VIMSEN – Smart Tool for Energy Aggregators

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***Abstract*— The subsidy feed in tariff policy, which has been adopted in the past few years, for accelerating renewable energy investments, cannot be retained as a sustainable business model for the future smart energy grid. This is mainly due to the fact that this policy increases the energy cost, especially when the amount of the energy generated by renewable sources is not negligible compared to the traditional ones, as is expected for the near future. Additionally, the current centralized electricity market prevents small or very small energy producers, who usually generate energy by renewable means – photovoltaic units or wind turbines – to participate. There is a role for energy aggregators to act on behalf of these small prosumers so that they could sell their excess energy collectively in order to get a better price. To help the tasks of the aggregator a trading tool is required that will facilitate the clustering of prosumers who are able to offer energy at a certain time during the day based on contractual agreements. The VIMSEN project is set-up to produce such a system that will allow the aggregator to select prosumers and form virtual micro-grids by virtue of smart communication systems. VIMSEN is part of the European R&D 7th Framework Programme with the aims to develop, implement and demonstrate a new energy management and business model system using the concept of virtual microgrids, to enable an increase in the market participation of prosumers at neighbourhood and community levels.**

Keywords—active energy management, decision making, communication technologies, intelligent data acquisition

I. INTRODUCTION (*HEADING 1*)

During the past five years, generous government feed-in tariffs in a majority of EU member countries were used as an incentive to get more domestic consumers to adopt renewable power generation, in particular by the installation of solar PV systems. The take-up rate of solar PV installations grew at an accelerated rate and took both the utilities and governments by surprise to such an extent that a gradual but noticeable reduction in the feed-in-tariffs had to be phased in to limit the commitments by them. The reduction in the installed costs of solar PV system as a result of a booming market enabled the market to keep pace even with a reduced feed-in tariff. There were also a lot of community energy schemes put in place, in particular in the UK, where small cooperatives were set-up to buy, install and generate their own electricity within small villages or communities. With a liberalised energy market, these community energy schemes and small individual energy prosumers cannot get a reasonable income for selling their excess energy directly as individual customers to the utilities or energy traders. VIMSEN addresses the aforementioned difficulties by transforming the current centralized electricity market framework to a distributed one, introducing the concept of virtual micro-grid networks. Virtual micro-grids (VMGs) are associations of distributed energy generators and/or micro-grid networks, which they have been agreed to operate on a common basis. VMGs provides flexibility to small or very small energy generators, since, i) they can re-distribute energy resources with each other to compensate energy production-distribution and ii) they can directly participate in the electricity market through the respective association, which acts similarly as a big power generator unit.

The following topics form part of the VIMSEN research: i) intelligent data metering techniques suitable for the VMG distributed networks ; ii) information and decision making technologies for the dynamic VMG creation in a way to optimize participant benefits and macro-grid perspectives; iii) reliable communication infrastructure that permits QoS provisioning for data exchange in the VMG network and iv) active energy management and control tool for the operation of the virtual micro-grid as a common virtual power unit.

Future electricity distribution grids fostering synergies between *telecommunication, information and energy research* to increase the automation and promote new business models in the electricity network that promotes the usage of renewable resources [1], [2], [3] and especially of small productions, and provide a more efficient active demand/response energy management that permits load balancing and control.

The SmartGrids program, formed by the European Technology Platform (ETP) in 2005, created a joint vision for the European networks of 2020 and beyond [4], [5], [6], [7]. A Federal Smart Grid Task Force was established by the U.S. Department of Energy (DoE) under Title XIII of the Energy Independence and Security Act of 2007. In its Grid 2030 vision, the objectives are to construct a 21st-century electricity system to provide abundant, affordable, clean, efficient, and reliable energy power anytime, anywhere [8], [9]. The expected achievements, through smart grid development, will not merely enhance the reliability, efficiency, and security of the nation's electricity grid [10], but also to contribute to the strategic goal of reducing carbon emissions [11].

II. MICRO GRIDS

Macro-grids as commonly used in virtual power plant today have their own limitations, namely in gathering and processing the large amount of data as well as providing efficient energy management and introducing new business models in centralised electricity market. The centralized framework common in electricity market prevents small electric productions; mainly consist of renewable sources, to participate into the electricity market.

Typically, two versions of micro-grids exist; the *isolated micro-grid* and the *grid-connected micro-grids.* The isolated micro-grids operate under an autonomous way, while the grid-connected micro-grids are integrated with the bulk energy distribution grid. When connected to the main grid, micro-grids will rely on a mixture of power generation sources depending on the metric to be optimized (cost, Green House Gas-GHG, reliability) [12].

III. Virtual Microgrids

The micro-grid concept is a new way of thinking about the energy grid, as it moves from the conventional centralized way of energy production/distribution towards a more distributed landscape.

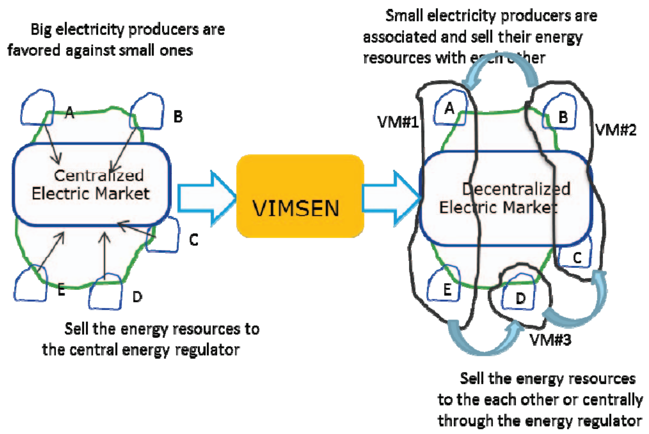

Fig. 1. The decentralized business model framework adopted by the VIMSEN project

New ICT technologies will be used to enable the dynamic associations of virtually connected micro-grids into a common operational framework (Fig. 1). This will create energy capacity comparable to that of conventional energy sources, thus changing the conventional centralized way of the electricity market.

IV. The VIMSEN Architecture

The VIMSEN architecture, shown in Fig. 2, consists of six main components, described below.

A. Energy Data Management System

The Energy Data Management System (EDMS) is part of the Intelligent Data Acquisition and Sensing Framework as shown in Fig. 3 above. This supports the intelligent energy information sensing either within a micro-grid or within the virtual association of multiple micro-grids. It includes new processing tools for efficient communication between energy nodes operating in a distributed manner. It can also handle additional information (apart from the consumption/production patterns), such as the status of the distributed energy sources, the weather conditions, critical information within the distributed network of the micro-grids which are required for the dynamic creation of the virtual micro-grids so as to maximize the long term benefits of its members. Fig. 5 below shows an Archimate representation of the EDMS and its connection to the other modules of the VIMSEN system. The EDMS is also used to carry-out the following functions: 1) energy usage pattern extraction; 2) electric energy disaggregation for domestic appliances and 3) short term load forecasting.

B. The Communication Framework

The Communication Framework used in the VIMSEN project is quite complicated as it has to interface with all the communicating components of the VIMSEN system as well as other external non-Vimsen systems. The main communicating sub-system of VIMSEN is the VMGA system which itself has a collection of sub-modules (DSS, ENS, FMS, GDMS, and EDMS). Communication is also needed for non-VIMSEN systems such as Market Operators (MO), External Energy Data Sources (BRPs, Suppliers etc.) and Weather Operators (WO) to name a few. These relations are identified in the Archimate representation in the figure below. There are also communication links to the Vimsen Gateway, the VIMSEN Prosumer Terminal System, On-board Weather Station, Smart Meter, Smart Plugs and various Sensors for completeness.

The main engine of the VIMSEN Communication Platform consists of a Core Network/Internet module which operates via three sub-modules: a WiFi/Cellular network (2G/3G/4G); Fixed WANs/LANs – Public xDSL/Optical/Other networks and a Powerline Communications (PLC) network. There are also two additional sub-modules; one for Mesh Networks and

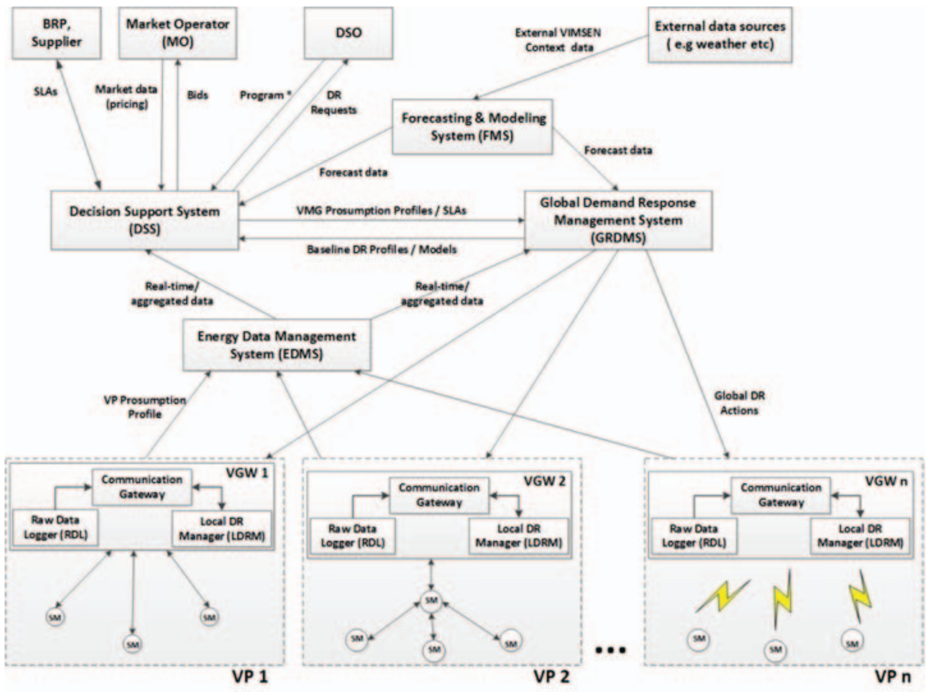

Fig. 2. The VIMSEN Architecture

the other for Home Area Networks. All these sub-modules are relayed to the VIMSEN and non-VIMSEN systems via Communication Service interfaces.

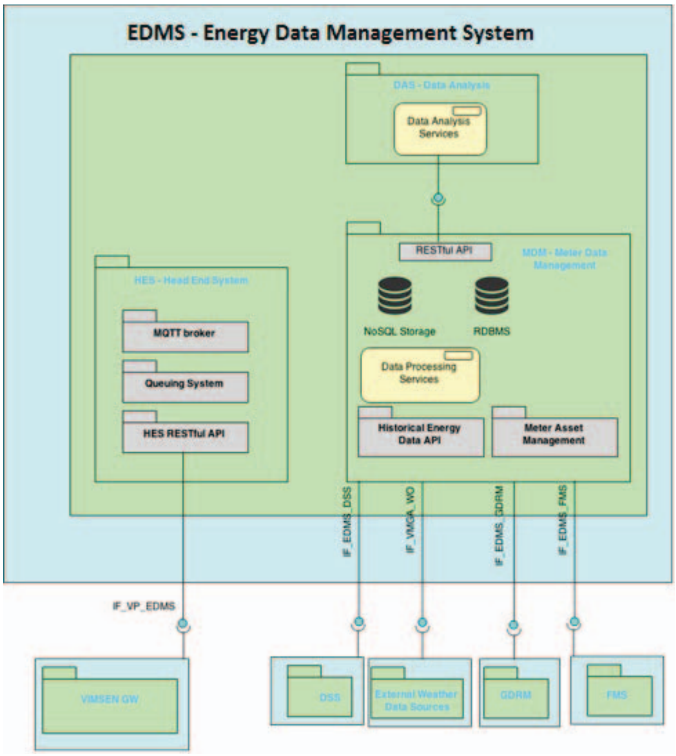

Fig. 4. The Energy Data Management System

C. *The Information Management and Decision Making Framework*

A properly designed Decision Support System (DSS) is an interactive software-based system intended to help decision makers to: a) compile useful information from raw data, documents, personal knowledge, and/or business models, b) identify and solve problems in the system operation and c) make automated decisions with the aid of decision making algorithms. The VMGA DSS component's main responsibility is to be a platform for implementing the intelligent decision support actions that will be necessary for maintaining the optimal operation of Virtual Micro-Grid Aggregator (VMGA). The DSS component will be responsible for aggregating the prosumers of the system into Virtual Micro-Grids through the application of appropriate clustering algorithms. In addition, the DSS component will be responsible for visualizing prosumption data from the individual prosumers, to negotiate with the market on behalf of the prosumers with an aim to maximize profits from the produced energy, and at the same time limiting the costs for the consumed energy, while maintaining the levels of energy security. Finally, the DSS module will be responsible for monitoring and enforcing that the production and the consumption are in accordance to the market contracts, through the application of novel aggregated demand response actions. The figure below shows an Archimate representation of the VMGA-Decision Support System with all the associated components.

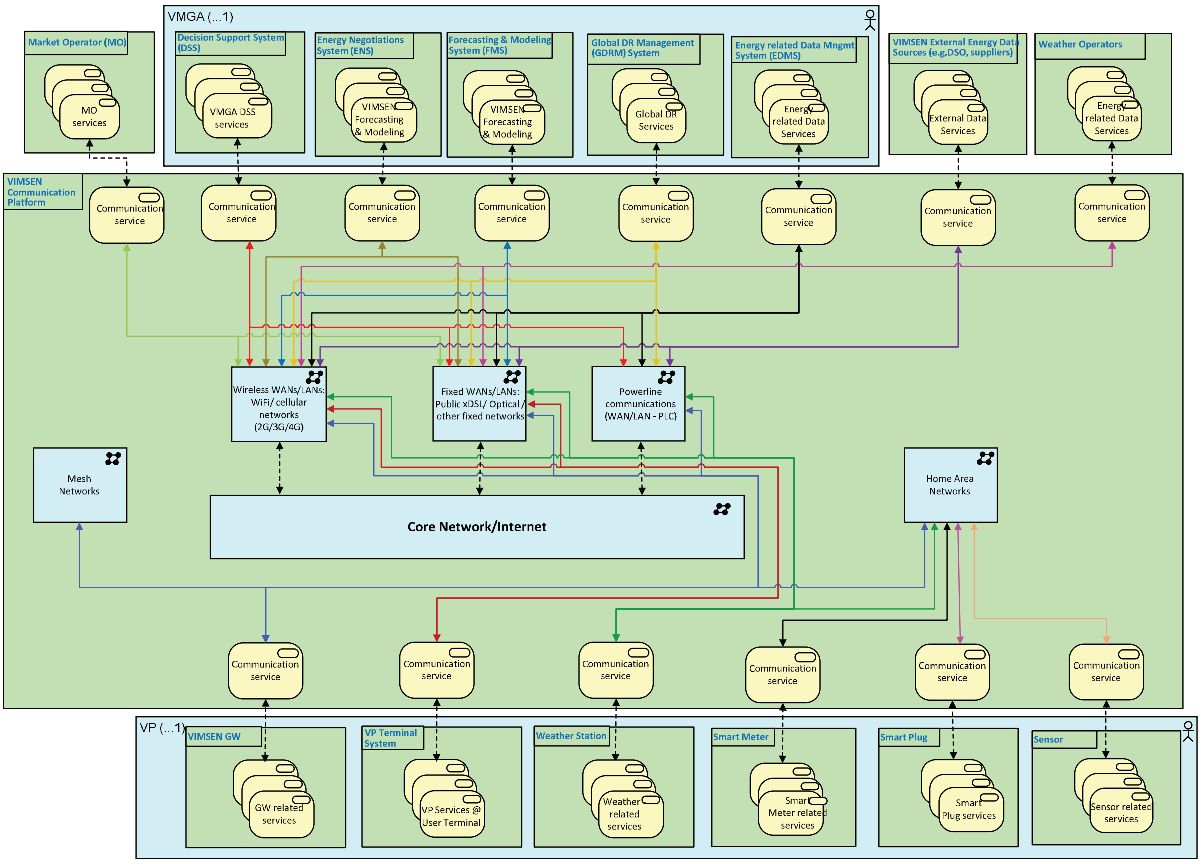

Fig. 3. VIMSEN Communication Architecture

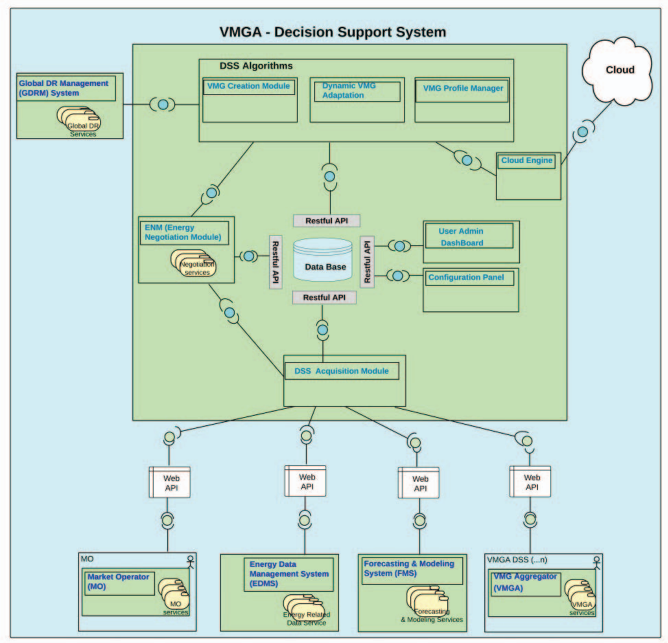

Fig. 5. VMGA – Decision Support System

D. The Active Energy Management Framework

As the need for more pervasive demand response programs continues to grow, the challenge of attracting participants becomes a reality. Reaching new resources for demand response flexibility requires the active participation of end-users, which are rather passive nowadays. Empowering and engaging them to make the transition from passive to active can be considered a major challenge for successful demand response take-off. In addition to traditional semi-automated load control, VIMSEN proposes to enable additional flexibility by helping participants to actively manage their additional power surplus, through an automated discovery of load management opportunities and delivery of clear day-ahead and near real-time notifications calling for planning and manual intervention.

The VIMSEN Active Energy Management Framework component is introduced by VIMSEN as a comprehensive demand management technology to:

- Profile and size demand response strategy over groups of prosumers according to global targets set by the VIMSEN Decision Support Module;
- Implement structured demand response mechanisms to achieve power surplus at each individual prosumer;
- Engage and help groups of prosumers to discover load reduction opportunities and achieve non-automated demand reduction through clear and actionable notifications, recommendations and user interfaces; and
- Maintain power levels and validate power surplus achieved through real-time measurement & verification and run-time correction.

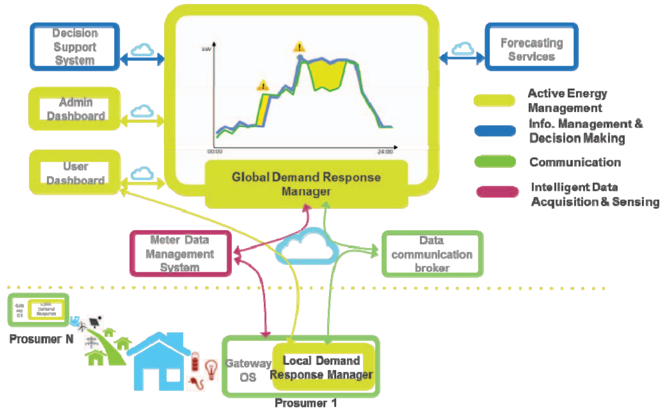

Fig. 6. Illustration of the dual-Layer design of the VIMSEN Active Energy Management Framework with other components of the VIMSEN system

E. Global Demand Response Manager

The Global Demand Response Manager (GDRM) is the coordinator of the VIMSEN Active Energy Management Framework. As such, this component is in charge defining the control strategy that will deliver the service level agreement agreed between VIMSEN and the market. It will interact with other VIMSEN platform components to acquire data that will enable both profiling of the individual VIMSEN prosumers on various aspects and situation-aware decision-making for the implementation of demand reduction. This component also includes engines for data management and validation of demand reduction achieved by individual prosumers, as well as two cloud dashboards for VIMSEN operators and prosumers to allow them to monitor and manage their performance in the demand response programs. Fig. 9 below shows the control strategy of the GDRM

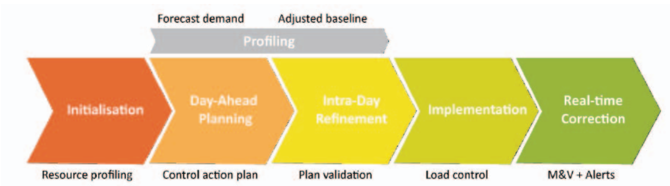

Fig. 7. VIMSEN GDRM demand response control strategy

F. Energy Modelling and Forecasting Tool

Forecasting is one of the key decision making tools in the safe, secure and efficient operation of an energy network or system. Every participant of the energy industry needs to forecast. Transmission networks need to maximize use of network capacity and ensure supply meets demand. Distribution networks also need to ensure security of supply and they need to nominate demands to the transmission networks or face penalties for over-runs. Energy suppliers and aggregators will also need to forecast for longer term (weeks/months, potentially years) to manage their supply/demand contracts efficiently and plan for realistic pricing strategies. In network operations, short-term forecasts feeding simulation tools to predict future network states and ensure security of supply could be highly beneficial.

In the current energy system, energy modelling and forecasting is very important, because many parties and many energy streams (top-down and bottom-up) are involved, and because the grid faces many limitations in transmission and distribution capacity. In the VIMSEN project, first of all the energy streams have to be modelled and predicted for the VMG formations. Furthermore, the monetary value streams need to be derived from this.

The Energy Modelling and Forecasting Toolkit (EMFT) is meant to forecast individual and aggregated energy demand and production profiles within a (micro-)grid on different time scales, ranging from a few minutes ahead to day, week, month and year ahead. For optimum energy forecasting, it is inevitable to start with an energy model of the individual consumers and producers under investigation. Therefore, the toolkit is a combination of an energy model and a forecasting model that can be used effectively to play through a range of scenarios to generate forecasts for any number of pre-defined entities (consumers, buildings, streets, etc.) for different use cases.

1) Energy Modelling System

The energy modeller as shown in Fig. 10 below will have the following in general:

- An input section for definition of the energy system: type of building, appliances within the building (including generation devices like PV), heat and/or electricity demand in general terms and more importantly number of users inside the building
- An input section for environmental conditions: time of the year, solar irradiation, outside temperature
- An input section for the time-dependent profiles of the power demand and generation of the appliances and the whole building.
- A modelling & simulation section, where the input is processed. Mainly, individual profiles are added up to create a profile of a whole building. Also, statistical processing is implemented to cater for human behaviour (switching appliances on/off, number of TVs in a house, etc.). Furthermore, energy parameters like efficiency may be used.
- Simulations are at a minute-by-minute level, but can be aggregated to form profiles with larger time step.
- The energy modeller can generate various output profiles, for example gas & electricity consumption and electricity generation of a certain building.

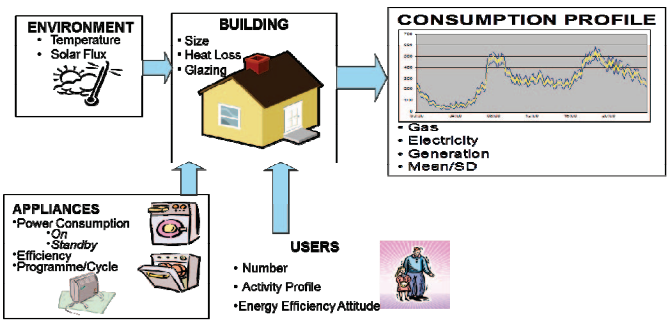

Fig. 8. Overview of the energy modelling system

2) Forecasting System

The forecasting tool will create forecasts of energy output profiles for various entities (depending on the user's needs), e.g. individual appliance, house, building, street, district. The predicted profiles may come out of the tool in a quite straightforward manner, or the tool may add some intelligent forecasting methods by varying the input parameters, the input profiles or the modelling parameters, based on different types of information such as weather and seasons. The main forecasting methods for energy use the following computational engines as listed below:

- Regression analysis
- Piecewise linear or non-linear approximation
- Artificial Neural Networks (ANNs)
- Autoregressive integrated moving average (ARIMA)
- Bayesian Networks

They all rely on a certain amount of given input profiles, either averaged or actually measured data. Fig. 11 below shows some of the details of these computational engines.

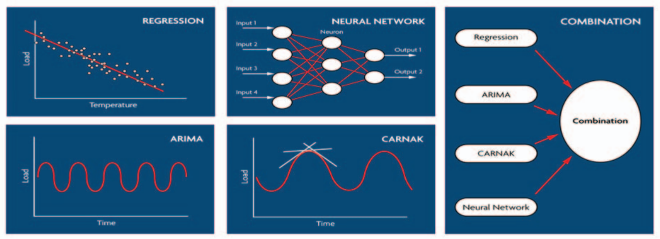

Fig. 9. Some of the computational engines used in the forecasting tool

The forecasting tool is dependent on the energy modelling system to generate forecasts of energy profiles for different time periods such as intra-day ahead, day-ahead, week-ahead etc. The forecasting tool architecture is shown in Fig. 12 below.

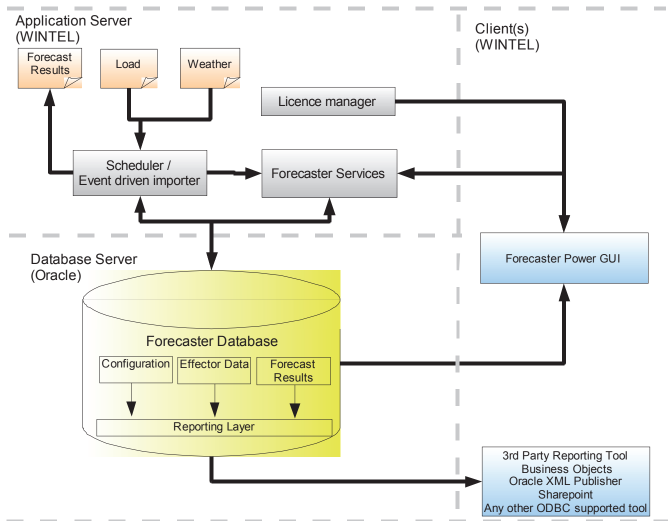

Fig. 10. The Forecasting tool Architecture

V. PROGRESS TO DATE

The VIMSEN project had it first review in April this year and with a few modifications the project was given the go-ahead to proceed. Demonstrations highlighting the virtues of different components of the project were presented at the meeting, in particular the EDMS, the Communication System, the DSS and the AEMF. The test sites both in Sardinia and Athens have been chosen and vetted and an inventory of equipment available for use in the trials have also been carried out. Additional test kits have been installed at some location in Sardinia to facilitate the collection of consumption and generation data from the chosen test sites. A high accuracy pyranometer was installed at one of the test site in Sardinia to get accurate measurements of solar irradiation in the vicinity of a bank of solar panels. This data will be used to validate the EMFT being developed for the project. Fig. 13 below shows the irradiation data collected over a 24 hour period.

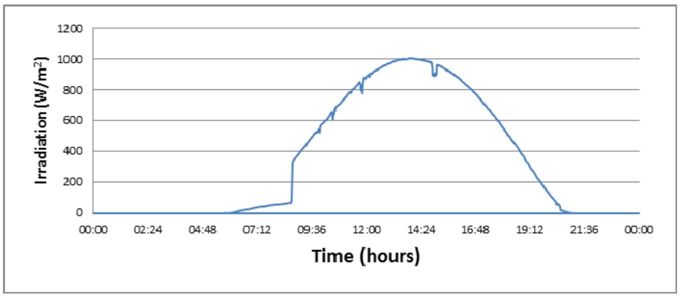

Fig. 11. Irradiation Data from Sedini

From these data, the maximum theoretical generation from the solar installation could be calculated and compared with the measured values. This will give the actual efficiency of the system and the results can be used to validate the EMFT that will be used to generate energy forecast data for an area of interest in Sardinia.

VI. CONCLUSIONS

Good progress is being made by all partners in the consortium, each working on their particular work packages.

Integration work between DSS and EMFT modules has started and good progress has been made to date.

The test site in Sardinia is up and running and preliminary data is already being generated from the chosen buildings; the Active Energy Management System is performing satisfactorily.

The test site in Athens has been assessed and is in the process of being kitted out. Data gathering will start in due course.

Work on the Communication System is progressing well and all the components required have been identified and are being worked on.

An Energy Advisory Board is being assembled to provide guidance and advice on the progress of the project; this will be made-up from active members from the energy industry in Europe.

ACKNOWLEDGMENT

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