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VIMSEN – New Energy Management Tool for RES Aggregators

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***Abstract*: The phasing out of Feed-in-Tariff has made domestic prosumers reluctant to invest in Renewable Energy Sources in most part of Europe. The limited availability of excess electrical power from domestic prosumers, 4 -10 kW, does not give them any bargaining power when dealing with energy suppliers or utilities. This paper describes a tool that is being developed under the umbrella of an EU-funded project – VIMSEN to help small prosumers participate into a decentralized energy market and to help meet the requirement of EU2020 legislation. This tool can be used by energy aggregators to represent groups of individual prosumers that can form the basis of their customer base. It uses a dynamic decision support system that can change the composition of the cluster of prosumers to satisfy an electricity demand requirement over a specific period of time.**

Keywords—decision support system, renewable energy sources, feed-in-tariff, active energy management, decision making, communication technologies, intelligent data acquisition, service level agreement.

I. INTRODUCTION

This paper gives an insight into the procedures under development on the smart integration of renewable energy sources as part of the work being carried out in the EU funded VIMSEN project [1]. The uptake of renewable energy throughout Europe and many other parts of the world was very heavily supported by governmental financial incentives over the past five years. This was done to promote their penetration into the energy market and enable domestic customers adopt renewable energy producing systems such as solar thermals, PV panels and small wind turbines. Unfortunately the popularity of the PV systems was so great, especially in Europe and in particular the UK, that the Feed-in-Tariff (FiT) [2] initially offered has been greatly reduced and will be phased out completely by next year.

The disappearance of the FiT will make prosumers reluctant to invest in RES and even if they do, the only return on investment will be the minimum payment that utilities/suppliers are prepared to give for their excess RES power. In most cases, domestic prosumers have only limited capacity to spare because their installations range from 4 to 10 kW. Taking into consideration, the EU2020 climate change legislation [3] requires EU member states to generate 20% of their electricity from renewable sources by the year 2020. Very few countries in Europe will be able to meet this target and looking at future commercial installation capacity for RES, this target will be missed by most of them. The only way the majority of EU states can come near that EU2020 target is to make use of the spare capacity from domestic RES installations. The low spare capacity from individual domestic prosumers does not give them any leverage to bargain with the utilities/suppliers unless they form into some sort of association/cooperative arrangement.

This paper describes such a tool to help individual prosumers participate in the electricity market through an aggregator. It deals with the management of information through Service Level Agreements (SLAs) [4] between the aggregator and the prosumers and the formation of clusters of prosumers that can supply a required demand for electricity at a specified time period from a wide client base. Many other factors such as weather conditions, building types, occupancy and user habit, to name a few are used to generate day-ahead forecast both in terms of consumption and generation to help the aggregator meet its obligation to the market operator.

II. THE VIMSEN ARCHITECTURE

The VIMSEN architecture shown in figure (1) below shows all the components required to create the VIMSEN system that can be used by energy aggregators to manage and control the availability of excess electrical power from a group of prosumers. This will facilitate these small individual prosumers participate in the a liberalised electricity market and get a reasonable return on their investment by adopting small scale renewable energy sources in particular domestic PV panels. The application is not limited to any type of system and in this study only PV panels are used; but the technology can be easily adapted to cater for most types of RES.

There are five main modules in the system, namely; the Decision Support System (DSS), the Forecasting and Modelling System (FMS), the Global Demand Response Management System (GDRMS), the Energy Data Management System (EDMS) and the VIMSEN Gateway

(VGW). These modules have been fully described in previous work [5], [6] and in this paper the interactions between the modules will be briefly examined and the DSS will be analysed in more depth, investigating one of the algorithms used to generate clusters/microgrids that will enable small domestic prosumers to participate in a distributed electricity market. Some preliminary results and findings of the DSS system will also be discussed.

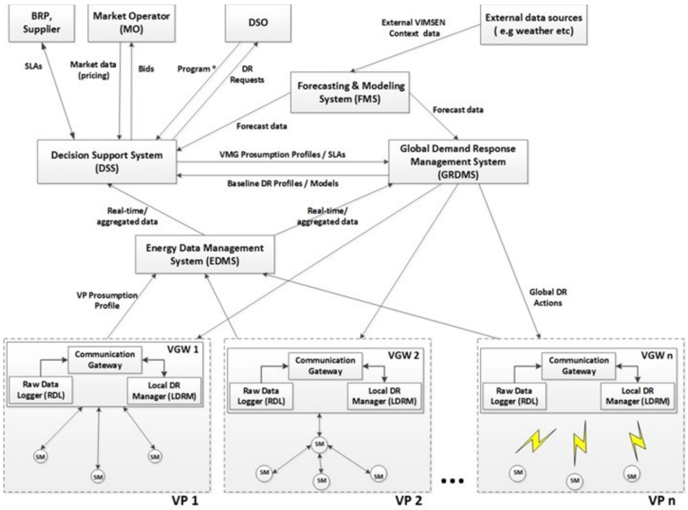

Fig. 1. The VIMSEN Architecture

III. THE VIMSEN SYSTEM OPERATION

The DSS platform is a critical component used by the VIMSEN Aggregator (VA) to manage the RES of multiple VIMSEN Prosumers (VPs) in its client base. It is also responsible for enabling these individual VPs to participate in the decentralized electricity market with the aim of getting a fair return on their investments. Furthermore, it provides the necessary information tools and service engineering methodologies (based on the Web service technology) to create the microgrids and the availability of excess distributed energy sources within the Virtual Micro-Grid (VMG) framework, to meet a specific energy demand requirement. It has also got the necessary algorithms to modify the composition of these microgrids dynamically so as to continue to meet its RES energy provision over a continuous time frame as dictated by the supply contract to the Market Operator (MO). A range of novel algorithms regarding the VMG groups' formation and dynamic adaptation, and VMG profiles' management has been designed, developed and integrated into the DSS platform. These algorithms take advantage of an innovative Hybrid Cloud Computing Infrastructure (HCCI), which allows heavy-processing tasks/jobs to be executed in less time and thus real-time decision making procedures to be realized, which is very important for the successful operation of the whole VIMSEN system. The figure below shows detail of the DSS and its interactions with other VIMSEN modules.

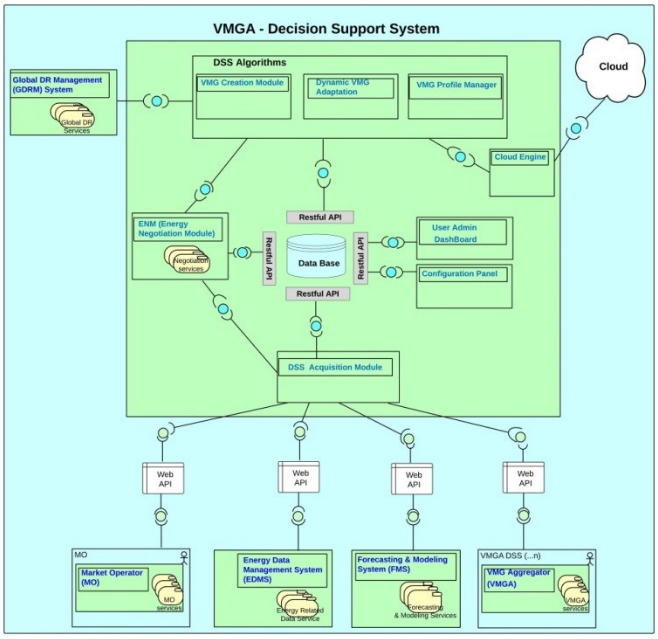

Fig. 2. VIMSEN DSS Module Details

Details of the VIMSEN system operation and information flow are presented in figure (3) below and described in the following steps:

1. Real-time data measurements are sent by All VPs (through their local VIMSEN Gateway (VGW) to the Energy Data Management System (EDMS), which acts as the VIMSEN data repository.
2. The EDMS component acts as a single meter data repository which sends VMG measurements in various timeframes to the Forecasting and Modelling System (FMS) for further processing, and the results are available for the Decision Support System (DSS) upon request.
3. The FMS exploits data sources obtained from VPs and provides predictions on the future energy consumption and generation availability within the VA client base. Prediction results about weather forecasts are also received from online Weather Operators (WO) and other credible sources to help generate the energy forecast on a range of time frames to suit.
4. The DSS then scans through the VPs SLAs and creates an optimal microgrid that could supply the required electricity demand as contracted by the MO/electricity supplier. In case when a VP prosumer is not able to supply its contracted RES electricity, due to unforeseen circumstances, the DSS will find a suitable replacement from the pool of VPs under contract. The outputs from the VPs are regularly monitored so as to ensure the demand requirements are met at all time during the contracted period.
5. There will be cases when the demand requirements cannot be honoured simply by changing the composition of the microgrid; this will kick-in the demand response system into play. Based on the SLAs, certain VPs will then be notified in advance about their obligations and failure to comply will result in the GDRM taking the necessary actions to meet the demand requirements.

6. As a matter of last resort, the GDRM will perform automatic control on agreed appliances, as per SLA negotiation, at the VMG level. The final automatic control is carried out through the Local Demand Response Manager (LDRM0 and VGW following instructions from the GDRM.
7. The VGW uses the Raw Data Logger (RDL) module to continuously monitor and log the consumption/generation data and transfer these data to the EDMS at regular intervals.

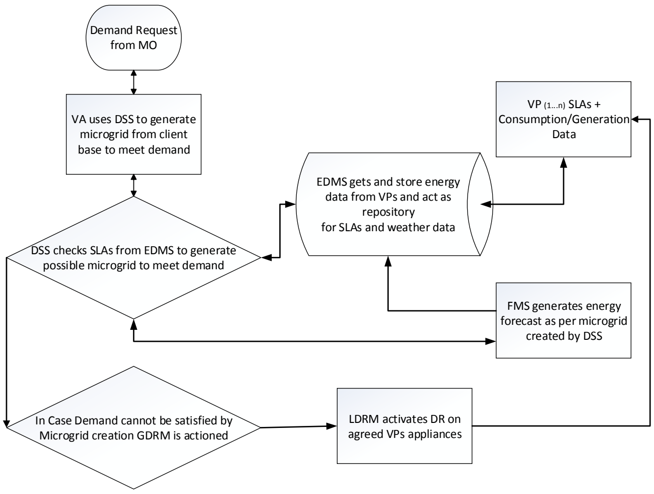

Fig. 3. VIMSEN – Information Flow

IV. DSS WEB PLATTORM FUNCTIONALITIES

The DSS platform has been designed to make it very user friendly and efficient. This section describes some common functionalities of the VA DSS platform. In particular, four main DSS operations are showcased, namely: A) DSS user ability to visualize aggregated historical and real-time data from multiple VPs, B) DSS visualization capabilities to show forecast vs. real data for multiple VPs, C) the ability of the DSS user to visualize open energy data published by a MO/Energy Supplier, and D) how the DSS user will be able to create and adapt a VMG creation to meet an required energy demand. In the following subsections, a brief description is given regarding each capability of a DSS user offered by the platform, accompanied by respective illustrative figures.

A. DSS real time data visualization

The VA can action the DSS to show historical VPs data that is acquired from the database via a RESTful API. In cases where real-time data is requested, the DSS component uses a web API to retrieve the appropriate data from EDMS. Then, it stores the data locally into its database and the results are visualized in a Configuration Panel (CP) via the RESTful API. The data visualization functionalities of the DSS consist of presenting different types of data to the DSS users, namely the VA. Different functionalities have been implemented, to allow for viewing, plotting and extracting relevant prosumption data, including historical and real-time views, individual or aggregated prosumption profiles, and different types of measurements, such as, consumption and generation measurements, on a range of suitable timescales (hour/day/week/month/year). Figure 4 shows an example of real-time consumption data from an individual VP that has been streamlined for a specific time period in order for the VA to be able to continuously monitor the real-time operation.

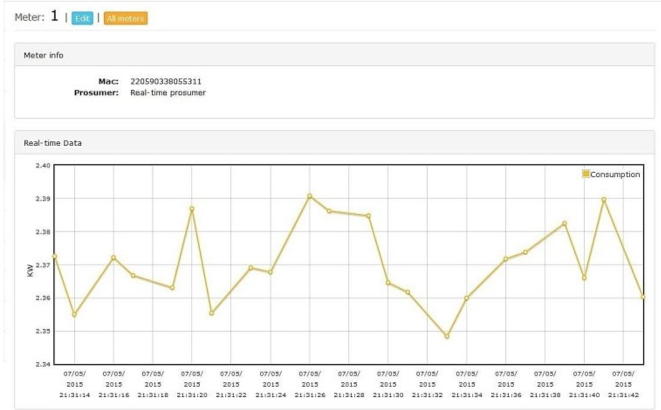

Fig. 4. Real-time Consumption Data from a VP

B. Aggregated data visualization

The VA can request day-ahead forecasts from the FMS regarding a single VP or a group (cluster) of VPs. These forecasts are then used as baseline prosumption profiles by DSS to fine-tune the creation of a microgrid in the day-ahead market to meet the RES electricity demand as contracted by the MO/energy supplier. In the automated case, forecast prosumption profiles are used by DSS algorithms for the creation of a VMG infrastructure. By using accurate forecasting results the aggregation of VPs can considerably reduce the deviations between forecasts and real-life measurements, thus respective SLAs agreed between the VA and MO/energy supplier can be better met. The VA can also use the DSS to visualize the monetary profits that the aggregation of VPs can provide to individual prosumers as a result of their participation in VMG associations. The figure below shows results of real against forecast aggregated data for a microgrid created by the DSS.

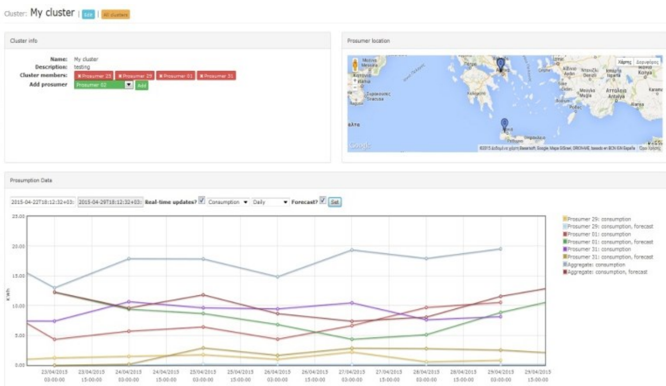

Fig. 5. Real vs Forecast Aggregated data from a Microgrid

C. Open Energy Market data capabilities

Market related data can be retrieved from the MO/energy supplier data base upon the receipt of a new electricity demand contract based on either an intra-day or day-ahead basis. The market operator is responsible for providing the necessary data that will facilitate the VA to create the right microgrids to meet the requirements of the MO/energy supplier. In order to participate in the market, the DSS platform may submit bid requests to the MO's Internet platform according to the forecast prosumption profiles of its portfolio.

The DSS is able to acquire historical data regarding the volume of exchanges and the bid/ask prices in the electricity market, while DSS can also be informed about the market clearing prices published by MO. Other relevant data from the market may be the total demand and supply of energy, including historical data, as well as real time information. In particular a VA using the DSS, as in the VIMSEN case, can select via CP: a) an MO (e.g. Italian, Greek, Irish, Nordic Pool, etc.), b) specific geographical region (e.g. Sardinia in Italy), c) a specific timeframe (day, week, month, year, etc.), and d) an electricity market variant (day-ahead, intra-day, energy efficiency certificates market, etc.). This open data is then stored in the DSS database (DB) and is mainly used as input for its algorithms. Following a contractual request for RES electricity by the MO/energy supplier, the DSS platform should be able to respond accordingly by providing RES offers via the aggregation of individual VPs in the residential sector under the umbrella of the VA. The DSS acquires the notification from the MO and a message is also displayed at DSS user's side (CP). In figure 6, day-ahead and intra-day prices examples are given for Sardinia in Italy by the Italian MO [7].

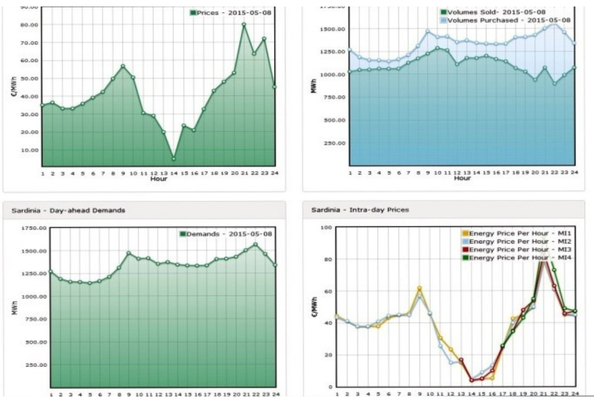

Fig. 6. Examples of Open Data Acquisition from a Market Operator

D. Virtual MicroGrid (VMG) Creation and Management

A VA can use the DSS to create a VMG infrastructure by selecting and configuring a wide range of parameters via the Configuration Panel (CP). The prosumer organization into virtual microgrids (VMGs), consists of intelligent algorithms execution that can provide a host of information to benefit both the VA and its clients, the VPs These information range from: a) the appropriate composition of the microgrid to meet the demand requirements of the MO/energy supplier, b) determination of the optimal timing periods for buying and selling energy in the market, c) to determine what is the appropriate quantity and appropriate price to participate in the market, in a way that maximizes the revenue from producing renewable energy, while d) maintaining a high-standard in security of supply for the energy being traded.

The creation of a VMG association may be subject to regulatory constraints (e.g. the "entry barrier" constraint is used in many countries where a minimum amount of energy is required for a VMG to enter the market). The VA can visualize the results of different VMG infrastructure creation scenarios and compare them to determine to the most efficient one for each type of event. Figure 7 shows various microgrids created by the DSS at a VIMSEN test site in Athens and the VA is able to "edit" an existing VIMSEN association (e.g. add/remove VPs or adapt some VMG configuration parameters). The DSS user can visualize the results in real-time and conclude to an efficient VMG infrastructure that meets all the requirements to satisfy a demand contract and generate a good return for the VPs.

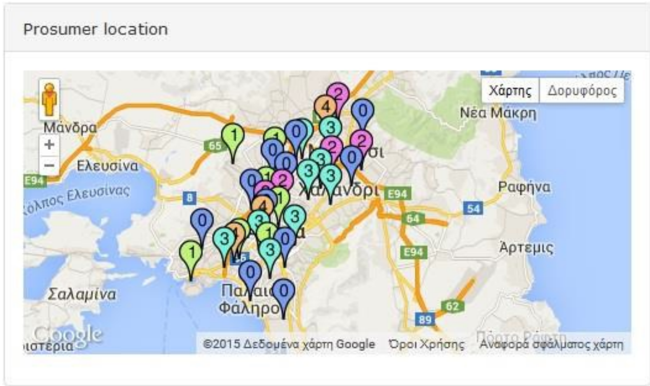

Fig. 7. A Range of Microgrids Created at the Athens Test Site

E. Prosumer Clustering Approach – Genetic Algorithm

The approach used to generate the most appropriate cluster formation (microgrids) in this study is based on a genetic algorithm. This is derived from the definition of a chromosome solving problem related to a specific issue. A fitness function to determine the suitability of each candidate solution is also defined.

E.1 Representation of the Genetic Algorithm

In order to use a Genetic Algorithm for solving the prosumer clustering problem, the genetic representation has to be defined first, i.e. the structure of the chromosome that will be used to solve the optimization problem. In the case of prosumer clustering, each solution has to be represented by a vector of size N, where N is the number of prosumers that are to be clustered into virtual microgrids. Thus, solution S_j may be written as:

$$S_j = \left(g_{j1}, g_{j2}, ..., g_{jN}\right) \quad (1)$$

where $g_{ji} < K$ is the id of the cluster where prosumer k is assigned, and K is the maximum number of clusters.

E.2 Role of the Fitness Function

The role of the fitness function in the genetic algorithm is to determine how good or bad one solution is compared to another. It should be defined in a way so that better solutions have a higher fitness value than worse solutions. The objective of the clustering algorithm is to organise the prosumers into clusters or microgrids in a way that minimizes their costs, by reducing the uncertainty in the estimation of their prosumption, and thus reducing the penalties that they will be charged in case of non-compliance. Thus the fitness of a solution will depend on the percentile improvement in the penalty costs that each cluster in the system may achieve for its prosumers. A microgrid will have the most benefit if it manages to make the term:

$$f_{jk}^{a} = \sum_{t} \sum_{i \in m_k} u(e_i(t)) \tag{2}$$

as small as possible in relation to the term

$$f_{jk}^{b} = \sum_{t} u(\sum_{i \in m_k} e_i(\mathrm{t})) \tag{3}$$

where $e_i(\mathrm{t})$ is the error in forecasting the prosumption of prosumer i for hourly block t, and m_k defines the clustering that is applied, through the following equation:

$$i \in m_k \Leftrightarrow g_{ji} = k \tag{4}$$

Finally, the fitness function is defined as:

$$f(\mathrm{s}_j) = \sum_{\substack{1 \le k \le K \\ m_k \ne 0}} \frac{f_{jk}^{b} - f_{jk}^{a}}{f_{jk}^{b}} \tag{5}$$

There are other functions that need to be taken into account to generate a better clustering formation and to provide other processes. They are briefly described below.

E.3 The Mutation Function

The mutation function is essential for maintaining genetic diversity from one generation of a population of chromosomes to the next one. This method is applied to the genetic algorithm implementation to enable swapping the position of two consecutive genes. It will also enable the use of extreme boundary conditions to check if a better solution can be available on a random basis, if not the algorithm can revert back to the last best fit. This might be useful in solving issues related to congestion in the distribution network.

E.4 The Crossover Function

The crossover function is used to combine two chromosomes (solutions) into a single new chromosome. There are several ways to combine two chromosomes, such as one point crossover, two-point crossover, cut-and-splice, edge recombination, etc. In this study, the two-point crossover is used to combine the chromosomes. According to this method, two random numbers $1 \le x_1, x_2 \le K$ are selected. The new chromosome consists of the first parent's genes, for indexes between x_1 and x_2, and the second parent's genes for indexes outside the above interval. In the VIMSEN context, this might be useful to obtain or replace the outputs from two prosumers into a single one to provide the required demand within a specified period of time.

E.5 Evaluation of Clustering Algorithm

The genetic clustering algorithm performance evaluation has been evaluated using data from 37 prosumers located in Greece. These prosumption data were from real customer and were provided by Intelen [8], a member of the VIMSEN consortium.

The configuration parameters used for evaluating the genetic algorithm were as follows: the initial population was 200 randomly created chromosomes, and the genetic system evolved for 100 generations. The number of clusters was set to 5. The penalty factors p_s and p_v were set to 0.2 and 0.3 respectively where p_s is when the real prosumption exceeds the forecast, and p_v is when the prosumption is below the forecast value. The fitness of the best solution at each generation of the training is shown in Fig. 8. The prosumption data of the week 24/3/3015 to 31/3/2015 was used in to train the clustering algorithm. The clustering that was formed consisted of the allocation shown in Table I.

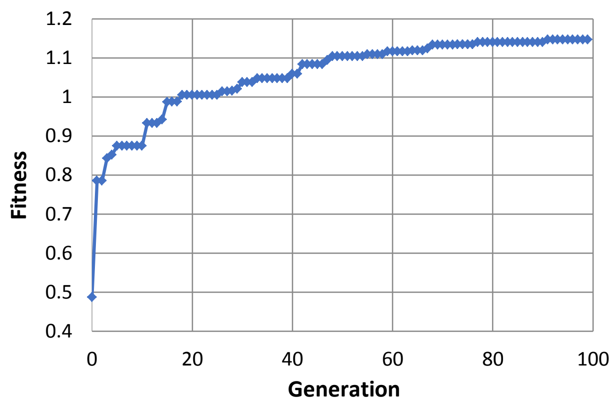

Fig. 8. Evolution of the Genetic Algorithm

Cluster name	Cluster members
Gen 0	16, 22, 25, 26
Gen 1	17, 19, 20, 24, 27, 32
Gen 2	1, 2, 10, 12, 15, 36
Gen 3	11, 13, 14, 31, 33, 34, 35
Gen 4	3, 21, 23, 28, 29

Table 1 .Outcome of Clustering Process using the Proposed Genetic Algorithm

The above clustering arrangement was evaluated using an iterative process generated by the algorithm, over a period of nine consecutive weeks, with new forecast and real prosumption data. For each of the following weeks, the costs according to our model were calculated, based on the clustering that was generated using data from week 0. The results are presented in Figure 9 below.

The performance of the clusters that were created using the genetic algorithm over a limited number of iterations, just to show the process, can be observed over the 5 weeks period following the training, in terms of the percentile reduction in the penalties for each cluster. It can be seen that the penalty reduction is largely retained for the following weeks in most cases. The higher reduction that is observed in this experiment reaches up to 50%, whereas even in the worst case scenario, a positive reduction of a few percentage points was observed. The results can be improved by running a larger number of iterations and getting the optimum number needs further investigation.

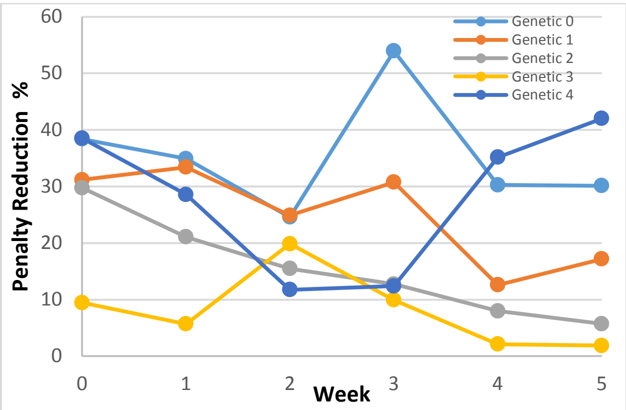

Fig. 9. The penalty reduction of each cluster for the weeks following the training period

V. Conclusions

The principal components of the VIMSEN system were presented and the functionalities identified. The innovative decision support platform as part of the VIMSEN system was presented and analysed for optimizing the participation of small domestic energy prosumers into the distributed electricity market through future smart grid. The components of the DSS were presented and one associated algorithm used for this study was highlighted. The operation of the platform's capabilities was shown for a particular application to create generic clusters or microgrid through the use of the genetic algorithm, with the aim to reduce penalties caused by forecasting errors. The outcome of the DSS, using real data from a group of prosumers in Greece, resulted in the creation of clusters that could meet a contracted demand requirement while optimizing the profit generated for the prosumers and minimizing the penalties in case of non-compliance.

The study to date is only in its initial stages and future work aims to integrate in this ICT platform on larger set of real prosumers' data combined with more complex power demand requirements from MOs/service providers. A larger range of algorithms will also be investigated to find a better fits for the creation of clusters/microgrids to increase the benefit of small domestic prosumers to a higher level. The integration of real weather data to gauge prosumption measurements will also be implemented and this will hopefully increase the accuracy of the forecast which in turn will help in the formation of the desired microgrids to meet a contractual energy demand requirement.

Acknowledgment

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