

Towards a future energy grid

Irfan Younas

European Energy Centre (EEC), Edinburgh, United Kingdom

Mukhtaj Khan

Abdul Wali Khan University Mardan, Pakistan

Abstract: The future of energy supply and consumption is through a Smart Grid system. This is accomplished by updating the existing grid by inclusion of a new system encompassing metering, communications and control technologies. Therefore new strategies are needed to provide an optimised power system that includes not only energy from distributed resources, such as renewable energy, but also facilitates customer participation in maximising power system efficiency and reliability. Smart grids have the potential to contribute positively in achieving energy efficiency, conservation and carbon emissions targets. This paper discusses the financial benefits and technological challenges in adopting a smart grid with distributed energy resources.

I. Introduction

Electricity is part of our everyday life, and we take it for granted. For over hundred years coal and other fossil fuels have been used to produce the electricity we use every day. The electricity grid is a network of power lines and sub-stations that carry electricity to homes and businesses. In many areas this grid often relies on a single power source and doesn't provide detailed information on usage; causing electricity demand projections difficult to manage. Today the electricity grid has problems, it needs updating and also it is running near capacity. Furthermore enhancing power capacity in line with consumption is neither feasible nor advisable. Also if power lines break, due to extreme weather, or when power plants cannot produce enough power then blackouts can occur; which in severe circumstances can cause fatalities. These problems were addressed in the past by building new power plants. But now, bearing in mind the volatility of energy supply and global pollution due to carbon emissions, there is a need to work towards sustainability and reduce our dependence on fossil fuels by using a smarter grid.



Figure 1. Traditional Electricity Grid

Figure 1 shows a sketch of the traditional electricity grid that is reliant on robust connectivity of transmission and distribution lines to ensure steady flow of energy supply to the consumer. With the ever increasing energy demand, particularly from emerging economies, such as India and China, it is projected that global energy consumption is expected to rise by 41 percent from year 2012 to 2035 [1]. Therefore the question of finding efficient and sustainable ways to manage energy demand is more relevant than ever. Hence there is a need to replace the existing energy grid with a smart grid [2]. In essence, the smart grid manifest itself by adding *sensors* and *software* to the existing grid, such that it will give utilities and individuals' new information that will help them understand, react and minimise impact on supply due to sudden variations in demand [3]. Consider a scenario where a tree falls on a power line and consequently one thousand homes loses power. In the current grid – utility employees often physically reroute power or repair the faulty lines, both of which are time and resource consuming exercises. With the smart grid, sensors and software are used to detect and immediately reroute the power around the problem. This remedy has the ability to limit the power loss issue to fewer homes. One other reason for introducing the smart grid is that the price of electricity varies throughout the day, through different tariffs, though this may not be evident through meters installed in our homes. However, the cost of electricity is expensive at peak hours and cheap during the night where load is minimal. With new smart meters installed at home, there is a real possibility to run certain appliances at specific times at night, when electricity is

cheap. This provides more control on energy bills and also prevents supply problems at peak load hours. Consequently, dependence on new power plants can be reduced in future energy projections. The smart energy grid also facilitates new ways of deploying renewable energy in to the system, in that power generation can be distributed across multiple sources, leading to a more stable and efficient energy system. It is this ability to communicate and manage electricity supply/demand that makes the grid smarter; leading to efficient power management. Hence, introduction of smart energy grid will help manage our energy bills, mitigate carbon emissions and help the economy, by simply making an informed decision on how we use our electricity.

II. The smart meter

A smart meter is a two way communication device that provides real time information on energy usage in a dwelling and relays that information to the energy supplier or utility company.

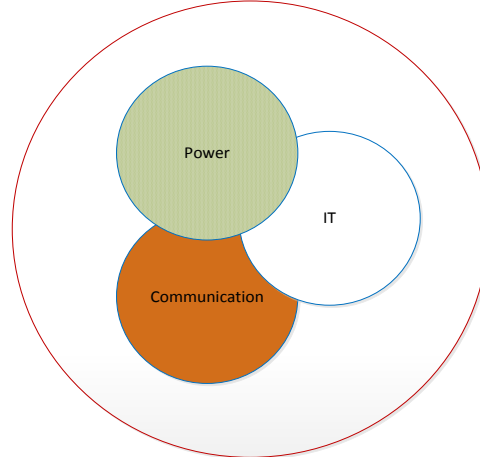


Figure 2. Embedded ICT required in a smart meter

This information is used for tariff purposes, better load projection and other business insights. Figure 2 displays a conceptual understanding of a smart meter based on the IEEE-1547 standard. This meter shows a fusion of energy technology with information and communication technologies. The IEEE-1547 standard provides a detailed understanding of Interconnecting Distributed Resources (DR) with Electric Power Systems (EPS) [4]. Furthermore, if the smart meter is connected to a smart energy monitor, that provides information on energy usage volume for each major domestic appliance, and also energy tariffs based on consumption thresholds, then the end user has more insight and control on how the energy is being consumed.



Figure 3. Smart energy monitor

Figure 3 shows a smart energy monitor provided by a utility company such as British Gas Plc to the domestic user [5]. The deployment of this energy meter is still in the test phase and yet to be rolled out on a large scale. It is envisaged that utility companies in the United Kingdom will gradually move away from the passive energy meter to the smart meter with integrated energy monitor that has many built-in applications for closer energy monitoring, control and budgeting [6]. In future, this smart energy monitor could easily be integrated on a mobile device such as a smart phone or tablet as an application, for mobility and ease of use. One aspect that is yet to be implemented on a larger scale is the decentralisation of energy production, where a diversified set of energy sources are fully integrated into the grid with appropriate monitoring and load-balancing.

III. Future vision of a smart energy grid

As mentioned earlier, the world energy demand is projected to increase by 41 percent in year 2035, and the biggest rise in demand will come from emerging economies such as India and China. But the consumption of fossil fuels is having a negative impact on global environment, along with uncertainty in supply caused by conflicts and political instability. We therefore must contemplate a smart energy generation, storage, distribution and management system that cater for our future energy needs. Figure 4 depicts a futuristic but realizable smart energy grid [7], which contains seven domains, interconnected by secure communication (solid lines) and power flows (dotted lines).

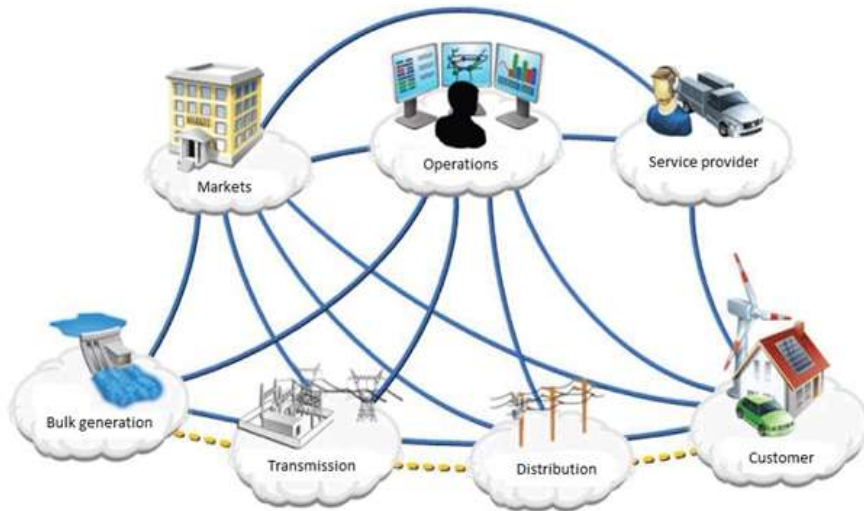


Figure 4. Smart grid interconnection of domains

The above figure shows that all information flow pertaining to energy usage is monitored by the ‘operations’ domain. This is accomplished by strategically positioning of smart monitoring devices throughout the grid. These devices (smart meters) are used to gather all kind of statistics, be it consumer or market data. The ‘operations’ domain is communicating with ‘bulk generation’, ‘transmission’, ‘distribution’ and ‘consumer’ domains. Information from these domains helps understand availability of energy and how it is distributed and consumed. Furthermore, connection with the ‘market’ and ‘service provider’ (utilities) domains facilitate market opportunities (buying/selling power) and energy tariff bands for residential and commercial clients. This enables accurate system models and consequently more reliable and efficient energy grid. In the following we shall present a closer look at opportunities offered by the smart energy grid.

A. Electricity-Heat Cogeneration

As a starting point society needs to upgrade the conventional fossil fuel power plants with that of Combined Heat and Power (CHP) plants. The CHP plants have about 95 percent energy efficiency as compared to the conventional power plants with energy efficiency on average at 38 percent [8]. This is because conventional power plants waste massive heat energy when producing electricity. This wasted heat could be used to heat residential homes or assist in industrial processes. Furthermore transmission losses could be reduced by building CHP plants near to the consumer, and not in centralised locations as we witness today. So efforts are required to (i) move from conventional power plants to CHP plants and (ii) replace large centralised power plants to smaller decentralised CHP plants to reduce energy transmission losses.

B. Multi-faceted energy generation

Although fossil fuel power plants and domain specific CHP plants will continue to play a central role in energy production; there is a need to diversify energy generation. The Scandinavian countries have taken the lead in wide spread off-shore wind farms, solar PV systems and geothermal energy production, both for electricity generation and district heating [9]. So in essence energy is produced everywhere by diversified sources depending on location and transported in every direction. As renewable energy generation becomes economically viable, this process will intensify and reduce the current dependence on conventional energy production.

This effort of injecting electricity generated from renewable energy into the power grid has significantly reduced the Scandinavian countries dependence on fossil fuels; and Denmark has set a target to become fully independent from fossil fuels by 2050 [10].

C. Intelligent dwellings

The future of residential homes will consist of ‘intelligent’ houses, where residents will be able to control energy consumption easily, conveniently and intelligently. For example, air-conditioning, heat pumps, freezers, refrigerators, washing machines and tumble dryers will all be controlled intelligently. The user could use an app

on the mobile phone to schedule operation of an appliance depending on the price of electricity. Also the gas-fired boiler would be replaced with an intelligent electrical heat pump. There would be a widespread use of electrical vehicles, for which charging would be done overnight when demand is low and consequently cheaper electricity. Electricity and heat consumption will also change in these houses as insulation would be much better.

Most people would start producing their own energy from renewable resources, such as PV cells on roofs or wind energy, heat pumps or micro CHP plants fuelled by Hydrogen tanks in the house basement. This would further lead to competitiveness amongst utility companies and consumers would buy electricity when cheap and sell back to the grid when demand would be high and thus electricity would be expensive. The important change is that we now have a two-way electricity supply, with distributed supply, where some power is generated from renewable resources and facilitating overall robustness of the grid in case of power outage.

D. The intelligent power system

In order to realise the transformation to a smart grid, a strong power system is needed. This power system must contain certain elements namely, (i) flexible production (ii) a robust power grid and (iii) demand response mechanism.

First, focus will be on generating electricity based on renewable resources. However when the sun is blocked by dense clouds or wind is not blowing, then backbone power stations will be required for power generation. These power stations should be able to quickly ramp their output up or down, to ensure power production and consumption always balance.

In the long term, these power stations need not generate electricity on fossil fuels alone, and can easily be replaced by, or converted into, plants running on biomass or biogas. Importance should also be placed on storing the excessive renewable energy, produced under favourable conditions, in large storage facilities for later use.

Second, a strong power grid is needed to transport large amount of renewable energy from where it is produced to where it will be consumed. This aspect is particularly relevant when harnessing the power of off-shore wind farms [11]. A strong power grid ensures that energy is produced where it is cheap and consumed where it is needed, and where it has the highest value. This will also result in stronger international ties between trans-border energy suppliers.

Third, the demand response mechanism will also be changed. Energy will not only be produced when it is required, but consumed when it is plentiful and cheap. Since electricity is the most perishable commodity in the world, in that it must be consumed the second it is produced, unless adequately stored. Therefore we must change our habits of consuming energy to the times of day when there is a surplus and the power grid is not so heavily loaded.

One way to optimise consumption is to store electricity in the form of heat, using heat pumps, in district heating plants. This idea is particularly useful in Northern Europe, where nations use huge amount of energy to heat homes and in industrial processes.

Surplus and cheap electricity could also be used to produce hydrogen in safe tanks in the basement or yard of the house. Later when demand is high, this hydrogen could be used to produce electricity and heat using fuel cells in a micro CHP plant [12], before purchasing electricity from the grid. Also this surplus energy could be sold back to the grid when price is high.

The future Smart Grid is an energy system that is intelligent, offering production, transport, load management and consumption of energy. Where, future “PROSUMERS” will be both producers and consumers of electricity at the same time using the smart grid.

Figure 5 depicts a future residential energy “prosumer” who consume energy through district Heat and national electricity grid but also produce energy through Solar PV, wind turbines and a microCHP resources. This is the future scenario of electricity generation and consumption that is aspired, where energy flows in both directions as per requirement.

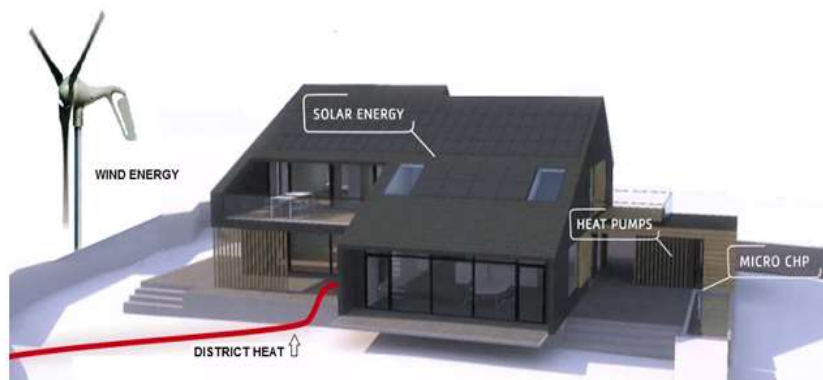


Figure 5. Intelligent homes both producing and consuming electricity

IV. Conclusion

In this paper we have discussed the challenges that must be overcome to fully benefit from the energy grid. These challenges include technological challenges, business and financial challenges as well as societal norms of using energy. In terms of technological challenges, the current and conventional electricity production must be reviewed in which a greater heterogeneity of energy resources that can be accommodated. These resources must have higher focus on renewable energy; even if the initial implementation costs are high. Also importance must be placed on developing flexible and changing technologies that are required to build interfaces between technology components. This technological advancement will assist mitigate carbon emissions and help cap global pollutions. In terms of business incentives and financial viability, it is important to communicate the value proposition of a smart grid deployment. Each stakeholder must be made aware of the end goal and the benefits that it will bring. This may not always be easy as the financial risks and rewards can change business plans for smart grid investments. However, most of the uncertainties and risks can be quelled by building strong regulatory body and develop incentive schemes for both businesses and consumers. A fundamental change in societal norms is needed to implement policy objectives, which may include affordability of introducing renewable energy, sustainability of energy supply, and changing of consumption patterns. Therefore the consumers must be on board for understanding and accounting for the benefits of the smart grid. Furthermore, incentive mechanisms for job creation and development of a technically skilled workforce are essential for advancement. These steps will help move the world towards a sustainable future.

References

- [1] Muhammad Azhar Khan, Muhammad Zahir Khan, Khalid Zaman, Mariam Arif, Global estimates of energy-growth nexus: Application of seemingly unrelated regressions, *Renewable and Sustainable Energy Reviews*, Volume 29, January 2014, Pages 63-71, ISSN 1364-0321, <http://dx.doi.org/10.1016/j.rser.2013.08.088>.
- [2] Salvador Ruiz-Romero, Antonio Colmenar-Santos, Francisco Mur-Pérez, África López-Rey, Integration of distributed generation in the power distribution network: The need for smart grid control systems, communication and equipment for a smart city — Use cases, *Renewable and Sustainable Energy Reviews*, Volume 38, October 2014, Pages 223-234, ISSN 1364-0321, <http://dx.doi.org/10.1016/j.rser.2014.05.082>.
- [3] K.S. Reddy, Madhusudan Kumar, T.K. Mallick, H. Sharon, S. Lokeshwaran, A review of Integration, Control, Communication and Metering (ICCM) of renewable energy based smart grid, *Renewable and Sustainable Energy Reviews*, Volume 38, October 2014, Pages 180-192, ISSN 1364-0321, <http://dx.doi.org/10.1016/j.rser.2014.05.049>.
- [4] K. Kauhaniemi, 4 - Integration of distributed energy resources (DER) to the grid, In *Woodhead Publishing Series in Energy*, edited by Ziad Melhem, Woodhead Publishing, 2013, Pages 108-129, *Electricity Transmission, Distribution and Storage Systems*, ISBN 9781845697846, <http://dx.doi.org/10.1533/9780857097378.1.108>.
- [5] James Carroll, Seán Lyons, Eleanor Denny, Reducing household electricity demand through smart metering: The role of improved information about energy saving, *Energy Economics*, Volume 45, September 2014, Pages 234-243, ISSN 0140-9883, <http://dx.doi.org/10.1016/j.eneco.2014.07.007>.
- [6] Thomas L. Webb, Yael Benn, Betty P.I. Chang, Antecedents and consequences of monitoring domestic electricity consumption, *Journal of Environmental Psychology*, Volume 40, December 2014, Pages 228-238, ISSN 0272-4944, <http://dx.doi.org/10.1016/j.jenvp.2014.07.001>.
- [7] Henrik Lund, Sven Werner, Robin Wiltshire, Svend Svendsen, Jan Eric Thorsen, Frede Hvelplund, Brian Vad Mathiesen, 4th Generation District Heating (4GDH): Integrating smart thermal grids into future sustainable energy systems, *Energy*, Volume 68, 15 April 2014, Pages 1-11, ISSN 0360-5442, <http://dx.doi.org/10.1016/j.energy.2014.02.089>.
- [8] Jan-Olof Anderson, Andrea Toffolo, Improving energy efficiency of sawmill industrial sites by integration with pellet and CHP plants, *Applied Energy*, Volume 111, November 2013, Pages 791-800, ISSN 0306-2619, <http://dx.doi.org/10.1016/j.apenergy.2013.05.066>.
- [9] Hadi Ghasemi, Elysia Sheu, Alessio Tizzanini, Marco Paci, Alexander Mitsos, Hybrid solar-geothermal power generation: Optimal retrofitting, *Applied Energy*, Volume 131, 15 October 2014, Pages 158-170, ISSN 0306-2619, <http://dx.doi.org/10.1016/j.apenergy.2014.06.010>.
- [10] Pil Seok Kwon, Poul Alberg Østergaard, Comparison of future energy scenarios for Denmark: IDA 2050, CEESA (Coherent Energy and Environmental System Analysis), and Climate Commission 2050, *Energy*, Volume 46, Issue 1, October 2012, Pages 275-282, ISSN 0360-5442, <http://dx.doi.org/10.1016/j.energy.2012.08.022>.
- [11] Xiaoxia Gao, Hongxing Yang, Lin Lu, Study on offshore wind power potential and wind farm optimization in Hong Kong, *Applied Energy*, Volume 130, 1 October 2014, Pages 519-531, ISSN 0306-2619, <http://dx.doi.org/10.1016/j.apenergy.2014.02.070>.
- [12] Tekena Craig Fubara, Franjo Cecelja, Aidong Yang, Modelling and selection of micro-CHP systems for domestic energy supply: The dimension of network-wide primary energy consumption, *Applied Energy*, Volume 114, February 2014, Pages 327-334, ISSN 0306-2619, <http://dx.doi.org/10.1016/j.apenergy.2013.09.069>.