Piotr POWROŹNIK[1]

University University of Zielona Góra, Faculty of Computer, Electrical and Control Engineering, Institute of Metrology, Electronics and Computer Science (1)

doi:10.15199/48.2016.12.53

Reduction of peak demand in micro smart grid by means of elastic model of power management

***Abstract**. In this paper the idea of elastic model of power management in micro smart grid is presented. For the proposed model a method for reducing peak demand in micro smart grid has been defined. In addition, the algorithm of evaluation of the power values selection for nodes, which may be a renewable source of energy in the micro smart grid, is outlined. The idea of powers management presented in the article can be used not only in the micro smart grid networks, but also in the smart grid.*

***Streszczenie.** W artykule przedstawiono ideę elastycznego modelu zarządzania mocami w sieciach mikro smart grid. Dla zaproponowanego modelu określono sposób redukcji zwiększonego zapotrzebowania na moc (ang. peak demand) w danej sieci mikro smart grid. Ponadto przedstawiono algorytm oceny redukcji mocy w węzłach sieci mikro smart grid, które mogą stanowić odnawialne źródła energii. Przedstawiona idea zarządzania mocami może znaleźć zastosowanie nie tylko w sieciach mikro smart grid, ale również smart grid. **(Zastosowanie elastycznego modelu zarządzania mocami w sieciach klasy mikro smart grid w celu redukcji zjawiska peak demand**).*

Keywords: smart grid**,** peak demand, smart metering, electricity consumption
Słowa kluczowe: inteligentna sieć, zwiększone zapotrzebowanie na moc, inteligentne pomiary, zapotrzebowanie na moc

Introduction

The complex structure of current energy systems (ES) makes ensuring the reliability of power supply a difficult task [1, 2]. In such structures, in addition to conventional power plants, sources whose energy is obtained from renewable energy sources (RES) may also be attached. Energy from RES can be supplied to the ES from a variety of sources e.g. photovoltaic or wind energy generation. Ensuring the correct functioning of the ES is realized by advanced metering infrastructure (AMI) [1]. Two-way communication in ES [2, 3] between measurement - control devices, referred to as nodes, makes it possible to increase the level of reliability, availability and security of the supply of electricity to customers. A set of nodes, for which mutual communication AMI is applied, creates a smart grid (SG). SG network equivalent of a smaller scale, often territorially limited with local range is a network of micro smart grid (MSG). MSG may be composed of a network type of Home Area Network (HAN). Building management systems (BMS) are usually grouped together in HAN networks. A BMS consists of software and hardware. Such a combination is used for controlling electronic systems installed in buildings. BMS can affect smart appliances, system of water and gas, heating, ventilation, air-conditioning and refrigeration system (HVAC&R), lighting control system, irrigation system, monitoring and building security system. Application of AMI in SG and MSG, in addition to ensuring the functioning of these systems, gives primarily the possibility of power management. Such functionality is particularly useful in time of change (anticipated or unpredictable) of energy supply or demand. The changes of increased energy consumption have an increasingly wide range and are referred to as peak demand (PD). PD results from the current level of civilization, which is facilitating the everyday life involving the use of more and more consumers of electricity.

In the article [4] for selected Italian households the time of day during which PD may occur most often was identified (from 7am to 10am and from 5pm to midnight with the beginning of the stabilization of energy consumption from 8pm). Energy consumption optimization by PD shaving [5] is possible by means of planning the performance of specific tasks at certain time, for example: telephone use, hand washing, meal preparation, eating and medication use, and cleaning. For this purpose, the authors propose the use of hidden Markov models (HMM) to describe activities. The idea of planning the activation of the power consumers is also presented in [6,7].

Topic of energy modeling of a single machine (SM) has also been described in [8]. Energy modeling algorithm is described by the finite state machine (FSM). Start and end of individual states of SM are dependent on the current price of electricity. Failure of SM is also taken into account. The proposed solution [8] does not include the possibility of cooperation with other SM by means of AMI.

The ability to predict occurrence of PD for a given group of power consumers has been developed [9,10,11]. Prediction by means of Artificial Neural Network (ANN) [11] is most often performed for the following time intervals: 15-minute, hourly or daily.

In the article [12] a similar approach to energy management, as in the case [11] has been presented. The idea of the presented solution is based on the planning of calls of electricity consumers, with the schedule of their work. Authors combined the idea of ANN for Building Energy Management with Genetic Algorithm based optimization. In the presented approach [12], apart from the electricity consumers, photovoltaic and wind energy generation has also been included.

In the literature, there are also other proposal dedicated to energy management for BMS. The results of simulation studies for HVAC&R control are presented in [13]. The study was conducted for the BMS model developed by the authors. The model takes into account other data such as historical energy demand for the HVAC&R, architecture and geometry of the building and the current weather information. Verification of the model was made for the five algorithms: ANN, support vector regression (SVR), least-square support vector machine (LS-SVM), Gaussian process regression (GPR) and Gaussian mixture model (GMM). Apart from work [13], there are also other publications [14,15] available concerning the subject of BMS. The publication [14] proposed the concept of energy profiles which provide the ability to control each BMS. In the article [15] stochastic demand for electricity by the consumers belonging to different classes of energy efficiency in different seasons was modeled.

In the literature, a lot of space has been devoted to the issue of energy management (especially in recent years). Each proposal is most often a solution for a particular case. In some works RES are taken into account as photovoltaic and wind energy generation. Results from RES are, however, presented for places on Earth, where uniform climatic conditions prevail for most of the time. It is also necessary to take into account energy storage due to the unpredictable nature of the availability of energy in other places on Earth. In this case it is possible to use a prosumer approach. In this case, the ES would be energy storage. The choice of prosumer approach should be preceded by an analysis of legal regulations in each country. The difference between the cost of energy purchased and profits of energy sold to ES should be taken into account. In some cases, particularly in the long term, the purchase of own energy storage could appear to be more economically profitable than the prosumer approach.

An alternative to the presented power management solutions may be to use of the elastic model of power management (EMPM) [16].

Elastic model of power management

The main purpose of EMPM is to prevent PD by means of the balance between demand and supply of power, at any given time, for a given MSG. Maintaining the balance in EMPM is performed by selecting power values at the MSG power nodes. The power selection is performed between: appliances (A), storages (S) and generators of power (G). In the case of A, by using AMI, it is possible to control power consumption. The A node can be controlled in a two-stage manner (on/off). In more advanced A nodes there is a possibility to partially reduce the power to a preset level. An example of A node may be the air conditioner, which reduces power by reducing cooling efficiency. S nodes serve as a buffer to store excess power available in MSG. An example of G node can be a conventional energy supplier from which it is possible to purchase and provide the missing power at a given moment. The power from G node may also be available in a not controllable way when the G is a RES. In order to describe each node into MSG for EMPM the following parameters were introduced:

(1) $<P_{A\_MIN}, P_{A\_NOM}, W_A, P_{G\_MAX}, W_G, P_{S\_DIS}, P_{S\_LOAD}, W_S>$

where: P_{A_MIN} – the minimum value of power, for which in a case of reducing the power, the node will continue to work correctly. A value of zero would indicate that the node can be turned off completely, P_{A_NOM} – nominal value of the power which is charged by the A, W_O – determines the cost reduction of 1 kW of power for A. The cost is defined as the loss of benefits for example from delay to complete a task by A, P_{G_MAX} – for each G maximum power available, W_G – maintenance costs and the costs of power generation in the G node. The cost for the G node is calculated on the basis of the cost of obtaining 1 kW from a power source in the MSG, P_{S_DIS} – maximum power available for a given S, which can be designed for example to balance the supply and demand of power in MSG, P_{S_LOAD} – power that node S could take at a given moment, W_S – the cost of discharging S node possible to define as a price. The value is determined on the basis of the node S maintenance amortization. The cost takes into account the need to replace S after reducing the efficiency resulting from charging and discharging cycles.

At this stage it is assumed that in the MSG determination of the supply and demand for power will be designated by means of coefficient U:

$$U = \frac{\sum_{i=0}^{N_A} P_{A\_SEL_i} + \sum_{l=0}^{N_S} P_{S\_SEL\_LOAD_l}}{\sum_{j=0}^{N_G} P_{G\_SEL_j} + \sum_{k=0}^{N_S} P_{S\_SEL\_DIS_k}} \tag{2}$$

where: i, j, k, l – MSG nodes index, N_A, N_G, N_S – MSG appliances, generators and storages numbers, P_{A_SEL}, P_{G_SEL} – for the A, G selected power, $P_{S\_SEL\_DIS}$, $P_{S\_SEL\_LOAD}$ – for the S node selected discharging or charging power.

The value of coefficient $U > 1$ will mean that the MSG demand is greater than power supply. In order to restore balance new power setting for all MSG nodes (P_{A_SEL}, P_{G_SEL}, $P_{S\_SEL\_DIS}$, $P_{S\_SEL\_LOAD}$) should be selected. The choice should be made with EMPM so as to decrease the value of coefficient U. The value of coefficient U must be less than or equal to 1.

The selection of each of the power values in EMPM is implemented in two stages. In the first step, power increase occurs for G and S nodes. If maximum values (P_{G_MAX} and P_{S_DIS}) for all G and S nodes do not allow to balance supply and demand for power, then second stage is performed. During this step, the power is reduced for A nodes. The algorithm is divided into two phases so that the receivers are off only when it is not possible to provide power from all possible sources.

The existence of multiple combinations of selection of individual power values (class of NP hard problems [16]) lead to elaboration of fitness function Or:

$$Or = Or_A + Or_S + Or_G \tag{3}$$

where:

$$Or_O = \sum_{i=0}^{N_A} \frac{W_{A_i} \cdot \left(P_{A\_SEL_i} - P_{A\_NOM_i}\right)}{P_{A\_MIN_i} - P_{A\_NOM_i}} \tag{4}$$

$$Or_S = \sum_{k=0}^{N_S} W_{S_k} \cdot P_{S\_SEL\_DIS_k} \tag{5}$$

$$Or_G = \sum_{j=0}^{N_G} W_{G_j} \cdot P_{G\_SEL_j} \tag{6}$$

A smaller the fitness function Or value from formula (3) means economically more advantageous balance between supply and demand for power.

Reduction of PD by means of EMPM

The article presents the idea of EMPM for a sample MSG network. This MSG, despite the small number of nodes, makes it possible to provide a method to solve the PD problem with the use of EMPM.

In the MSG five nodes performing the role of power receiver (A_1, A_2, ..., A_5) were defined. List of A nodes parameters for a sample MSG is shown in Table 1.

Table 1. List of A nodes parameters for an exemplary MSG

	A_1	A_2	A_3	A_4	A_5
P_{A_MIN} [kW]	20	0	4	5	0
P_{A_NOM} [kW]	25	10	5	15	20
W_A [PLN]	1.00	0.10	10.00	5.00	0.01

For A_2 and A_5 nodes were allowed to be completely disabled. For other A, due to the stability and comfort of using the MSG, it is only possible (in a given scope) to reduce their power. Reduction of power in order to obtain the $U \leq 1$ can be carried out for all A. Due to the value of the fitness function Or (3) reduction should start from the A node with the lowest W_A value.

Delivery of power in an exemplary MSG will be implemented by means of nodes: G_1, G_2 and G_3. G_1 and G_2 nodes make RES, for which the available power will vary depending on weather conditions. List of G nodes parameters for a sample MSG is shown in Table 2.

Table 2. List of G nodes parameters for an exemplary MSG

	G_1	G_2	G_3
P_{G_MAX} [kW]	8	6	35
W_G [PLN]	1.00	0.50	2.00

On the basis of the parameters in Table 2 it can be concluded that G_3 node is able to provide most of the most expensive power. The least but the cheapest power can be achieved from G_2.

The S_1 node is provided to store excess power produced by G_1 and G_2 (Table 3). The power from S_1 node, can also be taken away if its demanded.

Table 3. List of S node parameters for an exemplary MSG

	S_1
P_{S_DIS} [kW]	5
P_{S_LOAD} [kW]	2
W_S [PLN]	3.00

The S_1 node is the most expensive source of power in comparison to the single G (Table 2). In this case the cost of purchase and operation of the S_1 was also included.

Table 4. Schedule delivery and receiving power by the individual nodes in the example MSG

	00:00	01:00	02:00	03:00 MP_1	04:00	05:00 MP_2	06:00
$P_{A\_SEL_1}$ [kW]						25	25
$P_{A\_SEL_2}$ [kW]							
$P_{A\_SEL_3}$ [kW]	5			5			5
$P_{A\_SEL_4}$ [kW]	15	15	15	15	15	15	
$P_{A\_SEL_5}$ [kW]	20	20	20	20	20	20	
$P_{S\_SEL\_LOAD_1}$ [kW]							
$P_{S\_SEL\_DIS_1}$ [kW]	5						
$P_{G\_SEL_1}$ [kW]							
$P_{G\_SEL_2}$ [kW]							
$P_{G\_SEL_3}$ [kW]	35	35	35	35	35	35	30
U	1	1	1	1.14	1	1.71	1

On the basis of parameters of different types of nodes A (Table 1), G (Table 2) and M (Table 3) an example of six hour delivery and collection power schedule (Table 4) is shown. For each enabled A, P_{A_SEL} value equals the P_{A_NOM} value (Table 4). In this way, a normal operating mode for A node without power reduction has been illustrated. A characteristic feature of A_3 is the periodicity of the switch and power consumption. Node S_1 provides power only at 0:00 am. Later S_1 node, due to the discharge, cannot be used as a power source. The G_3 node may be equivalent for example of a conventional energy supplier. Power would be purchased from the node G_3 depending on the needs. On the basis of the supposition (Table 2), more than 35 kW of the power cannot be bought from the G_3 node .

In Table 4 two mark places (MP) in which PD occurs are indicated. PD does not occur for the remaining time in the sample MSG, because from formula (2), U = 1. Later in the article, analysis was carried out by means of EMPM, for defined MP. The analysis was performed only for the chosen, often intuitive, selection of power. Selected choice of power has been marked as power selection scenario (SC). The analysis was restricted only to selected SC due to the complexity of the combinatorial problem. For all possible SC it would be required to use additional tools to solve the problems from the NP difficult class [16].

PD occurs in the case of MP_1, because the value of $U \approx$ 1.14. The power supplied from the S_1 and G_3 is not sufficient for the needs of A_3, A_4 and A_5. On the basis of the approaches presented in the literature [5-11], it would be possible to avoid PD in the example MSG by the postponement of the run of the A_5 node. In EMPM two stages will be carried out in order to avoid the PD (as described in the previous section of the article). The first step of EMPM for MP_1 does not provide a full solution of PD, because, on the basis of the schedule in Table 4, it is not possible to gain power from the S_1, G_1 and G_2 nodes. Whereas the G_3 node will not be able to deliver the missing 5 kW in this case.

The principle of operation of the second stage of EMPM was presented on select four scenarios SC (Table 5). Table 5 presents: $P_{A\_SEL_3}$, $P_{A\_SEL_4}$ and $P_{A\_SEL_5}$ with the Or function values designated from the formula (3).

For SC_1, SC_2 and SC_3 the power reduction was performed, until U = 1 was obtained from formula (2). In SC_1 power was reduced for the A_3 and A_4. In SC_2 power was reduced only for the A_4 node, and for SC_3 power was reduced only A_5 node. Elimination of PD in MP_1 was achieved at the same time for the SC_1, SC_2 and SC_3.

Table 5. The selection of power for an exemplary MSG, with the designated Or values for MP_1

	SC_1	SC_2	SC_3	SC_4
$P_{A\_SEL\_3}$ [kW]	4	5	5	4
$P_{A\_SEL\_4}$ [kW]	11	10	15	5
$P_{A\_SEL\_5}$ [kW]	20	20	15	0
$P_{G\_SEL\_3}$ [kW]	35	35	35	9
Or [PLN]	82.00	72.50	70.00	33.01

Comparing the individual values of the fitness function Or for the SC_1, SC_2 and SC_3 from formula (3), it can be concluded that SC_3 is the most favorable for final selection of power out of the three presented SC. In this case, the smallest W_{A_5} value at maximum power reduction for the A_5 node was decisive.

The scenario SC_4 is a special case due to the fact that power has been reduced to a P_{A_MIN} value (Table 1) for all three A. Reduction of power demand by A made G_3 node no longer necessary to provide the maximum available power P_{G_MAX3}. From the formula (3) the value of the fitness function Or for the SC_4 reached its lowest value, because despite the cost of power reduction for the consumers, it reduced the cost of purchasing power from the G_3. The example of SC_4 is presented as a special case to prove the necessity of the occurrence of two stages in the EMPM. From the cost point of view it is better to get everything off and then less power would need to be bought. But from the point of view of functionality and comfort of use of the MSG, it is better to first determine when and where energy is available, and then only turn off or reduce the power of individual A.

PD occurs in MP_2 (as previously in MP_1). This time, from formula (2) U ≈ 1.71. Table 6 presents results for power selection of individual nodes for the next two scenarios SC_5 and SC_6 for MP_2.

Table 6. The selection of power for an exemplary MSG, with the designated values of Or for MP_2

	SC_5	SC_6
$P_{A\_SEL\_1}$ [kW]	20	25
$P_{A\_SEL\_4}$ [kW]	5	10
$P_{A\_SEL\_5}$ [kW]	10	0
$P_{G\_SEL\_3}$ [kW]	35	35
Or [PLN]	76.01	72.51

In SC_5 power reduction was started from A_1 and completed on A_5 (to obtain from formula (3) $U \leq 1$). In the SC_6 reduction was carried out in the reverse order relative to the SC_5. Comparing the criteria for assessing the of selection power (fitness function Or) in the scenarios SC_5 and SC_6, selection of SC_5 was preferred.

Summary

The article presents the idea of EMPM together with an analysis of each SC enabling a reduction of PD in an exemplary MSG.

Reduction of PD occurs after applying EMPM, as a result of the modification of power settings for the individual nodes of MSG, so as to balance at the moment the demand with the supply of power. An advantage of EMPM, in comparison with other approaches known in the literature, is usually no need to completely disable A to reduce PD. The idea of EMPM may also find applications for the SG. The presented results of the work [17] suggest the possibility of application of EMPM also in SG or MSG, in which not all the nodes are provided with AMI. Identification of the power receiver, for which it is not possible to provide measuring and control functions, would mean a node with the immutable parameters in EMPM.

If there is more than one solution (SC), which allows PD reduction, the use of the idea of EMPM gives the ability to choose such SC, which is the most advantageous from an economic point of view. Such a choice is performed by determining the fitness function Or from formula (3). The smallest value of Or, for the SC, is the best choice.

Despite the presentation and choice of one SC (both in Table 5 and Table 6) all the other possible combinations of final power selection for each MSG node could not be verified. Manual analysis of all the possible cases would be difficult due to the difficult nature of the NP hard problem. For this purpose, it is reasonable to use, for example, heuristic algorithms to search and evaluate different power selection for each node in EMPM.

In the future, due to the complexity of the problem of class selection of individual power values in EMPM, it is planned to use heuristic algorithms, Max plus algebra and neural networks.

***Author**: dr inż. Piotr Powroźnik, University of Zielona Góra, Faculty of Computer, Electrical and Control Engineering, Institute of Metrology, Electronics and Computer Science, Szafrana 2, 65-516 Zielona Góra, E-mail: P.Powroznik@imei.uz.zgora.pl*

The correspondence address is:

e-mail: P.Powroznik@imei.uz.zgora.pl

REFERENCES

[1] Shawkat A. B. M.: Smart Grids Opportunities, Developments, and Trends, *Springer-Verlag,* London, (2013)

[2] Zubair Md. Fadlullah, Mostafa M. Fouda, Nei Kato, Akira Takeuchi, Noboru Iwasaki, Yousuke Nozaki.: Toward Intelligent Machine-to-Machine Communications in Smart Grid," *IEEE Communications Magazine*, vol. 49, no. 4, pp. 60 - 65, (2011)

[3] Su Y., Su R., Poolla K., Distributed Scheduling for Efficient HVAC Pre-cooling Operationsm, 19th *World Congress The International Federation of Automatic Control Cape Town*, South Africa. August 24-29, (2014)

[4] D'Oca S., Corgnati S. P., Buso T., Smart meters and energy savings in Italy: Determining the effectiveness of persuasive communication in dwellings, *Elsevier, Energy Research & Social Science 3,* (2014), 131–142

[5] Cottone P., Gaglio S., Lo Re G., Ortolani M., User activity recognition for energy saving in smart homes, *Elsevier, Pervasive and Mobile Computing* 16, (2015), 156–170

[6] Basua K., Hawaraha L., Arghiraa N., Joumaa H., Ploixa S., A prediction system for home appliance usage, *Elsevier, Energy and Buildings* 67, (2013), 668–679

[7] Kouveletsoua M., Sakkasa N., Garvin S., Batic M., Reccardo D., Sterling R., Simulating energy use and energy pricing in buildings: The case of electricity, *Elsevier, Energy and Buildings* 54, (2012), 96–104

[8] Gong X., Pessemier T., Joseph W., Martens L., A generic method for energy-efficient and energy-cost-effective production at the unit process level, *Elsevier, Journal of Cleaner Production* 113, (2016), 508–522

[9] Arghira N., Hawarah L., Ploix S, Jacomino M., Prediction of appliances energy use in smart homes, *Elsevier, Energy* 48, (2012), 128–134

[10] Weinert N., Chiotellis S., Seliger G., Methodology for planning and operating energy-efficient production systems, *CIRP Annals - Manufacturing Technology 60,* (2011), 41–44

[11] Grolingera K., L'Heureuxa A., Capretza M. A.M., Seewaldba L., Energy Forecasting for Event Venues: Big Data and Prediction Accuracy, *Elsevier, Energy and Buildings 112,* (2016), 222–233

[12] Yuce B., Rezgui Y., Mourshed M., ANN–GA smart appliance scheduling for optimised energy management in the domestic sector, *Elsevier, Energy and Buildings 111,* (2016), 311–325

[13] Donga B., Lia Z., Rahmana S.M. M., Vega R., A hybrid model approach for forecasting future residential electricity consumption, *Elsevier, Energy and Buildings* 117, (2016), 341–351

[14] Graditia G., Ippolitob M.G., Lamedicac R., Piccolod A., Ruvioc A., Santinic E., Sianod P., Zizzob G., Innovative control logics for a rational utilization of electric loads and air-conditioning systems in a residential building, *Elsevier, Energy and Buildings* 102, (2015), 1–17

[15] Ortiza J., Guarinob F., Saloma J., Corcheroc C., Cellura M., Stochastic model for electrical loads in Mediterranean residential buildings: Validation and applications, *Elsevier, Energy and Buildings 80,* (2014), 23–36

[16] Powroźnik P., Michta E., Elastic model of energy management in micro smart grid, *International School on Nonsinusoidal Currents and Compensation - ISNCC 2015, 12th conference - seminar. Łagów*, Poland, (2015)

[17] Wójcik A., Winiecki W., Kowalik R., Nogal Ł., Characterization of electrical appliances based on their immitance, *Measurement Systems in Research and in Industry - SP 2016*, 11th Scientific Conference Łagów, Poland, 2016, 69-72 (in Polish)