A Highly-Dynamic and Distributed Operational Framework for Smart Energy Networks

George Lyberopoulos, Eleni Theodoropoulou and Ioanna Mesogiti
COSMOTE Mobile Communications S.A., Athens, Marousi, 15122, Greece
E-mail: {glimperop, etheodorop, imesogiti}@cosmote.gr

Prodromos Makris and Emmanouel Varvarigos
Department of Computer Engineering and Informatics, University of Patras
Computer Technology Institute and Press "Diophantus", Rion Patras, 26504, Greece
E-mail: {pmakri, manos}@ceid.upatras.gr

Abstract— **The intense environmental concern regarding the CO_2 footprint of the energy sector entails the higher Renewable Energy Sources (RES) share in the energy mix of the global production profile. Currently, energy is produced and distributed under a centralized framework preventing small electricity producers from participating in the electricity market, unless they are part of larger energy associations, the administration of which necessitates the exploitation of new energy and ICT technologies. The VIMSEN project introduces a highly dynamic and distributed market framework, in which new market players will emerge and the current energy market ecosystem will be modified. The framework is primarily based on the concept of Virtual Micro-Grids (VMGs) and on the active participation of renewable energy prosumers. This position paper aims to analyze the VIMSEN ecosystem in a conceptual way and introduce novel market actors as well as their responsibilities that enable the implementation of beyond state-of-the-art ICT frameworks and business models in future liberalized energy markets.**

Index Terms*— *distributed energy market, RES integration, virtual micro-grids, renewable energy sources, demand response, energy prosumer, micro-grid aggregator

I. INTRODUCTION

Climate change, increased worldwide energy demand, rising fuel costs, outdated electricity grid infrastructure, non sustainable business models for the energy market and novel power/ICT technologies motivate the international research community to redesign the power infrastructure more efficiently [1]. Renewable Energy Sources (RES) play an increasingly important role with their integration in the future Smart Grid being the subject of much recent research [2]. Nowadays, energy is produced and distributed under a centralized framework, through which different energy producers sell their energy to centralized energy market operators or big power suppliers. However, such an approach prevents small electricity producers, which mainly generate energy from RES, from participating in the electricity market, and requires them to be organized in bigger energy associations. The effective administration of these large clusters of small energy producers necessitates the exploitation of new technologies in energy and telecommunication sectors, while new, decentralized operational models need to be defined.

This position paper presents a conceptual highly dynamic and distributed operational framework for smart energy networks. In section II, the state-of-the-art operation of energy market is described accompanied by the related research challenges and motivation. The innovative VIMSEN energy market framework is demonstrated in section III, while all novel VIMSEN ecosystem market actors are described in the subsequent section. Section V provides a high-level description of proposed VIMSEN system operation divided in six main phases. Conclusively, the paper ends up with providing some useful future research insights about the work, which is going to take place in the VIMSEN project's context [3].

II. CURRENT OPERATION OF ENERGY MARKET

Currently, in most countries supporting the production of energy from renewable sources, the operational context of the energy market is based on the subsidization of small electricity producers. This "policy", called Feed-In-Tariff (FIT), has been mostly used in Europe in the recent years, in order to stimulate investments on RES. FIT relies on long-term contracts among renewable energy generators on one side and the power electricity corporations on the other, in a way that small energy generators are credited to sell energy at (often much) higher prices than the normal market rate, resulting in a total increase of the electricity price. This, subsequently, increases inflation, industrial cost and causes recession phenomena to the state economy [4].

To avoid the FIT consequences, the European Union examines the case (Horizon 2020 and Grid 2030 agendas), to invoice small RES investors, using a similar cost model with the traditional power operators. However, in this case, the main difficulty is the administration of the large number of RES producers, which contribute, however, an infinitesimally small amount of energy to the electricity grid, as well as to the maximization of profit for each individual producer.

From another perspective, the micro-grid (MG) concept [5] is a new way of thinking about the power grid, as it moves from the conventional centralized way of energy production/ distribution towards a more distributed model. However, as in the case of individual small energy producers, the legacy centralized energy production and distribution framework prohibits MGs from playing an important role in the future Smart Grid. It becomes obvious that in order to exploit the full potential of the energy production sector, a new, de-centralized operational model needs to be defined. For this purpose, utilizing ICT technologies will facilitate the administration of the large number of small energy producers and MGs and will allow for the convergence of dynamic constructions of associations of virtually connected MGs (VMGs) into a common operational framework. VMG concept can be considered as an extension of Virtual Power Plant (VPP) concept [6] but for small RES producers instead of big power plants owned by major electricity utilities.

A. Existing Energy Market Players

Considering the current operational and regulatory context of energy markets [7], the energy provisioning by producers (from various energy sources) to consumers (wholesale, retail consumers or energy suppliers) entails the involvement of various actors such as:

The Power Suppliers (PS), who buy energy from producers (if not being the same entity) for the purpose of reselling it to consumers, thus acting as a consumer in energy wholesale market and as a supplier in energy retail market.

The energy Market Operator (MO) (natural or legal entity) being responsible for clearing and settling wholesale transactions (bids and offers) in energy market, for operating a platform over which the energy products can be traded, and guaranteeing the deals made by forming the relevant Service-Level Agreements (SLAs).

The Transmission System Operator (TSO) and the Distribution System Operator (DSO) being responsible for the operation, maintenance, development and expansion (in terms of capacity, load balancing, etc.) of the transmission system (in a given geographical area) and its interconnections with other systems and the distribution system, respectively.

Finally, the administrative role in the electricity market is undertaken by an independent Energy Regulatory Authority (ERA) as stated in [7] for EU area, while corresponding regulatory entities exist in USA and other states worldwide.

III. VIMSEN APPROACH

The main focus of VIMSEN research is on exploiting ICT in order to allow the creation of VMGs under a highly dynamic and distributed framework. In VIMSEN terms, VMGs are associations of distributed energy producers and/or MGs that have agreed to operate on a common basis. This: a) allows the MGs to participate in the electricity market through the respective association, which acts similarly to a big power generator unit with more market negotiation power, and b) gives MGs the flexibility to re-distribute energy among each other to compensate for forecasting errors in their energy production-consumption and help them meet the corresponding SLAs they have made.

Dynamic clustering mechanisms that allow the formation of VMG associations in a way to maximize both the day-ahead and long-term benefits/profit of the participants and the utilization of RES are required. This is achieved by responding to the energy market demand in an optimized way based also on the geographical area (GA) of energy production and consumption, using efficient active energy management policies that offer better load management and congestion control as well as reduction of energy losses.

The dynamic and optimal formation of VMG associations within the smart energy grid, transforms the traditional centralized day-ahead electricity market into a distributed one, where distributed energy sources are able to sell/buy their energy resources among each other. Real-time negotiation transactions for energy exchange between small energy producers' associations and PSs complement the VIMSEN concept towards a totally liberalized energy market. The transformation of the traditional centralized operational context into the decentralized one introduced by the VIMSEN project is depicted in Fig. 1.

Complementarily, the use of advanced home automation and demand response (DR) systems allow for the maximization of benefit for small energy producers/MGs through the effective control of the energy consumption and possibly production.

IV. VIMSEN ENERGY MARKET ECOSYSTEM

To enable MGs and small energy producers to enter the energy market, new market players will emerge and thus the current ecosystem needs to be modified. The proposed VIMSEN ecosystem, the market actors and their relationships are presented in Fig. 2. The new VIMSEN eco-system related market actors are the following:

<u>The VIMSEN Prosumer (VP):</u> A VP is defined as an individual energy producer/consumer or as an operator of a local MG that manages his energy profile through his flexible loads and production (micro-generators, photovoltaic panels (PVs), etc.), in order first to cover his own energy needs and then to offer surplus energy to interested parties. Example VPs are: (a) individuals (e.g., small scale PV owners), (b) Small/Medium/Large Enterprises (PVs, windmills, etc.), (c) municipalities (e.g., PVs on lamp-posts), (d) Solar/wind parks.

<u>The VIMSEN Micro-Grid Aggregator (VMGA):</u> A VMGA undertakes the role of the administrator of a VPs' association to satisfy the association's own energy needs (i.e. cover VPs' energy needs internally) as well as the role of the VP association's representative in order to sell the surplus energy to the market. In this context, VMGAs are responsible for notifying the energy market of their association's surplus energy and negotiating with PSs through the MO.

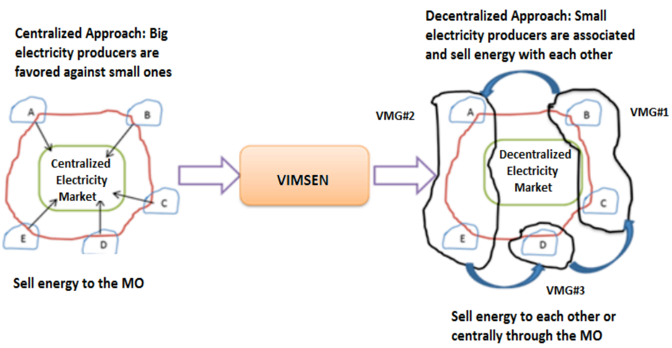

Fig. 1. Transformation of traditional centralized electricity market into a distributed energy market framework [8]

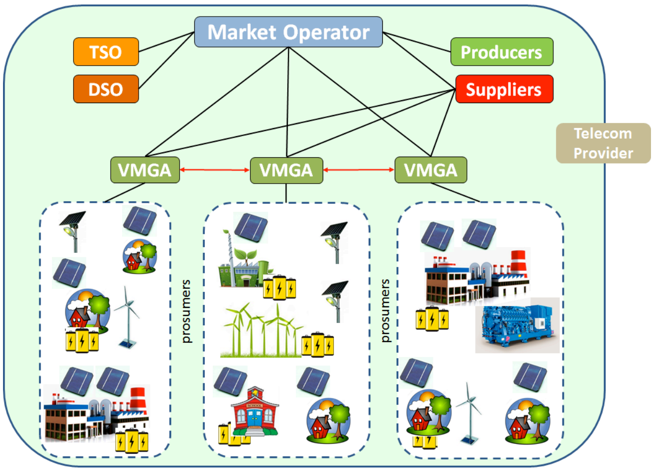

Fig. 2. The Proposed VIMSEN Eco-System [8]

Given the high cost of energy transmission and distribution, the profit (for the VP/energy producer/supplier) is higher when the location of energy consumption is geographically near to the location of production. Thus, it is preferable for VPs to sell energy to suppliers/consumers close to their GA. At this point, it shall be possible for the negotiations between PSs and VMGAs to be optimized based on the GA of energy production and consumption in order for both the VMGA and VPs to benefit from the positive RES externalities that the latter bring to the distribution network system.

The Telecom Provider (TP): A TP provides the telecom network infrastructure (fixed and/or wireless) for the support of the VPs, VMGAs, PSs and MO interactions (DR, real-time auctioning, commands' execution, etc.)

The apparent benefits for the mostly affected energy market stakeholders stemming from the adoption of MGs at any scale have been identified in bibliography ([9] [10] [11] [12]). Since VIMSEN complements and expands the MGs' concept, it enforces the accomplishment of these benefits.

V. HIGH-LEVEL VIMSEN SYSTEM OPERATION

The high-level VIMSEN system operation is depicted in Fig. 3. As shown, two major process categories can be identified: (a) the ones performed on a day-ahead basis and (b) the real-time (short-term) ones. More specifically, VIMSEN utilizes the existing day-ahead energy market procedures (day-ahead forecasting performed by MO and PSs, day-ahead auctioning in the energy market, etc.) and leverages upon them to include the VMGAs' and VPs' operations. At the same time, real-time procedures (monitoring, auctioning, DR, etc.), performed by PSs, VMGAs and VPs are also part of the VIMSEN system operation. More details about the role of each market actor are provided in the following paragraphs.

A. The Role of VMGA in VIMSEN Eco-System

A VMGA performs day-ahead forecasting of production/ consumption (i.e. prosumption) of its VPs on an hourly basis and manages the energy resources produced by the VPs aiming at covering the association's own needs first and at determining whether an aggregated power surplus can be made available to the energy market (see phase 2 in Fig. 3). A distributed model is assumed, where the VPs can send their energy prosumption profiles to VMGA. A VMGA may pre-negotiate with other VMGAs in order to buy additional energy at beneficial tariffs compared to the "standard" market prices.

In case of energy surplus, in order to maximize the profit for its associated VPs, a VMGA performs initial clustering of VPs, forming Virtual MGs (VMGs) so as to respond optimally to the energy demand of a certain GA near the location of the VMG. The VMG formation process shall enable the VMGA to create an energy offer that is competitive to others. Then the VMGA:

- Communicates the energy surplus to the energy market through the MO.
- Negotiates with PSs and possibly with other VMGAs on the day-ahead energy market also through the MO.
- Performs optimal VMGs formation based on the negotiations' outcome.

The negotiation phase between VMGA and PSs through the MO adheres to the market principles and can be based on various models (e.g. bilateral agreements, auctioning). The outcome of the negotiation phase is the formation of specific SLAs between the involved parties (VMGAs, PSs). Market negotiations refer both to wholesale and ancillary services market (see phase 3 in Fig. 3).

Subsequently, a VMGA is responsible for monitoring in real-time the active SLAs with VPs, other VMGAs as well as the PSs. For this purpose, information collected from sensors, metering equipment, etc. can be utilized in order for possible faults, alarms, etc. to be identified and short term forecasting to be performed so as to check whether the SLAs can be met and inform the related parties of any deviation (phase 4).

Potentially, in case an existing SLA cannot be met with MO, in order to ensure the active SLAs fulfillment, a VMGA may take proactive actions such as optimal formation of VMGs and DR actions with its own VPs. For this purpose as well as for selling excessive energy or even buying energy in order to satisfy the associated VPs' needs, a VMGA may also (re)-negotiate with other VMGAs at the "spot" market and purchase energy at lower price compared to the "standard" market prices. Potentially, it could be possible to store part of the surplus energy power in order to cover future needs (phase 4).

B. The Role of VP in VIMSEN Eco-System

On the other hand, one VP can be associated with one cluster, one VMGA. A VP's main role in the association is to offer the surplus energy (when available) to the VMGA and to contribute to the VMGA's energy planning by providing information on its daily energy profile such as: production/ consumption measurements vs. time, day-ahead forecasting (optional), planned consumption profile (e.g. schedule of energy hungry devices on a daily basis), planned deviations from normal behavior (e.g., special occasions such as production unavailability due to maintenance works or consumption minimization due to leave on holidays etc.)

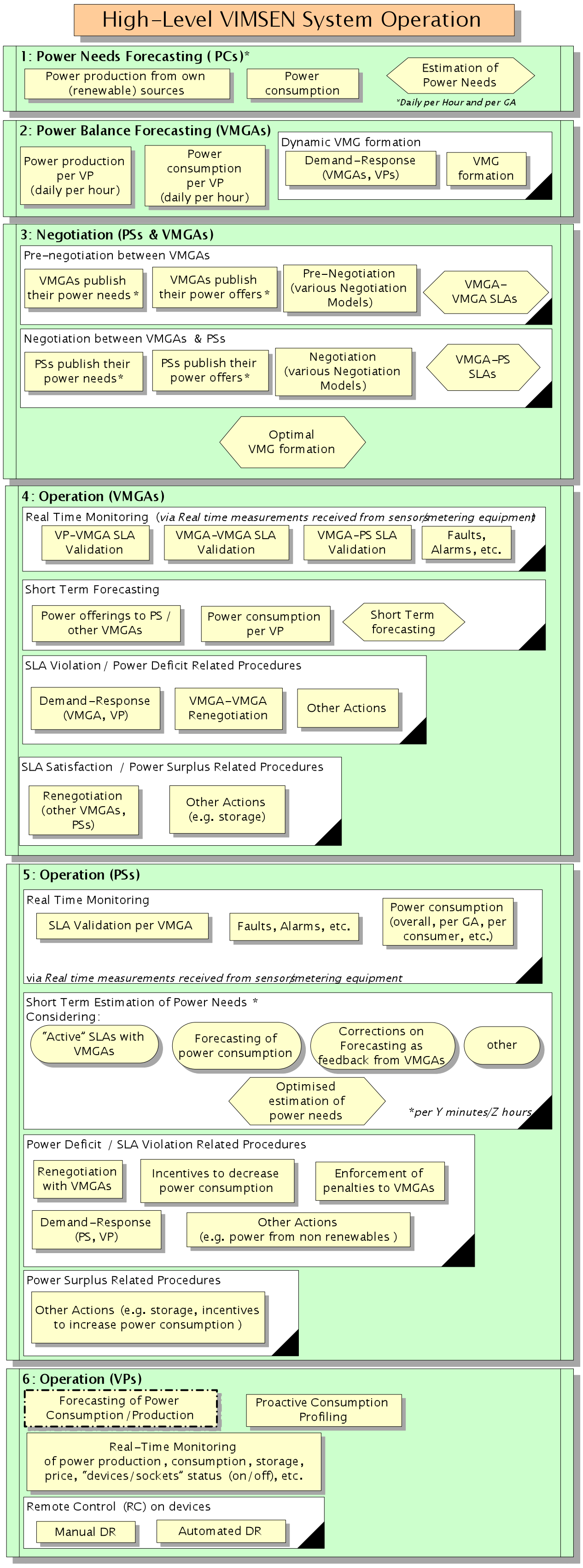

Fig. 3. High-Level VIMSEN System Operation [8]

VPs shall be able to monitor in real-time their energy production and consumption as well as pricing info by the VMGA/PS.

In order for the VMGA to mitigate SLA violation and for VPs to maximize their profit, it shall be possible for (willing) VPs to have active control over their energy production/consumption, by responding to VMGA's DR requests in real time through a home automation system. DR achieves load shedding by turning off certain appliances or sinks, and possibly triggering operation of power generation units. The VMGAs' DR requests would be applicable to a pre-defined set of devices and can be either automatic or manual (phase 6).

In case of automatic DR, VPs participating to short-term load balancing agree to allow the VMGA to have partial control over their set of devices in case of an emergency situation, imminent SLA violation, etc., through a home-automation system. VPs receive advance notice of grid stress so they know that automated DR will take place shortly. After the completion of DR procedures, VPs are notified that automatic control of equipment has been executed as pre-agreed.

In case of manual DR, the VP receives push notifications through communication devices (e.g. desktop or smart phone), informing about the necessity to reduce demand or increase production and/or requesting additional actions to be taken immediately for immediate reward. The VP shall be capable of modifying the energy consumption by re-scheduling loads either locally or remotely through a home-automation system in order to comply with the existing SLA, or even in order to obtain the additional benefit. Actions taken and new energy schedule can be communicated to the VMGA.

C. *The Role of PS in VIMSEN Eco-System*

In the context of the VIMSEN eco-system, existing functions of PSs are enhanced in order to include interactions with VMGAs. More specifically, PSs after performing a day-ahead forecasting may publish their energy needs to the MO, negotiate and buy energy through the MO from a number of VMGAs besides the existing large power producers. We assume that PSs buy energy from RES on a daily and on a per GA basis.

PSs' real-time monitoring functions of their existing SLAs with producers, power consumption, possible faults/alarms etc. are also enhanced to include input regarding energy received from VMGAs.

Optimally, it could be possible for a PS to perform short-term estimation/forecasting of its power needs per GA for the next time interval, taking into account the "active SLAs", info received from the VMGAs, the day-ahead forecasting of the power consumption (per GA), the real-time consumption per GA, weather data, etc., in order to take up actions pro-actively in case of energy deficit and respond to demand for the imminent time interval. Such actions could be re-negotiation with VMGAs to buy additional energy (in the context of a totally de-centralized and liberalized market), energy increase from own non-renewable sources, incentives offering to consumers/VPs to reduce their consumption (through a DR procedure), etc. (see phase 5 in Fig. 3).

D. The Role of TP in VIMSEN Eco-System

The proper administration and orchestration of VPs from the VMGA side, as well as VMGAs and PSs from the MO side can only be performed over a robust and reliable telecommunication system.

Initially a reliable, low latency, high-speed network infrastructure is needed for the support of energy negotiations between VMGAs, PSs and MO. Prioritization of negotiations' related messages/sessions over other lower priority traffic is mandatory especially in cases of high traffic or even congested networks.

Real-time monitoring of VPs and VMGs' energy profiles imply the existence of an "always on" connection over a high speed network infrastructure, allowing for the prioritization of faults/alarms notification messages, commands, etc.

At the same time, according to the VIMSEN concept, the market is structured in such a way that VMGAs can dynamically group VPs willing to participate and having the flexibility to balance their energy production and loads upon DR requests. Effective response to short-term load balancing requests through communication and activation of DR mechanisms requires both communication and control equipment at the VP side, as well as operational processes and communication systems at the VMGA side. Prioritization of specific VIMSEN DR related communication sessions/ messages such as commands in cases of emergency situations is also required.

Given the need for frequent communication and data exchange between VPs and VMGAs, and the need for robust, fast communication between VMGAs, PSs, the MO etc., a TP can be considered as a facilitator. Therefore, there seems to be plenty of room for offering various telecommunication service packages -each differentiating in terms of service quality, prioritization, data volume, price, etc.- that specifically appeal to VP/VMGA/MO/PS telecommunication needs. Depending on the market/business plan, the TP may act as service provider for a subset of VIMSEN services to VPs, e.g. by providing a lightweight VP gateway, along with data connectivity, prioritization, etc.

VI. CONCLUSIONS & FUTURE WORK

The VIMSEN project revolutionizes the traditional framework of centralized electricity market, transforming it into a distributed market, which favors the participation of VPs in the energy market. New players in the energy market value chain are defined namely the VP, the VMGA and the TP, while the role of long-established energy market players is expanded. Among the challenges to be faced towards the adoption of the VIMSEN framework –or even parts of it- from the energy market one can distinguish the required changes in the regulatory environment ruling the energy market transactions and the producers' terms and condition under which they can sell energy to and buy energy from multiple suppliers.

From the technical point of view, the VIMSEN concept is based on the dynamic clustering of VPs and the aggregation of their surplus energy to be offered to the energy market via the VMGA. Active participation of VPs is facilitated via automatic and/or manual DR mechanisms. In addition, the administration and orchestration of the various market players necessitates the incorporation of advanced decision support systems and telecommunication network services, and their tight integration with energy systems, posing at the same time a number of technical challenges depending on the capabilities of the existing energy networks infrastructure.

Regarding future challenges, VIMSEN consortium will undertake R&D activities in specifying individual frameworks such as: a) intelligent data acquisition and sensing, b) communication, c) information management and decision making, and d) active energy management towards the entire proposed VIMSEN operational framework realization.

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