Demand Dispatch Framework for Smart Distribution Grids

Nicoleta ARGHIRA, Iulia STAMATESCU, Ioana FĂGĂRĂȘAN, Grigore STAMATESCU, Vasile CALOFIR, Sergiu Stelian ILIESCU
Faculty of Automatic Control and Computers, University "Politehnica" of Bucharest
Bucharest, Romania

{nicoleta, iulia, ioana, grig, vasile, iliescu}@shiva.pub.ro

***Abstract*—The paper presents the new concept of demand dispatch at the distribution level, in addition to generation dispatch. It benefits of new communication capabilities and computation knowledge to support the introduction of strategies that modify the demand according to relevant objectives. The properties of demand dispatch are clearly defined, as well as the characteristics of smart distribution networks. A critical analysis on demand response/ dispatch strategies was conducted. Consumer energy modelling for dispatchable loads with artificial intelligence methods (e.g. C4.5 decision tree) is presented. This is a prerequisite for load shaping forecast at a general scale, for the distribution level. The proposed demand dispatch framework brings benefits for distribution system operators in terms of supply flexibility and economic advantages.**

Keywords*—*smart distribution grid; demand dispatch; smart metering; demand-side control

I. INTRODUCTION

In the power system, the challenge of maintaining system adequacy is more and more difficult to achieve. At some periods of the day (e.g. load peak) or year (e.g. bad weather conditions - drought), the energy demand needs cannot be satisfied or it is expensive to satisfy by generation. Traditionally, this situation was solved by load shedding. But this method is a drawback for the consumers. With the technology advances and communication protocols development, new load control solutions can be reached. One of the major challenges is to exploit these new capabilities and knowledge to support the introduction of strategies that modify the demand according to relevant objectives.

An analysis of the final end-use of energy in the EU-28 in 2014 shows three dominant categories: namely, transport (33.2 %), industry (25.9 %) and households (24.8 %), [1-2]. Fig. 1 shows the distribution of demand by sector and an important part is represented by dwellings. Therefore, households and services sector occupies an important share in the energy consumption mix (38 % - EU countries) and the focus on controlling the electrical demand in these sectors deserves attention.

The electrical grid is moving from a load-following to a load-shaping strategy, [3] and the issues that occur with this change must be addressed. In this context, methods to control the demand side resources should be developed and more concepts were defined lately: demand dispatch, demand response and demand side management.

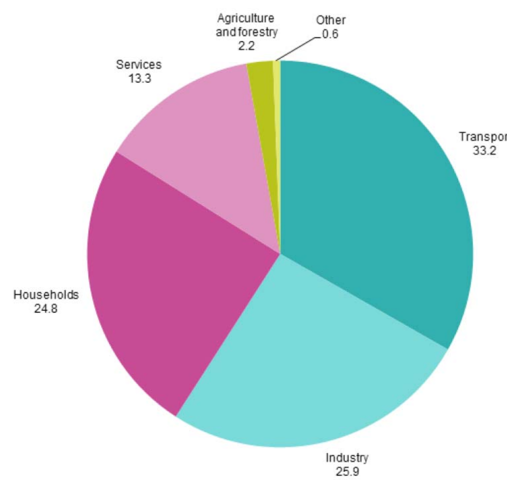

Fig.1. Final end-use of energy distribution in 2014 in EU-28, [1]

The concept of demand dispatch (DD) appears as a complement to the supply dispatch since the later relies on "generation following the load" while demand dispatch allows "load to follow the generation" enabling full optimization of both supply and demand.

DD refers at "control behind the energy meter" for several resources: renewable power produced by the consumer, energy storage and controllable loads. Demand dispatch represents a possible end state that can optimize grid operations beyond what can be achieved with Supply Dispatch alone, [4]. Demand response (DR) includes both modifications of peak electricity consumption in response to price and the implementation of more energy efficient technologies by consumers with installed smart meters. Demand side management (DSM) involves programs and activities in the energy market that shape the consumers' purchase pattern of electricity. These three concepts are overlapping at some point and they all have the goal of controlling the energy/electricity demand.

The issue of finding control solutions for energy demand should be tackled in the present context of a growing electricity consumption corroborated with an insufficient classical generation and a fluctuating production from renewable resources. Distribution system operators (DSO) can benefit directly from this control capabilities on the end-user.

II. Demand Dispatch Strategies in Smart Distribution Grids

A. Smart Distribution Grids

The concept of smart grid influences each level of the power system. At the distribution level, the notion of *smart distribution grid* appeared. Conventionally, DSO responsibilities involved, [5]:

- Distribution equipment monitoring;
- Load curve control for incident prevention (load curtail);
- Optimization of low and medium voltage equipment operation;
- Automatic voltage control in distribution grid;
- Micro hydro power plant control;
- Operation planning, analysis and simulation outside real-time.

With the benefits of modern IT&C capabilities (bidirectional communication with the customer, numerical protection and automation systems, real-time computation), more functions can be added to the distribution management system (DMS), such as:

- Demand dispatch with control on load shaping (load shedding just in emergency cases);
- Real-time analysis and simulation of the distribution grid;
- Distributed generation operation control for the units connected at the distribution level etc.

This paper will consider such a smart distributed system operated by a DSO prepared to apply dispatch control for users in the residential and services sector. A state of the art in this area was conducted and two main types of control can be defined at this level:

- Direct Load Control (DLC): user loads are controlled in a direct manner if they have the proper infrastructure. Some of their loads can be remotely stopped.

- Indirect Load Control (ILC): consumers modify their consumption behavior deliberately.

B. Direct Load Control

Direct load control can be achieved through different technologies. Peak clipping involves demand reduction at periods of system power peak. [6] presents a method for battery energy storage system use for peak shaving for a consumer with photovoltaic panels as well, [7]. Load shifting methods modify the time of consumption such as the load is moved during off-peak periods. [8] proposes a multi-agent model predictive control scheme for thermal house comfort and energy savings through load shifting. A similar multi-agent approach framework based on load shifting is proposed in [9] and it is applied on singular dwellings or office buildings. This approach is limited to household and it does not provide solutions at a larger scale for the distribution grid.

C. Indirect Load Control

One of the ILC methods is the control by energy price (alternative electricity price, incentives) and deliberate consumer demand reduction. The role of cost control is to change the load curve shape in such a way that energy consumption peak decreases, even though the total consumption for the specific household is the same. This mechanism involves increasing the prices for energy at peak periods.

Valley filling is another method for load shifting and it involves augmenting the load demand in off-peak periods (considered load curve “valley”, periods with low demand).

ILC is preferred to DC by the consumers because it is more acceptable to decide if the resident will turn off an electrical device than to accept the automatic stop of an appliance by a distribution dispatcher. Still, this happens mostly in the case of residential houses, but for a commercial building, if the economic gain is attractive, the administrator can agree on a remotely action of the dispatcher for delay or curtail of the electrical supply.

III. Energy Monitoring and Modelling

A. Energy Smart Metering

Demand dispatch measures cannot be applied without a proper energy metering system that allows double - way communication between the consumer and the energy supplier. Considering the households and services sector, energy metering consists mostly of monitoring of electricity consumption in buildings, [10-11].

The monitored energy data is useful for both user awareness and it can also be valuable for demand dispatch control strategies validation.

An energy metering device, based on Raspberry Pi 3, will be used for acquisition of energy data in an office building. Fig. 2 shows the eMonPi3 device that allows measures for several electrical parameters such as current, voltage, active power, energy consumption etc. Several loads can be monitored in a building since this device allows the measurement with maximum 4 current sensors. Table I presents the electrical characteristics of the equipment.

The system transmits data through Wireless technology with a 5 minutes’ sample time to an online platform (https://emoncms.org/vis/list), Fig. 3.

TABLE I. eMonPi3 Electrical Characteristics

Function	***Recom. Min***	***Recom. Max***
CT 1-2	-	23kW
3.3V Rail current output	-	150mA
5V Input Voltage	+3.4V	+6V
3.3 Supply Voltage	2.6V	3.3V
Power consumption	7mA no RasPi - 14mA RasPi Halted	300mA RasPi idle

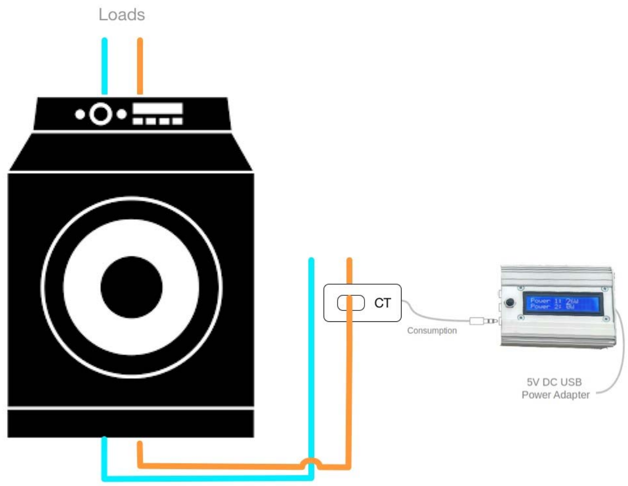

Fig. 2. Energy monitoring system

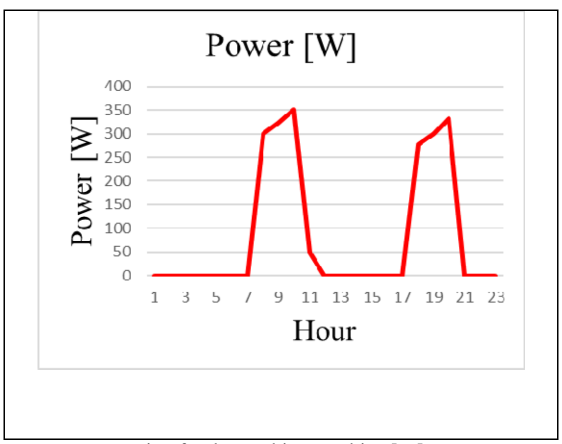

Fig. 3. Power consumption for the washing machine [W]

B. *Energy Modelling for Demand Dispatch*

Demand dispatch strategies involve load prediction for the end-users enrolled in such programs. In this context, the energy modelling will consist of consumers' energy prediction. Day-ahead load forecast at a time scale of one hour can be done and it can be sufficient for demand dispatch measures.

This short time prediction is performed daily in order to feed the dispatch algorithm. The prediction methodology includes a historical database, a knowledge based expert system and a C4.5 decision tree predictor, as proposed in [12].

The forecast goal is to determine if an electrical device is consuming or not at a certain hour during the 24 next hours. The attributes used for computing the results are as follows:

- *Past 24 hours'* consumption (0 for no consumption and 1 for when the appliance is started at a certain hour).
- *Hour* (0, 1, 2, …, 23);
- *Day* (Sunday, Monday, …, Saturday).
- *Season* (1 for spring, …, 4 for winter).
- *Month* (1, 2, … 12)

Since the classification methods have discrete/binary results, the computation of load value is done considering the following formula:

$$P(h) = pr(h) * \overline{P} \tag{1}$$

where $pr(h)$ is the computed forecast (0/1) and $\overline{P}$ is the mean value for nonzero values of the load.

Fig. 4. presents the result for load curve prediction for a washing machine in a residential building compared to real values. The load curve forecast was conducted and validated for a full year of historical data and the prediction performance was 92%. This historical data was previously gathered through IRISE database since the energy monitoring system presented in Fig. 2 has just been installed and the available data is not sufficient for training.

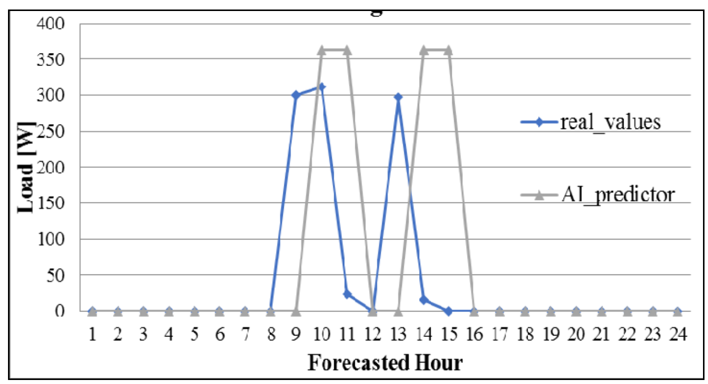

Fig. 4. Load curve prediction/modelling validation

IV. Demand Dispatch Framework for DSO

A. *Distribution grid – consumer interaction*

A methodology in 7 steps for the interactions between the three involved actors in the Demand Dispatch (DSO, consumer and energy market) is depicted in Fig. 5. This diagram was developed based on the direct control interaction between the smart grid, the smart home and the energy market in [13].

First, based on short time energy forecast, DSO computes the global energy demand in order to ask for the energy market price. Then, it computes load – resources allocation through an optimization algorithm that considers energy price and users DD consumption programs. The optimization objective is to minimize the DSO energy costs, [14].

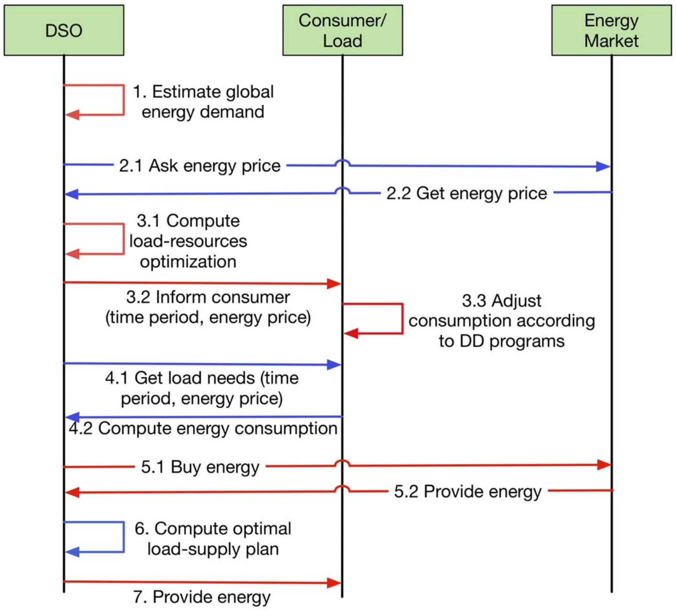

Fig. 5. Smart distribution grid interactions

After computation, the utility informs the user on the energy price and the latter adjusts its consumption. Depending on the demand dispatch user response, the new energy demand is calculated and it is bought from the energy market. The optimal supply-load plan is applied and the consumers get the best price-preference energy price.

B. Demand Dispatch Schema for DSO

The electrical distribution network has 2 reliability indicators:

- System Average Interruption Duration Index (SAIDI) is the average outage duration for each customer served.
- System Average Interruption Frequency Index (SAIFI) is the average number of interruptions that a customer would experience.

These indexes consider the global load of the consumer. The DSO goal is to minimize the values of SAIFI and SAIDI. With demand dispatch programs, a repartition of the load is possible and each consumer can be treated individually. The chance of user power curtailment is significantly reduced.

Further, the development of a dispatch control algorithm for load into the distribution network based is presented. This control algorithm will be based on an adequate electricity demand prediction and optimal allocation of users' resources accounting also several influential factors: energy market prices, technical considerations (safety of the grid, possible congestions), user comfort demands. The consumers involved in demand dispatch control should be able to adjust (reduce, move etc.) at least 500W.

Fig. 6. shows a global framework for demand dispatch control and optimization for a distribution system operator. Generally, the consumer is only sensitive in load reduction or load moving when economic benefits occur.

Two types of user load control are proposed: incentives in periods of peak consumption and a flexible price, defined hourly. DSO can provide ***incentives*** during 2 - 4 hours a day, but not necessarily each day in ***periods of peak demand***. The users involved in such programs will provide the period of the day when they could shed the power, the quantity of energy willing to shed and the value of the incentive. The options of the users can be provided to the DSO seasonally (each 3 months).

During demand dispatch, the *energy price will fluctuate hourly* based on demand - supply balance and energy market price. The consumer will set at the beginning of the month the quantity of energy to be shifted, the period and the minimal price for which the moving of the load curve will be conducted.

Based on the two types of dispatch control, the DSO energy management system will conduct a supply optimization based on energy price (provided by energy market), consumer preferences and the quantity of available demand side resources.

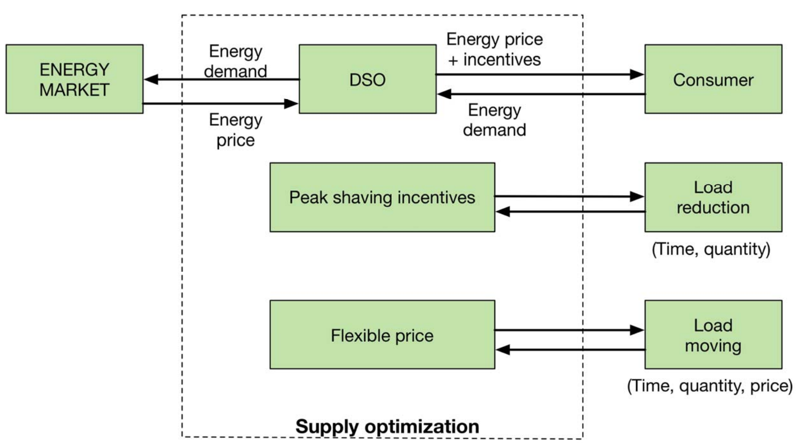

Fig. 6. Demand dispatch control framework

V. CONCLUSIONS

The paper presents the new concept of demand dispatch at the distribution level, in addition to generation dispatch and several paradigms are defined. Load control approaches are critically described. Load modelling and monitoring are practically illustrated and validated.

The proposed demand dispatch control algorithm can have a practical implementation for consumers with a minimum of 500W to vary (shed, shift) and for dispatchable electrical devices such as air conditioning, auxiliary lighting, battery charging, washing machines, clothes dryers, electrical vehicles. Two types of user load control are proposed: incentives in periods of peak consumption and a flexible price, defined hourly.

Based on the two types of dispatch control, the DSO energy management system will conduct a supply optimization subject to energy price (provided by energy market), consumer preferences and the quantity of available demand side resources.

ACKNOWLEDGMENT

This work has been funded by University Politehnica of Bucharest, through the "Excellence Research Grants" Program, UPB – GEX. Identifier: UPB–EXCELENȚĂ–2016 through Research the following projects: "Demand dispatch in an Electrical Distribution Grid", no 21/26.09.2016 and "New Dynamic Consensus Algorithms for Building Thermal Energy Management (CONSENSYS), Contract no 20/26.09.2016.

REFERENCES

[1] Eurostat Report, "Consumption of energy", website: Statistics Explained 20/12/2016: http://epp.eurostat.ec.europa.eu/statisticsexplained/, 2016

[2] P. Bertoldi and B. Atanasiu, Electricity consumption and efficiency trends in the enlarged European Union, ISBN 978-92-79-05558-4, Italy, 2007

[3] A. Brooks, E. Lu, D. Reicher, C. Spirakis and B. Weihl, "Demand Dispatch", IEEE Power and Energy Magazine, Vol. 8, Issue 3, ISSN 1540-7977, pp 20 – 29, 2010

[4] C.W. Gellings, "Evolving practice of demand-side management", Journal of Modern Power Systems and Clean Energy, pp 1–9, DOI 10.1007/s40565-016-0252-1, 2016

[5] ***, Transmission Network Technical Code, Romania, 2004

[6] Y. Yang, H. Li, A. Aichhorn, J. Zheng and M. Greenleaf, "Sizing Strategy of Distributed Battery Storage System with High Penetration of Photovoltaic for Voltage Regulation and Peak Load Shaving", IEEE Transactions On Smart Grid, Vol. 5, No. 2, March 2014

[7] F.A. Barata, J.M. Igreja and R. Neves-Silva, "Demand Side Management Energy Management System for Distributed Networks", Springer - Technological Innovation for Cyber-Physical Systems, eISBN: 978-3-319-31165-4, pp 455-471, 2016

[8] H. Yan, B. Li., S. Chen, M. Zhong et al, "Future evolution of automated demand response system in smart grid for low-carbon economy", Journal of Modern Power Systems and Clean Energy, vol 3(1), pp 72–81, DOI 10.1007/s40565-015-0103-5, 2015

[9] M. Shin, S. So and K. Kim, "A control approach of battery energy storage systems to reduce kW demand", Proc of 2016 Int. Conf. on Industrial Engineering and Applications (ICIEA), vol. 68, 2016, DOI: 10.1051/matecconf/20166810001,

[10] I. Opris, S. Costinas, C. Ionescu and D. Nistoran, "The household energy consumer in a smart metering environment", Proc of 9th Int. Symposium on advanced topics in electrical engineering, pp 43-48, 2015

[11] G. Stamatescu, I. Stamatescu, C. Dragana, D. Popescu, "Large Scale Heterogeneous Monitoring System with Decentralized Sensor Fusion", Proc. of 2015 IEEE 8th International Conference On Intelligent Data Acquisition And Advanced Computing Systems: Technology And Applications (IDAACS), VOLS 1-2, pp: 2-5, 2015

[12] N. Arghira, S. Ploix, I. Fagarasan, S.S. Iliescu, "Forecasting Energy Consumption in Dwellings", Advances in Intelligent Systems and Computing, Volume: 187 Pages: 251-264, 2013

[13] Basu, K., Hawarah, L., Arghira, N., Joumaa, Ploix, S., A prediction system for home appliance usage, ELSEVIER Journal Energy and Buildings, ISSN: 0378-7788, eISSN: 1872-6178, vol 67, pp 668-679, 2013

[14] I. Stamatescu, G. Stamatescu, N. Arghira, I. Fagarasan, "Fuzzy decision support system for solar tracking optimization", Proceedings of Development and Application Systems Conference (DAS), pp 16-20, 2014