Demonstration of the Smart Energy Neighbourhood Management System in the VIMSEN Project

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***Abstract*—The VIMSEN project, part of the European R&D 7th Framework Programme, started in February 2014. The VIMSEN project aims to develop, implement and demonstrate a new energy management operation and business model using the concept of virtual micrigrids, able to increase the market participation of prosumers at neighbourhood level. The new control system (VIrtual Microgrids for Smart Energy Networks – VIMSEN) will be developed to manage and control distributed energy resources, stationary storage devices, electric vehicles charging infrastructure, building appliances, etc. The VIMSEN concept enables the large-scale integration of distributed energy resources by utilizing aggregated demand response to the maximum. Two demonstration sites are committed with VIMSEN: Sedini, on the island of Sardinia, Italy, and Athens, Greece. The results and conclusions coming from the demonstration activities will provide the basis for the elaboration of recommendations for future virtual microgrids for smart energy networks. This paper presents the VIMSEN architecture and the use cases.**

***Index Terms*—Active demand control, Distributed power generation, Microgrids, Smart grids.**

I. INTRODUCTION

A. Alternative for the feed-in-tariff

The big environmental concern regarding the CO_2 footprint of the power sector is leading to a high share of renewable energy sources (RES) in the energy mix worldwide. Exploiting large and small renewable generation units can make the power sector more "green". Currently, the centralized electricity market framework prevents the market participation of small distributed renewable generation units due to their limited capacity. The common practice for promoting RES investments is the prioritization of the RES power production compared to fossil generation units and their reimbursement at a fixed price rate ("feed-in-tariff" concept). If this means that small energy generators are credited to sell energy at higher tariffs than the normal market prices, the electricity prices increase for society as a whole. The incentive for "home storage" at low feed-in-tariffs, on the other hand, might lead to cost increase because of the high price of storage systems, and to possible additional safety concerns.

As the energy sold by RES is green (a positive "green" externality, since it avoids possible CO_2 penalties) and is often closer to the consumers (a positive "geographical" externality, since it reduces the investments needed in the transmission network for long distances), a higher price for it is to some extent justified, but the situation today is that the "feed-in-tariff" price is determined in a rather ad hoc way, outside the market, and is arguably too high. In order to avoid high electricity price increase, alternative RES deployment policies should be adopted.

B. The idea of VIMSEN

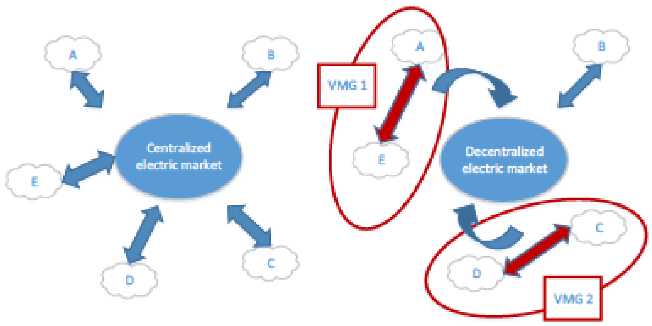
The aim of the VIMSEN project (www.ict-vimsen.eu) is to enable the market participation of small RES units belonging to end-users (thus producers and consumers: prosumers) without the need of implementing a "feed-in-tariff" policy. In this project, each prosumer is considered as a separate micro-grid with inherent ability of monitoring and managing its local energy resources in order to serve specific objectives (oriented to the market, the grid or himself). The main barrier towards the VIMSEN scope is the limited market visibility (selling power) of individual small RES units. However, this can be overcome if the available production of several micrograms is aggregated into a single profile meeting the market minimum capacity requirements. The creation of virtual associations or clusters of microgrids requires advanced management schemes and information & communication infrastructures that are analyzed and developed in the VIMSEN project. The creation of such associations would enable RES producers to participate directly into the market and also, with the introduction of appropriate corresponding business models, help them benefit themselves from the positive (green and geographical) externalities they create.

C. Virtual microgrids

The microgrid concept introduced by the Microgrids and More-Microgrids EU projects [1] enables moving from the

The VIMSEN project is has received funding from the EC Seventh Framework Programme FP7/2007-2011 under grant agreement n° 619547. The VIMSEN project website is available at http://www.ict-vimsen.eu/.

conventional centralized way of energy production/distribution towards a more distributed approach. Microgrids enable more efficient exploitation of energy resources that are located in a restricted geographical area. However, their participation as individual entities into electricity markets is still not possible. A solution to making microgrids commercially viable exists by virtually aggregating the generation capacity of several microgrids into a dynamic association whose operation is coordinated by the *Aggregator*. Such dynamic associations are called *virtual* microgrids (VMG). In the traditional market model, large energy producers sell their energy centrally(Fig. 1, left). Instead, in the proposed VIMSEN model (Fig. 1, right), small energy producers have the flexibility of either re-distributing energy between each other to compensate energy production-demand differences, or directly participating in the central market through the virtual microgrid association, which acts as a large power producer.



Centralized approach: Sell the power to the central market

Decentralized approach: Sell the power to each other or to the central market

Figure 1. The decentralized conceptual rationale adopted by the VIMSEN project. In the traditional model, the large power producers sell their energy centrally.

D. *VIMSEN objectives*

The aim of the VIMSEN project is to research ICT technologies that allow the creation of virtual microgrids under a highly dynamic and distributed market framework. Virtual microgrids are dynamic associations of multiple microgrids operating under a common control and communication framework that allows efficient energy management.

The main objectives of VIMSEN are:

- Maximize the use of distributed energy generation and green externalities
- Optimize the energy tariffs (buy and sell) to end users (prosumers)
- Aggregate microgrids, enabling wholesale market participation of the aggregated prosumers
- Integrate grid constraints (geographical externalities) and market requirements

E. *Overall Benefits*

VMGs offer new business models for small and very small energy producers to share their surplus of generated energy to the grid. In particular, small and very small producers through virtual associations of microgrids can sell the energy produced to the market at better prices because of their better trading position. The benefits of the VIMSEN concept are:

- It treats all energy producers equally without using subsidy policies that increase electricity prices.
- It gives real incentives to (very) small producers in order to share their generated energy with the grid.
- It achieves better sale prices for small and very small producers since they interface with the grid through virtual associations.
- It promotes rapid investments of renewable energy sources from small units without relying on subsidy policies.
- It does not require small energy producers to be physically connected to form the associations, as also virtual connections are supported.
- It makes energy production democratic, since almost all energy consumers can potentially be producers.
- It gives benefits to network operators and large energy companies by designing a power production policy not at the maximum loading level, reducing the level of redundant design of the network.

II. VIMSEN'S NEW MARKET ACTORS

A. *VIMSEN Aggregator (VMGA)*

The VIMSEN Aggregator (VMGA) acts as an energy administrator of an association of VIMSEN prosumers (VPs), to satisfy the association's own energy needs and/or as their representative in order to sell the surplus energy to the electricity market.

VMGAs' main responsibilities are:

- Establishing a VMG through a formation process.
- To perform day-ahead forecasting of production/ consumption of its VPs.
- To efficiently manage the energy resources owned by the VPs, aiming at covering the association's own needs first.
- In case of energy surplus, to maximize the profit for its own VPs, by:
    - Monitoring the energy market demand
    - Negotiating on the energy market
    - Monitoring the active service level agreements (SLAs) in real-time
    - Taking proactive actions to ensure the active SLAs fulfillment (e.g. optimal formation of VMGs, demand-response with its own VPs)
    - (Re)negotiating with other VMGA or with the market (if needed)
    - Managing energy storage systems

B. *VIMSEN Prosumer and Microgrid*

A VIMSEN Prosumer (VP), is a natural person or legal entity producing and simultaneously consuming energy with a time-varying energy profile that is partly manageable. A VP could be defined as an individual energy producer/consumer or as an operator of a local microgrid (MG) that manages his energy profile through MG's flexible loads and MG's production. Examples of VPs are: households (e.g., PV owners); small/medium/large enterprises (owning PVs, wind turbines, etc.); municipalities (e.g., having PVs on lamp-posts); and solar/wind parks.

VPs' goals are:

- To satisfy its own power needs, and
- To maximize its profit by taking part in VMG associations.

VP's main responsibilities are:

- To contribute energy surplus to the VMGA, according to its energy profile.
- To provide the VMGA with its daily energy profile (day-ahead forecasting (optional), consumption vs. time, possible deviations from normal behavior, etc.).
- To respond to VMGA demand-response requests in real time (e.g., turn on/off or re-schedule devices).
- To define of a set of devices over which the VMGA can have partial control (in case of an emergency situation, imminent SLA violation, etc.).

III. THE USE CASES OF THE VIMSEN PROJECT

A future ready-made market fitting the VIMSEN framework and tools could be the forthcoming community energy scheme (CES) put in place by the UK government [2]. A CES can be considered as a collection of microgrids and corresponds to a virtual microgrid in the VIMSEN framework. As a result of a fair number of conventional power stations coming off-line within the next five years, the CES has been identified as a potential source of replacing the energy requirement for the UK in the future. A range of related analysis tools for VIMSEN could be adopted to help such CES manage their energy networks in a more profitable way compared to the current operations.

On the other hand, the distributed market approach of VIMSEN is very promising for the macro smart energy grid (the macro-grid perspective) [3]. Using the virtual microgrid networks, the energy can be produced at a lower cost while simultaneously retaining incentives for the use of renewable energy sources.

The VIMSEM use cases are described below. From these use cases user requirements and system requirements have been derived, leading to the VIMSEN architecture presented in Fig. 2. In the course of the project, the parts of the VIMSEN architecture are further developed in more detail. They will be tested in a laboratory environment, integrated into a single VMGA control and communiction system and demonstrated in two sites, located in Athens and Sedini. Furthermore, the VIMSEN architecture will be modelled and simulated in different use scenarios under normal, abnormal and emergency conditions. Also, market & business models for all actors will be simulated and analyzed. The overall financial benefits of adopting the VIMSEN strategy and the amount of greenhouse gas reductions are also going to be investigated. And the potential of new services, including services offered by telecommunication operators, will be analyzed.

A. Use Cases regarding small power generators; the microgrid perspective

VIMSEN provides advantages to small (or very small) power generators since it allows the dynamic creation of associations of virtual microgrids. VIMSEN offers flexibility to small distributed energy producers to re-distribute energy resources with each other so as to permit local balancing between power consumption and production. Additionally, VIMSEN allows small generators to participate into bigger virtual associations and therefore enter the electricity market as a single market entity represented by a new energy actor: the virtual-microgrid aggregator (VMGA) or VIMSEN Aggregator.

1) Market participation of small DER units without "feed-in-tariff" policy (UC-A1)

This use case aims to enable the national market operator meeting his obligation to achieve a specific RES share target on the day-ahead market operation. This use case aims to enable the participation of small DER in the electricity market without adopting the "feed-in–tariff" concept.

2) Supplier's short-term balancing (UC-A2)

The aim of this use case is to balance the difference between the day-ahead energy schedule of the supplier and the real-time energy profile.

3) VIMSEN aggregator offering ancillary services to network and system operators (UC-A3)

The aim of this use case is to enable VIMSEN aggregators to offer demand response services to network operators in order to overcome grid operational issues, either global (i.e. frequency deviation) or local (i.e. voltage compensation, network congestion). The level of contribution of each VIMSEN aggregator to a grid service depends on the type of the grid issue (i.e. local or global) and the available aggregated flexibility of the microgrids.

B. Use Cases regarding the electricity market; the macro-grid perspective

The second business case study concerns the market operation, wherein the association of microgrids is a player in the wholesale electricity market. The VMGA manages this association for the benefit of the prosumers in it.

The day-ahead market schedule is highly dependent on the forecast accuracy of the demand and the renewable generation. In real time power system operation, any deviation from the market energy agreement due to prediction errors could result in high market penalties. The VIMSEN macro-grid use case investigates the options for balancing such deviations at lower cost, exploiting power flexibility (manageable loads/demand response, controllable generation units, RES surplus, energy storage, etc.) offered by the virtual microgrid associations.

1) Day-ahead schedule for optimal formation of VMGs (VMGA perspective) (UC-B1)

The scope of this use case is to define all main functionalities and steps to be taken, in order to optimally create VMGs in a general day-ahead market context.

VIMSEN's forecaster module provides a prediction about the amount of energy that can be exchanged to the day-ahead market, and thus a negotiation with other VMGAs and the market begins. The outcome of the negotiation phases will be the formation of specific SLAs between the involved parties (inter-VMGA, VMGA-market). According to these SLAs, a VMGA creates optimal associations of VPs (or VMG clusters) such that the benefits of VPs are maximized. Conclusively, demand response (DR)-related actions and recommendations are provided to all VPs such that their individual benefits are matched to the VMG association's benefits as a whole.

2) Short-term schedule to cope with power deficit/surplus contexts (VMGA perspective) (UC-B2)

The scope of this use case is to define all functionalities and steps that take place for power deficits or surpluses to be tackled on a short-term basis. This use case deals with intra-day electricity markets. It is assumed that a day-ahead market model is given and that SLA violation or over-satisfaction contexts happen at short-term timescales within the day.

Two main contexts are considered: a) SLA violation/power deficit-related procedures and b) SLA over-satisfaction/power surplus procedures. In context (a), the VMGA issues DR actions/recommendations to its VPs or retrieves power from storage or enters a (re)-negotiation phase with other VMGAs. In context (b), the VMGA can start real-time auctioning procedures with the market or other VMGAs or store the additional power for future use.

C. Use Cases regarding System Operators

The large-scale roll out of RES technologies will considerably modify the load profile of distribution networks, affecting their operational and management rules. More specifically, the large deployment of distributed RES in distribution networks can raise network operational issues such as voltage rise, frequency imbalance, local overload, etc. Instead of looking only at grid reinforcements or grid services by fossil-fired generators, these use cases investigate the operation of the VMGs for grid services, e.g. by adjusting demand and/or generation or using energy storage.

1) Day ahead balancing (from a Prosumer's point of view) UC-C1

The purpose of this use case is to define the functionality with respects to day-ahead prosumption scheduling for maximizing profits, and proactive announcement of the prosumption profile.

2) Short-Term Response (UC-C2)

Short-term Response to VMGA's requests for energy modification (production or demand)

A Prosumer that belongs to a virtual microgrid will be notified by the VIMSEN Aggregator when immediate modification of his energy profile must be implemented in order to allow the virtual microgrid to satisfy the SLA between the VMGA and the market. The prosumer will receive push notifications through communication devices (e.g. computer or smart phone), notifying that automatic control of equipment has been executed as pre-agreed to reduce demand or increase consumption, and/or requesting additional actions to be taken immediately for immediate reward. To some extent, the VMGA will generate demand reduction and production increase requests for specific equipment.

The prosumers will modify their energy use profile depending on existing agreement with VMGA, and will decide whether they have any interest in further modifying their energy use considering available options (proposed by VMGA and identified by prosumer) and valuating the associated benefits. The VMGA may redirect benefits from a prosumer not respecting the agreed energy use pattern to a new prosumer changing his energy use pattern to re-balance the production surplus. The VIMSEN communication framework will validate the transaction and will update the prosumer on immediate rewards.

3) Islanded Mode of Operation (UC-C3)

Defining the features and operations of a VP in islanded mode and how it can be self-adequate. The VP may be disconnected from the rest of the power system and operated as an island under emergency conditions (system faults) or as planned (e.g. for maintenance purpose). Another instance in which a VP or microgrid may be islanded is that of a remote community with no access to the main grid. In this case, the main function of the VMGA control is to ensure the stability and safety of the VP in island mode and in the transition from grid-connection to island mode v.v.

IV. VIMSEN Architecture

In Fig. 2 all sub-systems of VIMSEN architecture are depicted. The major steps of a baseline VIMSEN operation scenario is:

- Raw Data Logger (RDL) module (residing at the VIMSEN Gateway (VGW)) acquires the raw VP data. This is done for all VPs.
- VIMSEN Communication Gateway module (residing at the VGW) performs Quality of Service (QoS) provisioning of VIMSEN data and forwards them to Energy Data Management System (EDMS).
- EDMS (residing at the VMGA side) acts as a single meter data repository for all VIMSEN data and exposes real-time and aggregated interfaces to DSS and GDRMS.
- Forecasting and Modeling System (FMS) exploits VIMSEN external data sources and provides predictions of future states of the VMG associations as input to DSS and GRDMS.
- Decision Support System (DSS) processes:
    - VIMSEN real-time and aggregated data streams to create/dynamically adapt VMG groups towards optimizing a VIMSEN KPI (= key performance indicator),
    - Forecast data from FMS,
    - VIMSEN market data (pricing) acquired from market operator (MO).
- Global Demand Response Management System (GDRMS) acquires:
    - real-time prosumption data from EDMS,

- VMG prosumption profiles and SLAs from VMGA DSS, and
- forecast data from FMS.

Then, GRDMS performs automatic control policies at a VMG level and the output is "global DR actions", which are communicated to each member of the VMG via LRDM running on each VGW (VP side).

- VGW receives the DR action messages via its "local DR manager" module (residing at the VGW) and is responsible for implementing the actions at a VP level.
- GDRMS receives feedback about all actual demand response actions that have been made by all involved VPs constituting a VMG association and DSS/FMS are also informed about the final outcome of VIMSEN system operation in order to integrate it in their knowledge bases for more intelligent future decision-making.

The VIMSEN architecture has a 3-tier structure (Fig. 2). The three tiers consist of: a) external VIMSEN operators (i.e. Energy Operators such as DSO, TSO, suppliers, electricity market operator and weather operators interacting with the core VIMSEN system), b) Virtual Microgrid Aggregator (VMGA) incorporating EDMS, DSS, FMS and GDRMS software components, and c) VIMSEN Prosumers (VPs), which are having VIMSEN intelligence at DER/local side. VPs can communicate with each other on a peer-to-peer basis as well as the VMGAs.

Design and implementation work for each VIMSEN sub-system is currently in progress according to the project's description of work (DoW). In particular, TELINT (UK) is responsible for VGW. INTELEN (CY) is responsible for EDMS and RDL module (VGW side). DNV GL (NL) is responsible for FMS and CTI (GR) for DSS. Finally, WATTICS (IE) is responsible for GDRMS. Cosmote (GR) leads the work for the whole communication framework and all interfaces' specification among all VIMSEN actors. PPC (GR) is contributing on external VIMSEN operators' data, which is needed for VIMSEN system operation as well as with its knowledge on electricity markets and current electricity grid operation. Sedini serves as the real-life user of VIMSEN system aiming to prove the VIMSEN concept in real-life conditions.

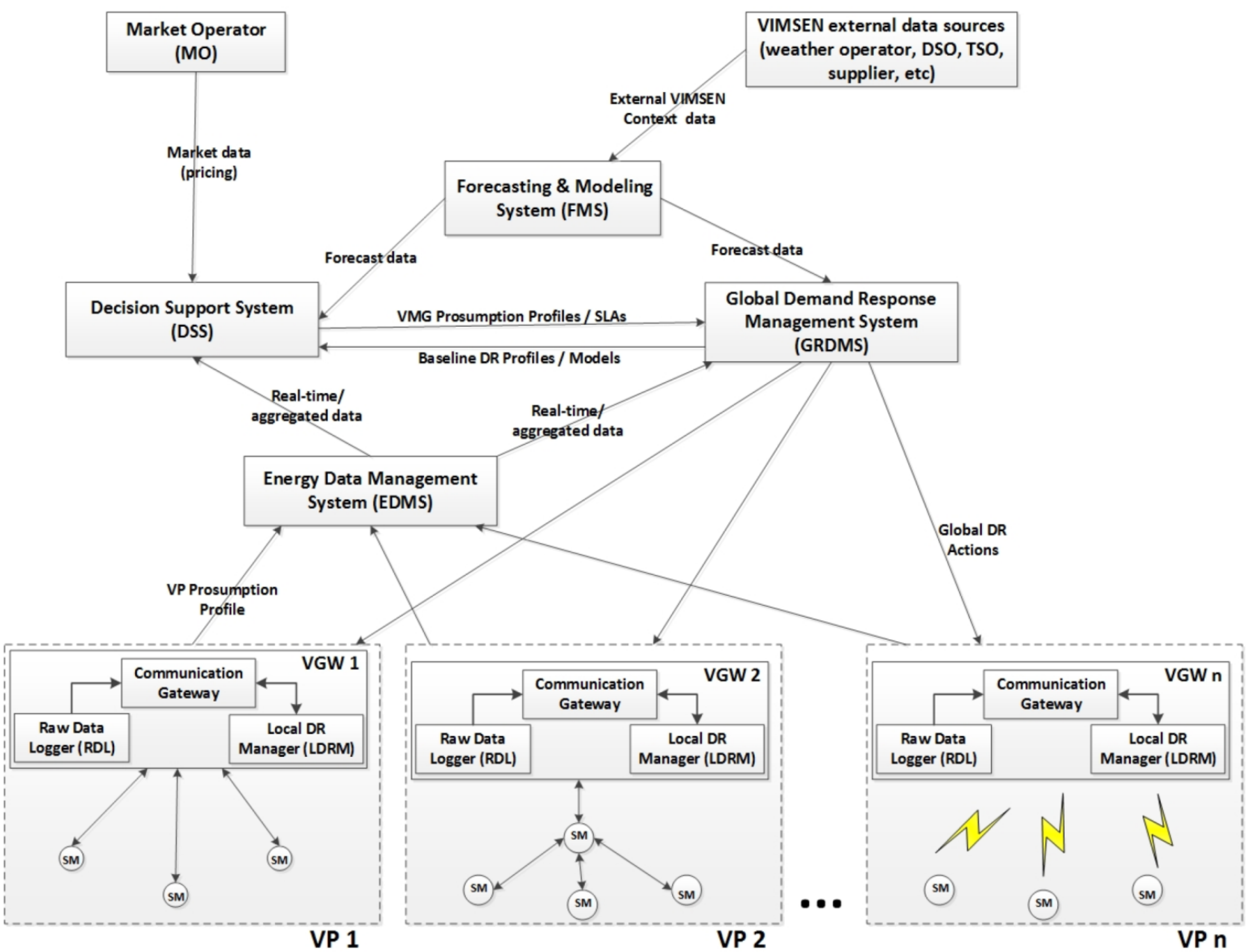


Figure 2. All subsystems of VIMSEN overall architecture

V. CONCLUSION

The VIMSEN project aims to develop, implement and demonstrate a new distributed energy management operation and business model using the concept of virtual micrigrids, able to increase the market participation of prosumers at household level. The VIMSEN concept enables the large-scale integration of distributed energy resources by utilizing aggregated demand response to the maximum. In this paper the VIMSEN use cases and the VIMSEN architecture have been described. Design and implementation work for each VIMSEN sub-system is currently in progress according to the project's description of work (DoW). To support the development of the VIMSEN aggregator, a software tool is being developed to model all the energy elements to be managed in the VIMSEN system. This way the VIMSEN management software will be tested on the virtial microgrids aggregator model, before it is tested in the demo sites.Two demonstration sites are committed with VIMSEN: Sedini, on the island of Sardinia, Italy, and Athens, Greece. The results and conclusions coming from the demonstration activities will provide the basis for the elaboration of recommendations for future virtual microgrids for smart energy networks.

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