysis.

During his **second secondment at LNE**, Jibran worked on the Validation material for subsystem of VPP, storage systems, and demand response. Support for arrangements of validation platform is supported, using LabVIEW RT for this purpose.

The activities in both secondments could be summarized as follows:

- Training on DIgSILENT; static and quasi-dynamic analysis
- Site visit of a hydroelectric power plant, 18 May 2017, Italy.
- Training on OPAL-RT, 26-28 July 2017,
- Individual course on learning Italian language, June-October 2017,
- Model of urban distribution network using DIgSILENT tool.
- Analysis of reactive power imbalances for the network in 6 due to DER (Distributed Energy Resources).
- Quasi-dynamic analysis of the network in 6 before, and after the penetration of DER.
- Modbus communication of customers metering data using LabVIEW tool.
- Development of HMI for metering information and data recording in excel file.

In addition, the secondment developed the model of a Storage System as a Stand-Alone portfolio element of an aggregator connected directly to the transmission network for the provision of services (primary regulation, secondary and tertiary)

Courses and summer schools organized in the framework of MEAN4SG

ESR06 has participated in all Specific Courses and Summer Schools organized in the framework of the project

- 1st MEAN4SG Specific Course: Hold in CIRCE, Zaragoza, Spain on 31/01/2017-02/02/2017, as a training activity within the ITN-ETN MEAN4SG project
- 1st MEAN4SG Summer School: Hold in the Van der Valk Hotel, Haarlem, The Netherlands, on 19-20/04/2017
- 2nd MEAN4SG Specific Course: Hold in the University of Strathclyde, Glasgow, UK, on 6-8/06/2017, as a training activity within the ITN-ETN MEAN4SG project
- 3rd MEAN4SG Specific Course: Hold in CIRCE, Zaragoza, Spain on 28-30/11/2017, as a training activity within the ITN-ETN MEAN4SG project
- 2nd MEAN4SG Summer School: Hold in the University of Strathclyde, Glasgow, UK, on 23-25/01/2018, as a training activity within the ITN-ETN MEAN4SG project,
- 3rd MEAN4SG Summer School: Hold in ORMAZABAL, Boroa, Spain on 19-21/06/2018, as a training activity within the ITN-ETN MEAN4SG project

Jibran did participate in Summer Schools on topics: “Changing Role of DSOs”, “Current Status of Renewable Integration”, “Ancillary Services”, “Flexibility and Reliability in Smart Grid”, “Large Scale Integration of Renewables in the Grid”, “Evolution of Ancillary Service Provision in TERNA”,

"Uncertainty Impacts of DER Integration", "Provision of Distribution Network Services by DER", "DER Aggregation and Energy Storage", "Enel Future Distribution Grid", and visit to TERNA dispatch center, 2-5 July 2018, Salerno, Italy. (5 ECTS)

Figure 7 Workshop session during the 2nd Summer School in Glasgow

Other training events performed/promoted within MEAN4SG

Among the training events taken place and promoted within the project's framework, ESR06 did participate to the following:

- Researchers meet Innovators. Hold in Berlin, Germany on 11-12/07/2019, an organized by the Marie Curie Alumni Association aiming researchers and innovators to synergistically and successfully work together.
- Demo workshop about insulation diagnosis on MV grids for maintenance departments of utilities. Hold in LCOE, Madrid, Spain on 03/06/2019, as a training activity within the ITN-ETN MEAN4SG project
- Demonstration Workshop on Electric System Modelling, Development of an integrated model of electric systems and Development and validation of distributed generation management at customer sites for service provision through virtual power plant concept. Hold online by ENEL with special guests from the Universities of Cagliari and Genova on 10.10.2019, as a training activity within the ITN-ETN MEAN4SG project

During the workshop on Electric System Modelling and as a part of the organization, the fellow has presented the tool for dispatch a Virtual Power Plant for provision of ancillary services as reactive power regulation. The degree-awarding universities and the host institution presented the activities related to the research project. Apart from ESRs, the external audiences from universities were present at the workshop.

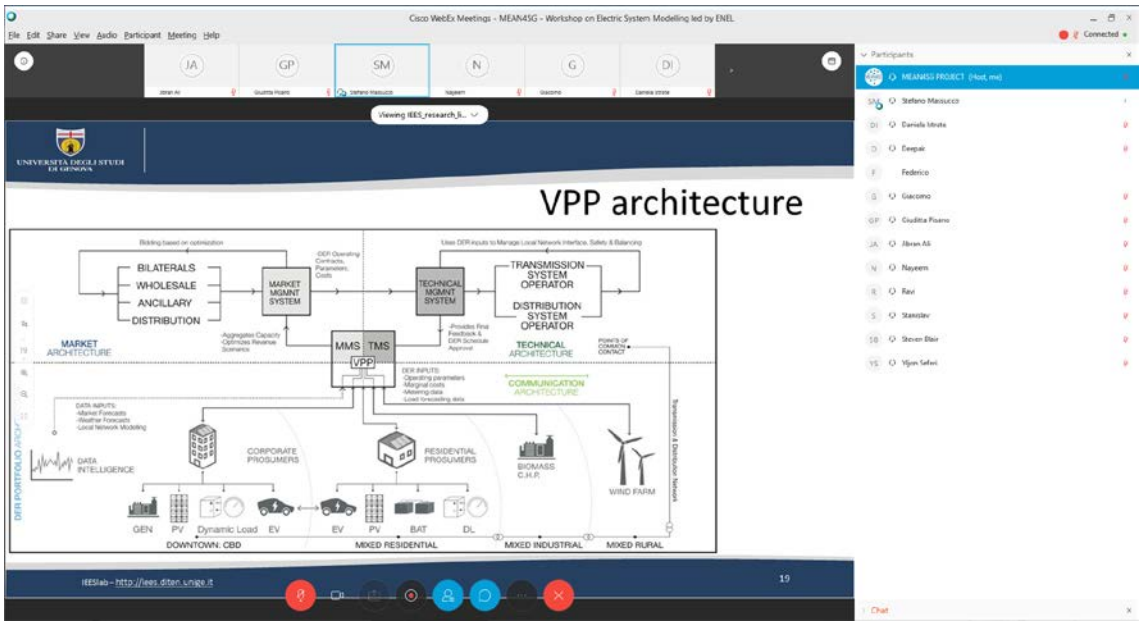


Figure 8 Presentation of Jibran's results during the Workshop

- Multiple training events on all relevant software within Europe.
- Attendance to conferences. The following list describe some of the conferences Jibran has attended:
    - Participation in IEEE International Conference on Smart Grid Communications, 23-26 October 2017.
    - Participation in CIRED Workshop on Microgrids and Local Energy Communities, along with presentation of a poster, 7-8 June 2018, Slovenia.
    - Participation in IEEE 18th EEEIC on Environment and Electrical Engineering with emphasis on Power Systems, along with presentation of a research paper, 12-15 June 2018, Palermo, Italy.
    - Technical committee (reviewer) of IEEE PES ISGT-Asia Conference 2018.
    - Participation in IEEE UPEC 2018 conference with emphasis on Power Systems, along with presentation of a research paper, 4-7 September 2018, Glasgow, UK.
    - Validation of subset of VPP (customer-aggregator) is performed, using LabVIEW-RT and DIgSILENT, at French Metrology Institute, LNE, June 1-July 31 2018, Paris, France.

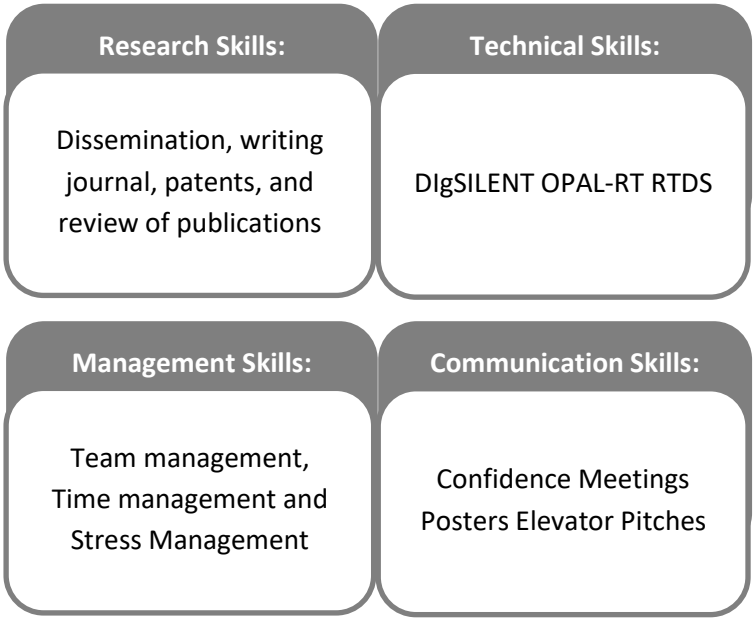
- Participation in IET MEDPOWER Conference 2018 with emphasis on Power Systems, along with presentation of a research paper, 12-15 November 2018, Croatia.
- Participation in IEEE AUPEC Conference 2018 with emphasis on Power Engineering, along with presentation of a research paper, 27-30 November 2018, New Zealand.
- Participation in CIRED Conference 2019 with emphasis on Power Distribution Systems, along with their operations, planning, and applications, 3-6 June 2019, Spain.
- Technical committee (reviewer) of IEEE EEEIC Conference 2019.
- Validation of full-scale VPP is performed, using OPAL RT, MATLAB/Simulink, and DIgSILENT, at OFFIS, Oct 1 – Nov 30, Oldenburg, Germany. This work is part of ERIGrid EU H2020 Project.
- Participation in IEEE RTSI Conference 2019 with emphasis on Power Engineering, along with presentation of a research paper, 9-12 September 2019, Firenze, Italy.

Seminar Presentations

ERS06 did participate in the following seminar events proposed in the framework of the project:

- European Researcher's Night, 1st year PhD seminar
- CIRED'19. The Leading Forum where the Electricity Distribution Community meets. 3-6 June 2019. Paper Title: "Optimal location of energy storage systems with robust optimization"
- PhD Webinar. Workshop on Electric System Modelling led by ENEL: October, Thursday the 10th: Jibran Ali [10:00] - Virtual Power Plant for Distributed Generation Management: [Link to the presentation https://youtu.be/b6qE1vdxK-k]

3.3.3 Skills learnt under MEAN4SG framework



3.4 Achievements

3.4.1 Research results

- ✓ Overview on FCR and aFRR control reserve markets in European countries
- ✓ Identification of KPI to evaluate performance of flywheel to provide services to the grid
- ✓ training on leading simulation tool (Digsilent), more towards dynamic simulations
- ✓ Modelling and simulation of a Storage System as a Stand Alone portfolio element of an aggregator. The storage in question will be stairs MW (10.5 MW) and connected directly to the transmission network for the provision of services (primary regulation, secondary and tertiary)
- ✓ modelling and simulation of technologies and systems (eg FACTS: SVC and STATCOM) to be integrated to conventional plants (COAL and CCGT) in order to increase the capability for the provision of voltage regulation services through reactive power
- ✓ 11 publications and a quality thesis

3.4.2 Thesis

- **Title**: Distributed Generation Management through Virtual Power Plant (VPP) Concept
- **Defense date** (Upcoming): 2020, the 12th of May
- **Defense place**: University of Genova
- **Doctoral school**: University of Genova
- **Thesis supervisor**: Stefano Massucco

3.4.3 Publications

Up to 8 conference papers have been published by Jibran

- **Jibran. Ali**, Stefano. Massucco, and Giacomo. Petretto, "Reactive Power Provision to TSO/DSO by Aggregators and Conventional Generators," in Proc. IEEE International Conference on Smart Grid Communications, Germany, Oct 2017.
- **Jibran. Ali**, "Coordinated Control Mechanism for Voltage Stability Utilizing Aggregation of Reactive Power Compensation Techniques," in Proc. EEEIC, Palermo, June 2018.
- **Jibran. Ali**, Stefano. Massucco, Federico. Silvestro, and Andrea. Vinci, "Participation of Customers to Virtual Power Plants for Reactive Power Provision," in Proc. UPEC, Glasgow, Sep 2018.
- **Jibran. Ali**, Stefano. Massucco, and Federico. Silvestro, "STATCOM Applications for Voltage Profiling of a Distribution Grid with High Penetration of Distributed Energy Resources," in Proc. MEDPOWER, Croatia, Nov 2018.
- **Jibran. Ali**, Federico. Silvestro, and Mahmood. Jamil, "Virtual Power Plant for Improving Power System Protection Issues – Solution to the Problem of Power System Reliability under Distributed Energy Resources," in Proc. AUPEC, New Zealand, Nov 2018.
- **Jibran. Ali**, Stefano. Massucco, and Federico. Silvestro, "Flexibility to DSO by VPP – Benefits, Regulatory Barriers, and Potential Solutions", CIRED 2019, Madrid, June 2019.
- **Jibran. Ali** and Federico. Silvestro, "Conventional Power Plants to TSO Frequency Containment Reserves - A Competitive Analysis for Virtual Power Plant Role";, RTSI 2019, Firenze, September 2019.

Up to 3 journal papers have been published by Jibran

- **Jibran. Ali**, Stefano. Massucco, and Federico. Silvestro, "Distribution Level Aggregator Platform for DSO Support - Integration of Storage, Demand Response, and Renewables; Frontiers of Energy Research Journal, 2019(https://doi.org/10.3389/fenrg.2019.00036)
- **Jibran. Ali**, Stefano. Massucco, and Federico. Silvestro, "Aggregation Strategy for Reactive Power Compensation Techniques – Validation", Energies Journal, 2019(https://doi.org/10.3390/en12112047)
- **Jibran. Ali, "**VPP Holistic Validation – KPIs for Ancillary Services**",** Sustainability Journal, 2019 (In process for review)

Jibran did as well participated in a (1) workshop paper

- **Jibran. Ali**, Stefano. Massucco, and Federico. Silvestro, "Architecture of Virtual Power Plant for Ancillary Services," in Proc. CIRED 2018 Workshop, Slovenia, June 2018.

3.4.4 Synergies with third parties

Jibran had attended several workshops, conferences and business meetings where he could interact with important key actors in the field. Nowadays Jibran collaborates in the North Carolina State University.

Among the potential collaboration with third parties, it should be highlighted the ERIGRID Project Support for validation of VPP using OPAL-RT. There is an important acknowledgement to Enel, (Giacomo, and Pasquale) for the support.

Besides, Jibran has identified potential ways of collaboration with other ESRs, notably:

- ESR-04 Nayeem Chowdhury (ENEL) | Development of Integrated grid model of electric System, especially on matters regarding power plants, system operators, research units, and policy makers
- ESR-07 Yljon Seferi (STRAT) | Implementing world class PMU algorithms on economic acquisition and computation platforms for ubiquitous deployment, especially regarding the use of real time hardware in the loop of the project
- ESR-09 Sonia Barrios (OCT) | Smart Network Diagnostics: Online Partial Discharge Monitoring of Electrical Networks, notably in the context of the PGCERT

3.4.5 Exploitable foreground that can potentially derive from the ESR project

The main target audience of the research are power plants, system operators, research units, and policy makers

In terms of relevant innovation activities carried out (prototypes, testing activities, standards) and new potential applications, products, services, reference materials, the innovation made represents a new VPP model that could incorporate distribution, transmission, and substation level issues. It is innovative, and the product is validated. It is disseminated at almost a dozen platforms, and therefore its verified solution. The applications are also tested for power system, and one publication based on grand VPP validation is under process. It will be disseminated by the end of this year. Special thanks to Enel for the support.

Table 6 Exploitation Plan for ESR06

Exploitation Plan for ESR06					
Fellow	**Title**	**Direct Applications / Commercial use**		**Patent**	**Future Research Required**
Jibran Ali (ESR06)	Distributed Generation Management through Virtual Power Plant (VPP) Concept	Yes	Yes	Possible	Yes

Details on how the detected patents could be developed are explained in its dedicated deliverable: “D8.2 Exploitation roadmap in consonance with the end user feedback”

4 CONCLUSIONS

The research activity in WP4 progressed well and the obtained results are in good agreement with the initially defined work plan.

Task 4.1.

The main contribution of the ESR04 research activity have been the following:

- ✓ Answer to the Development of an optimization tool for energy storage planning by adopting optimization theory, dynamics of energy storage and load flow analysis. Results: The tool efficiently decide the optimal location of energy storage device in the electric network.
- ✓ 6 papers delivered

Task 4.2.

Energy conservation in residential buildings through power disaggregation has been an issue to be addressed. In this sense, providing information on individual appliances consumptions to residents can make them aware of their energy profile and thus influence them to change their consuming behaviour so that to reduce the amount of energy they consume.

A Non-Intrusive Load Monitoring (NILM) method of disaggregation on which each appliance power demand has been modelled as a Hidden Markov Model (HMM). Based on these trained HMMs of the appliances, the total load disaggregation is modelled as a Factorial Hidden Markov Model (FHMM), and then the single most probable hidden state sequence across all appliances is inferred through the Viterbi algorithm.

By working in the Literature review of NILM, Machine learning and Probabilistic graphical models, ESR05 did help the implementation of NILM, achieving its further development. At this stage, future research is needed to optimize it

Task 4.3.

The obtained results have been:

- ✓ Overview on FCR and aFRR control reserve markets in European countries
- ✓ Identification of KPI to evaluate performance of flywheel to provide services to the grid
- ✓ training on leading simulation tool (Digsilent), more towards dynamic simulations
- ✓ Modelling and simulation of a Storage System as a Stand Alone portfolio element of an aggregator. The storage in question will be stairs MW (10.5 MW) and connected directly to the transmission network for the provision of services (primary regulation, secondary and tertiary)
- ✓ modelling and simulation of technologies and systems (eg FACTS: SVC and STATCOM) to be integrated to conventional plants (COAL and CCGT) in order to increase the capability for the provision of voltage regulation services through reactive power
- ✓ 11 publications and a quality thesis