FUTURE BENEFITS OFFERED BY SMART GRIDS REQUIRE NEW ENERGY MARKET DEVELOPMENT

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Key words: efficient energy, electricity market, gas market, smart grid

Summary. Blackouts in the mid-twentieth century in the USA and some European countries implied a necessity of the hierarchical natural monopoly power system (PS) deregulation. The most important target of PS operation is to deliver reliable electric energy (with proper parameters), which implies the necessity to include all existing sources of electrical energy (mostly renewable energy sources – RES) in the power grid. The existing networks could not provide those types of duties hence it was necessary to start with the Smart Grid (SG) idea with new characteristics of the power grid. The rapidly growing number of RES, the ones installed in smart homes in particular, has led to reduced consumption of electricity. This has required a new organization of distribution networks, i.e. development of microgrids and prosumers, changing the static hierarchical information system into a dynamic dispersed electric power system. This consequently implied the need to replace the existing electricity market with a new one. As a result of the electricity and gas system integration, efficiency of the electricity system has increased, however due to different market targets it is necessary to develop a new integrated market. It would also cover smaller energy systems, using such sources as liquid fuel, hot water that potentially could become integral parts of the new integrated market. In the process of building the new integrated energy market it will be necessary to take into account the need for long-term expenses on transmission and distribution networks modernisation applying direct current and using experience of advanced utilities/companies in the U.S.A., Europe, China and some other countries.

1. INTRODUCTION

Blackouts in the second part of the twentieth century in the USA and some European countries produced a necessity of the hierarchical natural monopoly power system (PS) deregulation. The most important target of PS operation is flexible and reliable delivery of electrical energy (with proper parameters), which implies the necessity to switch on all existing sources of electrical energy (mostly renewable energy sources – RES) to the power grid. The existing networks could not assure those types of duties hence it was necessary to start with the Smart Grid (SG) idea with new characteristics of the power grid [23]. Information society, which has evolved in the 21st century needs electrical energy as a platform for itself, and the idea of SG that has been developing since the late 20th century as a result of blackouts in the U.S.A. and other countries, is a hope to meet accomplish this expectation.

From the beginning of the twentieth first century, a declining trend in terms of electrical energy consumption has been observed in Europe: between 2005 and 2010 by2%, between 2010 and 2014 by nearly 9%, and it is forecasted that it will have declined by 20% by 2020. A similar trend has been observed in the U.S.A. and other countries [24] as a result of application of renewable energy sources (RES) in smart homes/buildings/.

According to [3] "The Europe and Climate Package of 2008 was based on three main pillars, to be reached by 2020: 20% of overall consumed end energy to be from RES, with a subtarget for the transportation sector of 10% mainly from biofuels, 20% reduction of green house gases (GHGs), 20% more efficient energy consumption compared to a (then undefined)benchmark evolution."

Taking into account operation of gas system on energy market, as well as smaller energy systems as liquid fuel, heat systems and other, additionally it has to be taken into account necessity of new transmission lines construction and modernization of distribution networks with DC (Direct Current) in transmission and distribution lines, "Microgrid Controller as an Energy Management System (MEMS)" etc., energy market needs reorganization.

It is important to remember that existing regulation concerning operation of energy systems need to be change by government, international organization etc. which must take into account needs of information society in XXI century.

2. MODERN POWER SYSTEM AND ELECTRICITY MARKETS

The concept of "Smart" which facilitated the development of SG and subsequently smart-homes/buildings, cities, industry, etc (Fig.1. using chip-based devices (such as Smart Meters). Each of the smart entity generates, sends, receives and stores data; according to CISCO's prediction, in 2020, the number of data will be equal to 1018, which will intensify the already growing Big Data (BD) problem [23]. The problem of the limited primary energy

implied development of RES which has to be connected with the SG, or work in microgrid islanding. BD is important, however it will not be considered in this paper, since by introducing new units between distributor and consumer operation of the existing energy market compatible with hierarchical energy management system (EMS) is changed. Moreover, in result of reorganization the following terms: transactive energy and hosting energy influencing market operation.

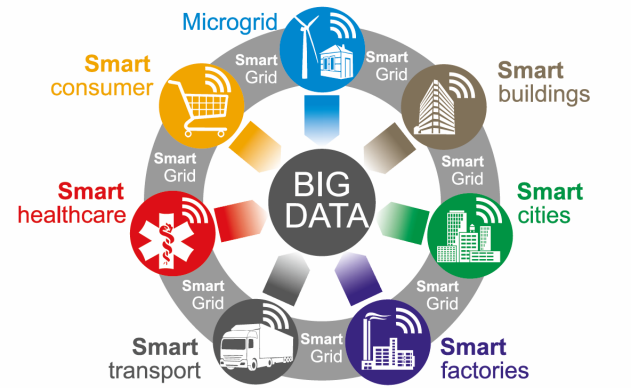

Fig. 1. Examples of Big Data sources[23]

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- The Grid can handle more Renewable Generation than it was previously believed.
- Geographic and resource diversity provides additional reliability to the system.
- Wind and solar forecasting provides significant value.
- Our electrical power markets were not originally designed for variable renewables, however they can be adapted.
- Modern power electronics create new sources of essential reliability services."

Development of battery storage and role of policy regulation should be taken into account next to the above facts[13].

RES influence on PS and on Electricity Market (EM) results of the variable energy resources (VER), and the list of seven VER have been presented in [8]. It required changes in EM design, and research in that area has been widely developed in different companies in the U.S.A. and in other countries. New EMs desiging must address both the physics and the economics, and authors in [8] present "primary R&D challenges including:

- Incentivizing compatible price formation,
- Promoting flexibility and reliability services,
- Developing advanced market clearing software that captures technical capabilities and limitations of technologies,
- Finding waves ways? to extend or interface the market with the distribution systems."

3. ELECTRICITY MARKETS AND GAS

S. Heinen et al. [10] considers flexibility of gas influence on PS flexibility, taking into account three following cases:

- "From gas power generation – technology and electricity market design
- In gas supply – gas storage and gas /electricity market coordination
- Through multiple-input, multiple-output plans and appliance".

There are several problems with gas/electricity market xzcoordination because they often operate "in isolation in different time frames throughout the day and have often failed to create a homogenous structure." To overcome the above-mentioned problems a hybrid energy conservation system integrating energy conversion system proving high level of flexibility has been considered [10].

In bibliography one can find a growing number of papers devoted to electricity market linked with natural gas which may be interpreted as forthcoming process of integration of electricity – and gas-market. The following works vhould be mentioned in this context:

Multi-Linear Probability Energy Flow Analysis of Integrated Electrical and Natural-Gas Systems [4].

A novel multi-stage stochastic programming model is proposed for the expansion coplanning gas and power networks considering the uncertainties net load demand. Meanwhile, the nonanticipavity constrains are taken into account to guarantee the decisions should only depend on the information of realized uncertainties up to the [resent stage [7.

Coupling two interdependent electricity and gas market models formulated as optimization problem. Each methodologies fulfills different wishes. The "electricity-perspective" methodology maximizes electricity market profits after calculating equivalent

gas contracts with the market model. In contrast the "gas-perspective" methodology minimizes gas operation costs after obtaining the relationship between the marginal revenue and the gas consumption with the electricity market mode l[9].

Comparing different types of gas-turbine with "regard to flexibility characteristics reciprocating engines could provide higher efficiency then open-cycle gas turbines (CCGTs) and aeroderivative gas turbines ((ADGT), lower on-load plant efficiency and very quick startup time (few minutes)" But when "gas plant is used together with VER, OCGTs are more flexible than combine-cycle gas turbines (CCGTs)". [11]

Electricity and natural gas are both energy that can be directly consumed. To improve the overall efficiency of the energy infrastructure it is imperative that the consumption gas power plants, electricity transmission lines and gas pipelines can be co-planned. The co-planning process is modelled as a mixed integer nonlinear programming problem to handle conflicting objectives simultaneously. We propose novel model to identify the optimal co-expansion plan in terms of social welfare [13].

The paper[19] studies the equilibrium of the coupled gas and electricity markets which is driven by the strategic offering behaviors: each producer endeavours to maximize its own profit y taking the market 0clearing process into considerations.

4. ELECTRICITY MARKET AND OTHER SMALLER SOURCES OF ENERGY

Challenges in terms of integration of electricity- and gas- systems are presented in paragraph 3. Bibliography occasionally contains brief references to other small energy systems. There are also some printed papers which consider these resources in detail. For example in [5] the "concept of energy hubs, flexibility from distributed multigeneration, flexibility from joint water-power optimization and control, tradeoff between complexity and flexibility, distributed control" as well as other subtasks are presented.

One can also find additional considerations on integration water system and energy networks in [2] (with the idea of Internet of Things application). The idea of hot and cold system harnessing flexibility with "short integrated energy system study and some real-world experience and applications" is presented in [11]. Consumer's influence on flexible energy systems [15] is also worth mentioning.

5. FINAL REMARKS

It is necessary to start development ofthe integrated energy market results due to the following observations:

- A growing number of variable energy resources and new electronic devices,
- Influence of natural gas on flexibility of energy market,
- Availability of small energy systems,
- Necessity to reconstruct transmission and distribution lines taking into account application of DC [16,20].

REFERENCES

[1] Bloom A., Helman U., Holttinen H**.,** Summers **K.**, Bakke J.,, Brinkman G.,. Lopez A: *It's Indisputable*. IEEE Power & Energy, vol. 15, 22-70-82, Nov./Dec.2017.

[2] Casey F.,. Beaini S, Pabi S.,. Zammit K,. Amarnath A.: *The Tripple Bottom Line for Efficiency,* IEEE Power & Energy, vol. 15, 34-42, Jan./Feb. 2017.

[3] Chakraborty P., Baeyenes E, Khargonekar P.P.: *Cost Causation Based Allocations of Costs for Market Integration of Renewable Energy*. IEEE Transactions on Power Systems, vol. 33, 70-83, Jan. 2018.

[4] Chen S., Wei Z., Sun G., Cheung Kwok W., Sun Y.: *Multi-Linear Probability Energy Flow Analysis of Integrated Electrical and Natural-Gas Systems*. IEEE Transactions on Power Systems, vol. 32, 1970-1979, May. 2017. M., q

[5] Dall'Anese E., Mancarella P., Monti A.: *Unlocking Flexibility*. IEEE Power & Energy, vol. 15, pp. 43-52, Jan./Feb. 2017.

[6] D'haeseleer W. de Vries., L, Kang H., Delarue E.: *Flexibility Challenges for Energy Markets*. IEEE Power & Energy, vol. 15, 61-71, Jan./Feb. 2017

[7] Ding T.,. Hu Z, BieŁ Y.: *Multi-Stage Programming With Nonaniticipativity Constraints for Expansion of Combined Power and Natural Gas System*. IEEE Transactions on Power Systems, vol. 33, 317-328, Jan. 2018

[8] Ela E., Wang C., Moorty S., Ragsdale K., O'Sullivan J., Rothleder, Hobbs : *Electricity Markets and Renewable*. IEEE Power & Energy, vol. 15, 70-82, Nov./Dec.2017.

[9] Gil M., Dueñas P., Reneses J.: *Electricity and Natural Gas Interdependency: Comparison of Two Methodologies for Coupling Large Market Models Within the European Regulatory Framework*. IEEE Transactions on Power Systems, vol. 31, 361-369, Jan. 2016.
[10] Heinen S., Hewiker Ch., Jenkins N., McCalley J., O'Malley M., Pasini S., Simoncini S.: *Unleashing the Flexibility of Gas*. IEEE Power & Energy, vol. 15, 16-24, Jan./Feb. 2017.
[11] Meegahapola L., Flynn D.: *Characterization of Gas Turbine Loan Blowout During Frequency Excursion in Power Networks,* IEEE Transactions on Power Systems vol.30, No.4 1877-1667, July 2015.
[12] Pereira A.CQuialheiro de Oliveira., A., Baptista E.C., Balbo A.R., Soler E.M., Nepomuceno L., *Network Constrained Multiperiod Auction for Pool-Based Electricity Markets of Hydrothermal Systems*, IEEE Transactions on Power Systems, vol.32, 4501-4514, Nov. 2017.
[13] Qiu J., Dong Z.Y., Zhao J.H., Xu Y., Zheng Y., Li C., Wong H.P,: *Multi-Stage Flexible Expansion Co-Planning Under Uncertainties in a Combined Electricity And Gas Market*. IEEE Transactions on Power Systems, vol. 30,. 2119-2129 July. 2015.
[14] Shao Ch., Shahidehpour M., Wang Y. Wang, B. Wang ;"I*ntegrated Planning of Electricity and Natural Gas Transportation Systems for Enhancing the X Power Grid Resilience*. IEEE Transactions on Power Systems, vol.32, 4418-4429, Nov. 2017.
[15] Schuitema G, Ryan L., Aravena C.: *The Consumer's Role in Flexible Energy Systems*, IEEE Power & Energy, vol. 15, 53-60, Jan./Feb. 2017.
[16] *Special Section on Frontiers of DC technology*. IEEE Transactions on Power Delivery,vol. 33, 259-536 Feb. 2018.
[17] Stenclik D., Denholm P., Chalamala B.: *Maintaining Balance*. IEEE Power & Energy, vol. 15, 31-39, Nov./Dec.2017.
[18] Wang Ch., Wei W, Wang J., Liu, F Qiu, C. M.,. Mei S.: *Robust Defence Strategy for Gas-Electric Systems Against Malicious Attacks*, IEEE Transactions on Power Systems, vol.32, 2953-2965, July 2017.
[19] Wang Ch,, Wei W., Wang J., Liu F., Mei S.: *Strategic Offering and Equilibrium in Coupled Gas and Electricity Markets*. IEEE Transactions on Power Systems, vol. 33,. 290-306, Jan. 2018
[20] Xu X., Jia H., Chiang H.-D., Yu D.C.,Wang D.: *Dynamic Modeling and Interaction of Hybrid Natural Gas and Electricity Supply System in Microgrid*. IEEE Transactions on Power Systems, vol.30, No.3, 1212-1221, May 2015.
[21] Zhang X., Shahidehpour M., Alabdulwahb A., Abusorrah A.: *Hourly Electricity Demand Response in the Stochastic Day-Ahead Schwduling of Coordinated Electricity and Natural Gas Network*. IEEE Transactions on Power Systems vol.31, No.1, 593-601, Jan. 2016.
[22] Zhou, Y. Zu Chg.,. Wu H., Song Y.: *An Equivalent Model of Gas Networks for Dynamic Analysis of Gas Electricity Systems*. IEEE Transactions on Power Systems, vol.32, 4255-4264, Nov. 2017.
[23] Zieliński J.S.: *Does Smart Grid needs new Informatics Tools*?, Przegląd Elektrotechniczny, 4/2018,.30-33.

PRZYSZŁE KORZYŚCI OFEROWANE PRZEZ SMART GRID WYMAGAJĄ UTWORZENIA NOWEGO RYNKU ENERGII

Słowa kluczowe: wydajna energia, rynek energii elektrycznej, inteligentna sieć

Streszczenie. Od połowy ubiegłego wieku „blackouty" w USA I niektórych krajach europejskich spowodowały konieczność deregulacji hierarchicznego (wynikającego z naturalnego monopolu) systemu elektroenergetycznego. Zaistniała konieczność dołączenia do sieci eletroenergetycznej wszystkich źródeł tej energii, w tym -źródeł odnawialnej energii (OZE). Istniejące sieci nie były w stanie podjąć się nowych zadań, zaistniała zatem potrzeba budowy nowych „inteligentnych" o nowych właściwościach, nowej organizacji sieci rozdzielczej, w tym mikrosieci, pojawienie się prosumentów, co zmieniło statyczny hierarchiczny system informacyjny w dynamicznie rozproszony system elektroenergetyczny. Integracja systemów elektroenergetycznego i gazowego zwiększyła efektywność elektroenergetyki, ale wymaga utworzenia nowego rynku energii, co jest przedsięwzięciem kosztownym i długotrwałym.

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