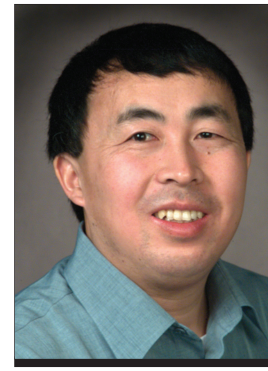
Empowering the Smart Grid with Wireless Technologies



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During the late 19th and early 20th centuries, electric power had replaced steam power as the driving force of the second industrial revolution. Critical inventions such as electric lighting and electric motors had significantly improved the production rate, transportation efficiency, and people's living standard. As named by the National Academy of Engineering (NAE), electrification is "the most important engineering achievement of the 20th century." As we enter the 21st century, the focus is on the green economy. Therefore, some of the basic assumptions and/or concepts of the original power grids gradually become obsolete and need to be updated. One obvious example comes from the fast growing deployment of distributed generation (DG) of electricity all over the world. According to the International Energy Agency (IEA), solar power can contribute 2.3 percent to the world's power by 2020, rising to 8.8 percent by 2030. Based on the forecast of BTM Consult, wind power market penetration is expected to reach 3.35 percent by 2013 and 8 percent by 2018. Coming along with the potential economic and environmental benefits of DG are the increased concerns about power system stability and reliability. Specifically, traditional electricity consumers are being gradually transformed into electricity "prosumers" who not only consume energy but also produce energy and send it back to the power grid. As a result, the basic assumption of unidirectional electricity delivery (from centralized generators to electricity customers) in traditional power grids is no longer suitable. Advanced power system operation mechanisms should be developed to address specific characteristics of the DG, such as the sunlight-dependent power generation of solar plants. Similar problems exist in traditional power grids as more and more electric vehicles (EVs) are integrated for transportation efficiency improvement, while more and more smart-meters are installed for household demand response purposes. All these surging demands require a transition of the current electric power grid toward a new generation of power grid, commonly referred to as the "smart grid."

Information and communication technologies have been significantly advanced over the last decades, which can be applied to enhance the stability and reliability of the power grid. Both wireline and wireless communication technologies can be used for the communication infrastructures of the smart grid. The wireline network such as fiber-optic network is typically used in traditional power grid to facilitate power system operation and control at extremely low latency. As the cost of deploying a wireline network is relatively high, the application is typically limited to utility-level communications (e.g. among the distribution substations), while the communications within the distribution systems (i.e. below the substation level) are not very common. Power line communications (PLC) enjoys the benefit of existing communication infrastructures in terms of power transmission lines and are more cost-effective than traditional wireline communications. However, since the power lines are not originally designed for communication purposes, PLC is more suitable for home automation and long-haul low-rate communications in transmission systems where the electromagnetic interference (EMI) is not extensive. In comparison with wireline networks, wireless networks have the advantage of low deployment cost and high flexibility, and are gaining more and more interest from both academia and industry for smart grid applications. The smart grid mainly requires three levels of communication networks, including home area networks (HANs) for the interconnections of household appliances; neighborhood area networks (NANs) for communications among smart meters, DG units, and distribution system devices; and wide area networks (WANs) for utility-level communications among upstream assets such as power plants and substations. Wireless communication technology can provide efficient solutions for all three levels of network infrastructures. Currently, wireless networks are widely used for smart meter applications and are clearly frontrunners for HANs (see "The path of the smart grid," IEEE Power Energy Mag., 2010). In what follows, I briefly discuss the critical issues of empowering the future smart grid with wireless networks.

Large-Scale DG Integration in Distribution Systems

Substantially increasing the penetration of sustainable energy (such as wind and solar energy) is a major objective of the smart grid. Although the utility-level wind/solar farms can be well controlled, as they are typically integrated in the subtransmission systems which are owned by the utilities, the adoption of sustainable energy based DG in the distribution systems poses great challenges on smart grid monitoring and control. One of the most critical problems limiting the DG penetration rate is the voltage rise problem, which is caused by the time-dependent nature of a DG output. As real and reactive power is injected at the DG connection point, the voltage at the connection point rises and is potentially greater than the regulatory limit. Although traditional methods such as network reinforcement and reactive power compensation can somehow solve this problem, they are not suitable for DG since the distribution network is extremely sensitive to monetary expenditure and the feeder resistance is comparable to feeder reactance. In order to push the level of DG installation to its theoretical limits, i.e. the thermal limit of the feeder, making the distribution system smarter is indispensable. In the context of smart grid, voltage regulators are deployed at strategic locations of a feeder to adjust the voltage set point, while remote terminal units (RTUs) are deployed at the DG connection points or critical load buses for voltage measurement and report. WiFi and ZigBee devices can be used to establish multi-hop communications among the RTUs at low deployment cost and negligible operation costs. The existing cellular communication infrastructure (e.g. 3G and LTE) can provide high-speed low-latency communications for emergency voltage report (e.g. significant voltage deviation caused by the start-up of critical loads) from an RTU to a voltage regulator. With such fine-tuned voltage regulation, large-scale DG integration in distribution systems becomes possible. Moreover, the highly flexible wireless networks perfectly fit the plug-and-play nature of the RTUs. As no re-wiring is required when deploying additional wireless communication RTUs, a smooth transition for making the distribution system smarter can be expected.

Pervasive EV Monitoring and Control

EV integration is another major issue in the smart grid. Most of the power distribution systems were built decades ago without considering the impact of EVs. For instance, if all EVs start to recharge their batteries during a mid-night off-peak period when the electricity is cheap, the thermal limits of the feeders and the capacity limits of the distribution transformers may be violated. On the other hand, EVs with vehicle-to-grid (V2G) capabilities can in turn compensate for the peak power demand by releasing excess energy back to the grid. However, if many vehicles discharge their batteries simultaneously when the electricity price is high, the frequency of the power grid can become unstable. In order to achieve a proper coordination among the recharging/discharging processes, "on-the-go" information exchange between the EVs and the power grid is indispensable since vehicles are mobile in nature. For instance, the location information, battery status, and recharging/discharging demand of EVs can be submitted to the utilities when the vehicles are moving. Then, the real-time electricity price can be calculated by the utilities based on the information collected at different locations. In this way, the electricity price can be used as a steering signal to regulate the recharging/discharging demand to maintain the power system stability. Obviously, wireless networks are the only choice for such information exchange. The information exchange can be performed through the existing cellular communication networks, which provide nearly ubiquitous coverage over the mobile vehicles. To further reduce communication costs, the emerging vehicular ad hoc networks (VANETs) with vehicle-to-infrastructure (V2I) communication capabilities can be used. The existing wireless networks for smart meters can also be used as auxiliary communication infrastructures, given that related issues such as mobility support and horizontal/vertical handover are properly addressed.

Cyber-Physical Security and Privacy

In the traditional power system operation, the system security (or physical security) corresponds to the reliability of power delivery. For instance, the North American Electric Reliability Council (NERC) emphasizes that the system operators maintain sufficient ancillary services under n-1 contingency conditions (e.g. under the loss of one critical generator). In the context of smart grid, various issues of cyber security emerge because of the application of communication technologies. The security issues are even more severe in wireless networks, which are based on the broadcast radio medium. A malicious attack can be easily launched via a wireless network by injecting fake measurement data and control signals to threaten the physical security of the power grid. The attacks can mimic the fault in transmission systems or the loss of generation beyond the n-1 contingency conditions. As a result, cascade failures in the power grid are likely unavoidable, which results in large-scale blackouts. To prevent such attacks, all the data transmitted in the smart grid should be verified. User privacy is also of paramount importance because of the introduction of smart meters. The power consumption data of electricity customers is closely related to their daily activities. For instance, low household power consumption reveals the absence of family members, and vice versa. End-to-end encryption should be performed to protect the data confidentiality, while the computational and communication overhead should be reduced, taking account of the limited capabilities of low-cost smart meters.

In conclusion, by integrating the electric power grid with information and communication technologies, the smart grid will bring huge economic and environmental potential to the current trend of green economy. As most of the world's electric power grids are still in the initial stages of a transition toward the smart grid, initiatives for long-term research and development activities are required from both academia and industry, which is interdisciplinary in nature and requires the understanding of both power grid and wireless networking technologies. I hope this Editor's Note is helpful with respect to "empowering the smart grid with wireless networking technologies."