ATLANTIS PRESS
Advances in Social Science, Education and Humanities Research, volume 359
4th International Conference on Social, Business, and Academic Leadership (ICSBAL 2019)

Smart grids as the leading concept in the Internet of Energy (IoE)

Aleksandra Tusova
Faculty of Information Technology
Russian State Social University
Wilhelm Pieck street 4, 129226 Moscow
Russian Federation
e-mail: TusovaEA@rgsu.net

Elena Romanova
Faculty of Information Technology
Russian State Social University
Wilhelm Pieck street 4, 129226 Moscow
Russian Federation
e-mail: romanovaeju@rgsu.net

Wadim Strielkowski
Prague Institute for Qualification Enhancement
Trnkovo náměstí 1112/2, 152 00 Prague
Czech Republic
e-mail: strielkowski@prizk.cz

Abstract This paper focuses on the implications of the smart grids that are based on the bidirectional exchange of information and energy flow in the electricity networks. By optimising, saving energy, and delivering power precisely where it is needed, smart grids represent the leading concept constituting the Internet of Energy (IoE). The power networks of the future are likely to be automated and based on algorithms run by the artificial intelligence (AI).
We tackle some of the implications of smart grids in the IoE with a special focus on electric transport. Electric vehicles might represent one of the biggest challenges for the smart grids of the future. Our results show that self-optimising consumers might combine the generation of energy with its trading via peer-to-peer (P2P) networks and using it for charging the electric vehicles for achieving a better balance and energy market equilibrium. Models are demonstrated and some useful results are derived and explained in detail. Our results might be of some special interest for policymakers and stakeholders dealing with autonomic power systems and energy efficiency and security.

1 Introduction

Electricity is supplied via the electricity grids. An intelligent (or "smart") power grid uses bidirectional power and information flows to create an automated power grid. The term "smart grid" is typically used to describe an electricity system that supports four basic operations that include electricity generation, electricity transmission, electricity distribution, and electricity control (see Strielkowski 2017).

Smart grid technologies include integrated communication, acquisition and measurement technologies, advanced components, advanced control methods, and improved interfaces and decision support (Kabalci 2016). With the cost and benefit analysis in smart grid, we have found that smart grid can really make people live a better, healthier, and higher-quality life. In contrast, today's power system raises big questions about its ability to continue providing citizens and businesses with relatively clean, reliable and affordable energy services.

The technological limitations in the measurement no longer lead to the averaged peak prices being passed on equally to all consumers. The rapidly declining costs indicate a major shift from the central network topology to a highly distributed one, where power is generated and consumed directly at the grid boundaries (Lakhov et al. 2018).

An intelligent energy management system keeps the grid stable by balancing the power generated from all sources with the power consumed. An IoE enables consumers and prosumers to independently coordinate supply and demand and is equipped with intelligent forecasting systems that use weather forecasts, expected traffic flows and other information to predict future energy needs (Evglevskaya et al. 2018). Some examples of these advanced apps include measurement data management, network analysis, substation management, distributed energy resource management systems (DERMS), and the low voltage outage management system.

Figure 1 that follows depicts the investments into smart grids by areas and departments. It becomes obvious that the overall volume of funding is growing with smart meters receiving an increasing amount of investments each year.

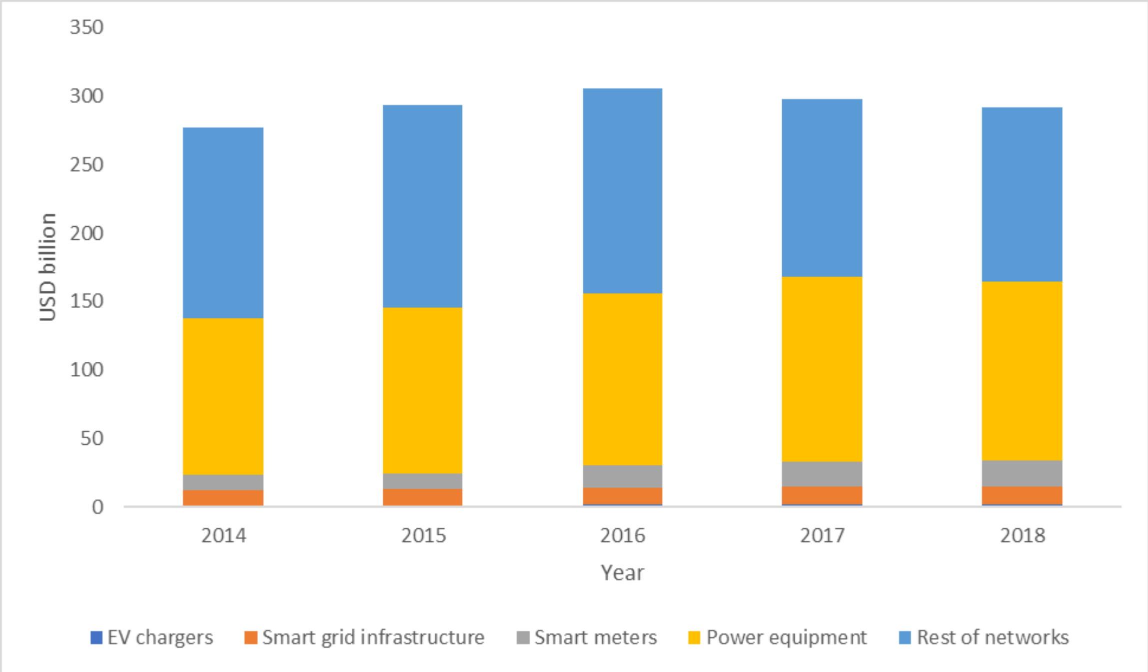

Fig.1. Investments into smart grids by area
Source: IEA (2019)

These observations are confirmed by the International Energy Agency that describes an increase in investments into smart grids at about 10 % in 2018, however, noting the slowdown that is probably caused by the uncertainty stemming from the inexistent legislative framework, varying standards as well as concerns about 5G networks (IEA 2019). Clearly, further effort and perhaps a wider institutional support are needed to promote the further deployment of smart grids.

2 Autonomic Power System network

Today, there is increasing pressure on electricity grids due to the complexity and integrity of the modern power system (Pollitt 2012; Moreno et al. 2015, Loukarakis et al. 2015; or Newbery et al. 2018). Thanks to the innovations to the electricity and power systems as well as smart meters that monitor and report the energy consumption and enable the control of various devices and appliances plugged into the network, management and control become quite robust.

One of the solutions to that might be the Autonomic Power System (APS) which is a concept of the power system that is marked as "self *" (self-configuring, self-healing, self-optimizing and self-protective) (see King et al. 2015; Xu and Milanovic 2015; or Strielkowski 2017).

The whole concept behind the autonomic power system is derived from the concept of Autonomic Computing that was invented by International Business Machines Corporation (IBM) in 2001 as a new tool for managing the increasingly complex information systems. The goal was to develop the computer systems capable of self-management. The APS takes its own independent decisions using high-level policies through constantly checks its status and automatically adapting to the new conditions. The APS computing framework consists of autonomic components interacting with each other. Even though the main rules for the system functioning are pre-programmed, its real-time behaviour stems from the steps and processes conducted by decentralized intelligence. This makes it possible for quite complex systems to reach optimisation of operations in real time with astonishing speed and accuracy.

At the moment, scientists operate with various models based on “self-regulating” APS-like systems can be traced back to the multi-agent systems and autonomic nervous systems. Such systems have been in existence for centuries and are known to everyone from biology. For example, bee or ant colonies represent a good example of these systems. In a bee colony, each bee is a part of the system as much as it is an individual living being. All information is stored and shared by the bees collectively and is immediately transmitted back to the hive for others to analyse and to be aware of. The same would be the concept of the APS-based systems. Imagine a power line in which each node is self-aware yet reports to the central system. In a case of fire, emergency of some sort, or a damage, the node can decide to disconnect itself from the system in order to prevent greater harm. Another example includes a smart grid system that would attempt to save the energy by cutting off the power in a given time span and in a given neighbourhood from selected house appliances (e.g. fridges or TV sets). Savings from this precaution might be considerable.

Thence, it is obvious that the smart grids, autonomic systems and electricity networks of tomorrow would have to cope with such pressing issues as global warming, increasing population, volatile energy prices, variability of energy generation and distribution, as well as a growing number of smart meters, smart houses and smart vehicles all operating within one single system embedded into the Internet of Energy.

3 Electric vehicles and IoE

The increase in the economic well-being in the developed and developing countries around the world inevitably increases the number of vehicles that also leads to the increase in the volume of harmful gases in the atmosphere, mainly in large cities. Global climate changes that include global warming and other harmful effects of human activity led to the introduction of strict environmental requirements for automobiles. This measure, accompanied by a rise in oil prices, contributed to the beginning of the search for alternative modes of transport, including the use of innovative technologies and smart grids (Balcombe et al. 2019).

Nowadays, the most popular sustainable mode of transportation is represented electric cars (or electric vehicles (EVs)). Many countries around the globe participate in the development of this alternative mode of transport. Many researchers and experts believe that electric transport is the future of transportation, as it might improve the environmental situation in large cities that become the hubs of human civilisation, as well as help to reduce the consumption of fossil fuels. Other alternative modes of transport include: i) gas vehicle; ii) fuel cell vehicle; and iii) electric transport (Lund and Kempton 2008).

Countries like Japan or China actively support EVs offering generous subsidies to the households and individuals. For example, in China the total amount of state support by 2015 reached about $ 15 billion. Since 2009, China offered the electric vehicle support program in the form of subsidies for the purchase of electric buses over 10 meters long and worth $ 79,000, as well as electric vehicles worth $ 8,800 (Du and Ouyang 2017).

In addition, there is a wide support for electric transportation in such countries as France, Italy, or the United Kingdom. This is often combined with the feed-in-tariffs for "green" electric energy generated by households themselves using solar panels or wind turbines.

In Russian Federation, despite the fact that electric vehicles are subjected to specific taxation which favourably differs for the buyer from taxing cars with internal combustion engines, consumers have little interest in them. This is partly due to the conservatism of the thinking of Russian consumers that is distinguished by the practical nature (see e.g. Belousov et al. 2017; Akberdina et al. 2018).

At the moment, there is no widespread network of recharging stations for EVs in Russia. Thence, development and creation of electric transport in Russian conditions is extremely expensive (Kuzmin et al. 2019). However, a scientific and engineering research in the field of construction of battery transport on electric propulsion is possible. Its production has significant differences from the production of cars equipped with gasoline or diesel internal combustion engines. First of all, it is connected with the creation of reliable electric motors with sufficient power and, at the same time, reduced energy consumption and high efficiency, as well as the creation of rechargeable batteries that meet a variety of requirements - high capacity, long service life, the possibility of effective operation at negative temperatures, fast charge cycle, availability for recharging from a usual household network of 220 V.

Considering that the demand for electric cars in Russia is extremely small, this project will not be able to reach the level of payback even for several years. Even those consumers who decide to transfer to an electric car might turn to buying cheaper foreign vehicles. Thence, it appears that Russian car industry is significantly lagging behind in development, the reliability of Russian cars with a traditional powertrain causes many complaints, hence low trust in electric transportation. For the same reason, few Russian electric cars might actually find any of the willing customers abroad. All in all, electric vehicles might take a long time to come into popularity and gaining wide acceptance in the case of a country abundant in cheap oil and gas.

When it comes to the Internet of Energy, EVs represents the perfect component within its whole existence. The best use EV can offer is the so-called vehicle-to-grid (V2G) and grid-to-vehicle (G2V) technologies. Both of them represent the concept of two-way use of electric vehicles and hybrids which means connecting the machine to the general grid for recharging the car and returning excessive electricity back. Owners of vehicles with V2G-enabled technology have the opportunity to sell electricity to the grid during hours when the car is not in use and charge the car at hours when electricity is cheaper, because in many countries the price of electricity depends on the time of day. It is also possible to connect cars with this technology to one's home power source and then use them as uninterrupted power for the home or office (Habib et al., 2015). Here is where IoE becomes very useful, since regulation of charging times and opportunities to sells excessive energy back to the grid or to the other EV owners might become a very complex task logically speaking. IoE might help to optimise these transactions by offering useful tools and pathways for exchanging information and energy between the users and grids which can effectively proceed both ways.

4 Empirical model: EVs and PVs

In the empirical part we would draw up a simple model that would allow us to compute the changes in the tariff for the households in case these households would install solar panels (PV) (which would it turn reduce the total metered import (M)) and start using electric vehicles (EV) (which would increase the total metered import (M)).

Let us yield the yearly (t) tariff for one household which is calculated as follows:

$$Tariff = F * 365 + v * M \quad (1)$$

The revenue of the electricity provider obtained by the provider from N customers per year (t) can be calculated as follows:

$$TR = Tariff * N = (F * 365 + v * M)N \quad (2)$$

One can see that the fixed tariff (F) remains unchanged (not additional power is needed). The only variable part will be (v) given that the volume of consumed electrical energy should remain unchanged after the adaption of PV and EV by some households. The total revenue (TR) should also remain unchanged:

$$TR = TRH1\ (v) + TRH2\ (v) + TRH3\ (v) + TRH4\ (v) = TariffH1\ (v)\ NH1 + TariffH2\ (v)\ NH2 + TariffH3\ (v)\ NH3 + TariffH4\ (v)\ NH4 = const \quad (3)$$

Electric vehicle (EV) in each type of a household would add complexity into our model. With a PV system in place, the EV battery is considered a storage device, as well as a battery that connects the power supply to a distributed photovoltaic system. Let us assume that an EV would add additional 3000 kWh per kW in electricity consumption. One can repeat the calculations for the households with and without solar PV but adding some hypothetical EV consumption of 3000 kWh per kW. Now, if we differentiate the share of PV and EV at 1 % and 50 % and 1% in different regions with different tariffs and the share of PVs and EVs, the situation becomes more complex. Let us use the data from the United Kingdom's various regions as reported in Strielkowski et al. (2019) (see Figure 2 that follows).

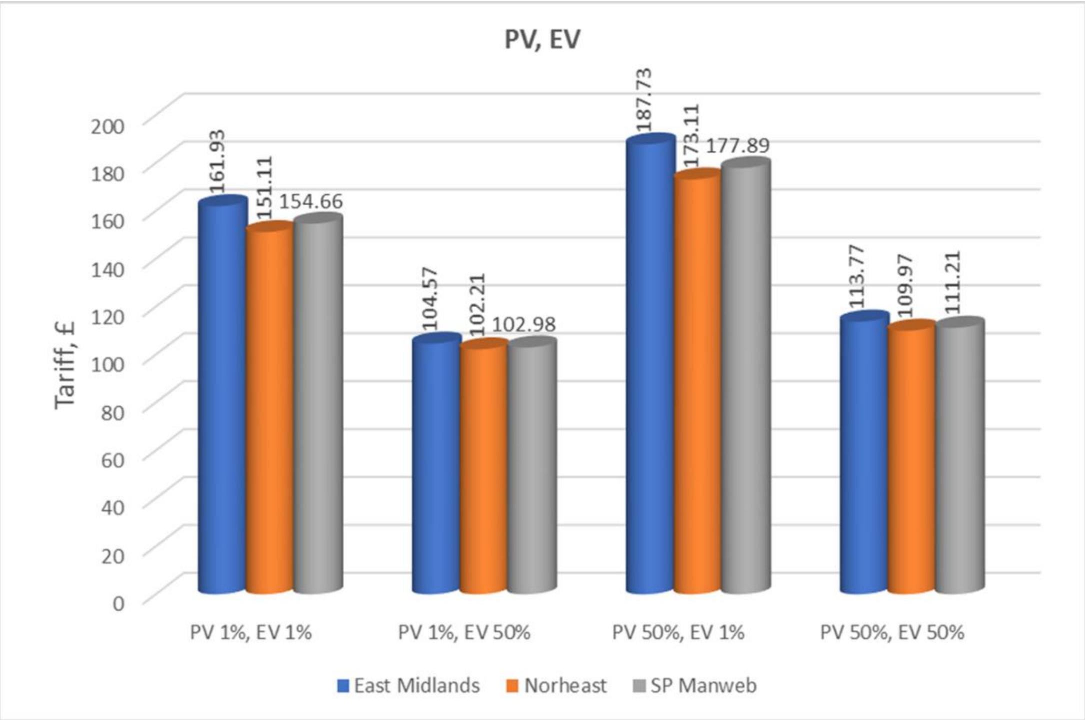

Fig.2. Comparison of PV and EV households in 3 different UK regions
Source: Own results

Figure 2 above shows the comparison of tariffs in three different UK regions that are distinguished by different numbers of customers, varying rate of deployment of PVs and EVs as well as by tariffs for electric energy and feed-in-tariffs (FiT). One can see that the differences can be quite significant even though the magnitude of tariffs is not that great.

It becomes obvious that differences in energy deployment, charging, tariffs and compensation are so complex that one needs smart system to operate and to manage them all in case everyone would own an electric vehicle and engage in P2P energy trading. Smart grids and autonomic power systems would provide an excellent solution to this problem.

5 Conclusions and implications

Generally, smart grids truly represent the leading concept in the whole idea of the Internet of Energy (which, in turn, is a sub-section of the Internet of Things). The volume of information sent back and forth from generating companies to consumer and back is enormous and the decisions the operators need to undertake are getting more complex. Smart grids with the autonomic features might help to overcome these obstacles.

The raising complexity of information exchange in energy and power systems is going to influence all spheres of this sector including such mundane issues as heating, lighting, and transportation. Electric transport (in particular electric vehicles, or EVs) is viewed by many as the future of transportation that would help to decrease the use of fossil fuels and pollution in large urban hubs. With this regard, electric vehicles might become a solution to many problems. However, our results show that special approaches and tariffs need to be applied in order to make this means of transportation attractive and appealing to the wider masses of customers.

All in all, it appears that the smart grids would make a significant impact to the whole concept of IoE. By using high computational power and artificial intelligence-based algorithms, they would ensure better coordination of energy input into the grid and its consumption by the users, residential households and industries alike. Future energy managers and stakeholders should use this communication for energy management and load shedding, which are among the main goals of smart grid supply projects. Ultimately, research centres developing AI and smart grid technologies could play a central role in the development and testing of smart grid concepts which will ultimately be used to improve national utility grids

References

Akberdina V, Kalinina A, Vlasov A (2018) Transformation stages of the Russian industrial complex in the context of economy digitization. Problems and Perspectives in Management 16(4):201–211. doi: 10.21511/ppm.l6(4).2018.17

Balcombe P, Brierley J, Lewis C, Skatvedt L, Speirs J, Hawkes A, Staffell I (2019) How to decarbonise international shipping: Options for fuels, technologies and policies. Energy Conversion and Management 182:72-88. doi: 10.1016/j.enconman.2018.12.080

Belousov EV, Grigorev MA, Gryzlov AA (2017) An electric traction drive for electric vehicles. Russian Electrical Engineering 88(4):185-188. doi: 10.3103/S1068371217040034

Du J, Ouyang D (2017) Progress of Chinese electric vehicles industrialization in 2015: A review. Applied Energy 188:529-546. doi: 10.1016/j.apenergy.2016.11.129

Evglevskaya NV, Paramonov AI, Smirnov PI, Shamilova RV (2018) Software Defined Network architecture model and cognitive control method for organizing multiple access in the Internet of Things. Radio industry (Russia) 28(4):68–75. doi: 10.21778/2413-9599-2018-28-4-68-75

Habib S, Kamran M, Rashid U (2015) Impact analysis of vehicle-to-grid technology and charging strategies of electric vehicles on distribution networks-a review. Journal of Power Sources 277:205-214. doi: 10.1016/j.jpowsour.2014.12.020

IEA (2019) Smart Grids. https://www.iea.org/tcep/energyintegration/smartgrids. Accessed on 18 September 2019

Kabalci Y (2016) A survey on smart metering and smart grid communication. Renewable and Sustainable Energy Reviews 57:302-318. doi: 10.1016/j.rser.2015.12.114

King JE, Jupe SC, Taylor PC (2015) Network State-Based Algorithm Selection for Power Flow Management Using Machine Learning. IEEE Transactions on Power Systems 30(5):2657-2664. doi: 10.1109/TPWRS.2014.2361792

Kuzmin EA, Volkova EE, Fomina AV (2019) Research on the concentration of companies in the electric power market of Russia. International Journal of Energy Economics and Policy 9(1):130–136. doi: 10.32479/ijeep.7169

Lakhov YuA, Fomina AV, Balashov VM (2018) Application of the method and tools for monitoring the energy consumption of clean rooms based on the use of the software package Statistica Neural Networks. Radio industry (Russia) 2:76–79. doi: 10.21778/2413-9599-2018-2-76-79

Loukarakis E, Bialek JW, Dent CJ (2015) Investigation of maximum possible OPF problem decomposition degree for decentralized energy markets. IEEE Transactions on Power Systems 30(5):2566-2578. doi: 10.1109/TPWRS.2014.2365959

Lund H, Kempton W (2008) Integration of renewable energy into the transport and electricity sectors through V2G. Energy Policy 36(9):3578-3587. doi: 10.1016/j.enpol.2008.06.007

Moreno R, Moreira R, Strbac G (2015) A MILP model for optimising multi-service portfolios of distributed energy storage. Applied Energy 137:554-566. doi: 10.1016/j.apenergy.2014.08.080

Newbery D, Pollitt MG, Ritz RA, Strielkowski W (2018) Market design for a high-renewables European electricity system. Renewable and Sustainable Energy Reviews 91:695-707. doi: 10.1016/j.rser.2018.04.025

Pollitt MG (2012) Lessons from the history of independent system operators in the energy sector. Energy Policy 47:32-48. doi: 10.1016/j.enpol.2012.04.007

Strielkowski W (2017) Social and economic implications for the smart grids of the future. Economics and Sociology 10(1):310-318. doi: 10.14254/2071-789X.2017/10-1/22

Strielkowski W, Volkova E, Pushkareva L, Streimikiene D (2019) Innovative Policies for Energy Efficiency and the Use of Renewables in Households. Energies 12(7):1392. doi: 10.3390/en12071392

Xu Y, Milanovic JV (2015) Artificial-intelligence-based methodology for load disaggregation at bulk supply point. IEEE Transactions on Power Systems 30(2):795-803. doi: 10.1109/TPWRS.2014.2337872