Chapter 2
Communication for Control in Heterogeneous Power Supply

The need to modernize the power grid infrastructure, and governments' commitment for a cleaner environment, is driving the move towards clean renewable sources of energy and many countries are now building power plants using green energy sources such as wind turbines and photovoltaic systems. Whilst these big energy generation stations will certainly help in addressing the environmental and energy dependence aspects, the related power grid management and congestion avoidance issues during peak demand remains a serious challenge that needs to be addressed.

One way of solving this problem is to bring these renewable energy generation sources closer to the consumer by connecting them directly to the distribution network. In many countries, consumers are encouraged by their respective governments to install renewable energy generators on their premises. In many cases these residential energy generators are capable of covering the consumer's electricity usage and could represent a cheaper alternative to electricity supplied from the central power station in the long term. In particular, the supply of isolated locations with electricity comes at a greatly increased cost to the utilities as the majority of the energy that enters the system is wasted in the form of heat before delivering any useful energy to the consumer. Therefore, bringing the electricity source to the consumers might be a more economical and reliable option.

In the smart grid, it is envisaged that these so called Distributed Energy Resources (DER) will become increasing pervasive within the distribution network. Moreover, DER will not be limited to satisfying local users' electricity demands, but could also use any excess to supply neighbours, and local communities. Ultimately, incentives offered by a future deregulated energy market will help consumers to choose the source of their electricity in near real time. For instance, a consumer could alternate between utilities electricity, and electricity provided by neighboring residents according to the price of electricity at a given time.

The implementation of this heterogeneous energy supply paradigm, however, implies a radical change from the centralized one-way electricity supply that characterizes the current power grid, to a two way electricity supply paradigm. Flexibility will be paramount to realize this vision, and therefore the system that governs control operation in the grid will need to be redesigned, particularly with regard to

F. Bouhafs et al., *Communication Challenges and Solutions in the Smart Grid,*
SpringerBriefs in Computer Science, DOI 10.1007/978-1-4939-2184-3_2

the communications aspects. In current control systems, these facilities are generally monitored by a relatively limited number of sensors that are deployed at critical places in the distribution network. This sparse deployment of control devices limits the penetration of the control system and does not provide an extensive, accurate real-time view of the network's status. Therefore, these control systems will not be able to address the challenge of ensuring a stable and healthy distribution network incremented with distributed generation as envisioned in the smart grid. In this chapter we will emphasize the importance of communications and wireless technology in modernizing control systems to support electricity flow management in the smart grid. We will present the limitations of existing control systems and the communications challenges that need to be addressed in order to provide more reliable control systems.

2.1 Control in Traditional Power Networks

The power network covers wide geographical areas and delivers electricity from large central power generation stations towards consumers via reliable transmission grids. Typically, a power grid consists of power cables that connect the power station to the consumers and different transformers and control entities, as depicted in Fig. 2.1. Transmission networks are used to send high voltage electricity towards urban areas, where distribution networks are then used to supply medium and low voltage electricity to consumers. These networks consist of substations, transformers, poles, and load wires that connect consumers to the power grid.

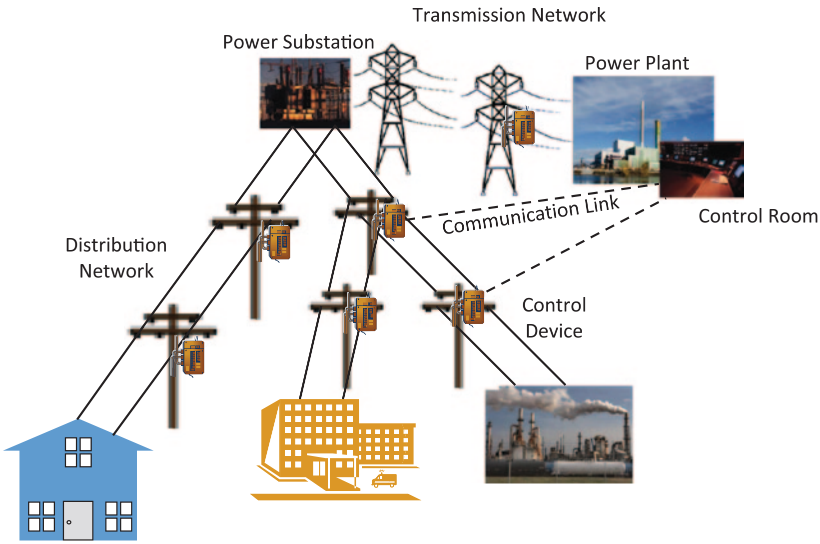

Fig. 2.1 Example of a power grid and its components

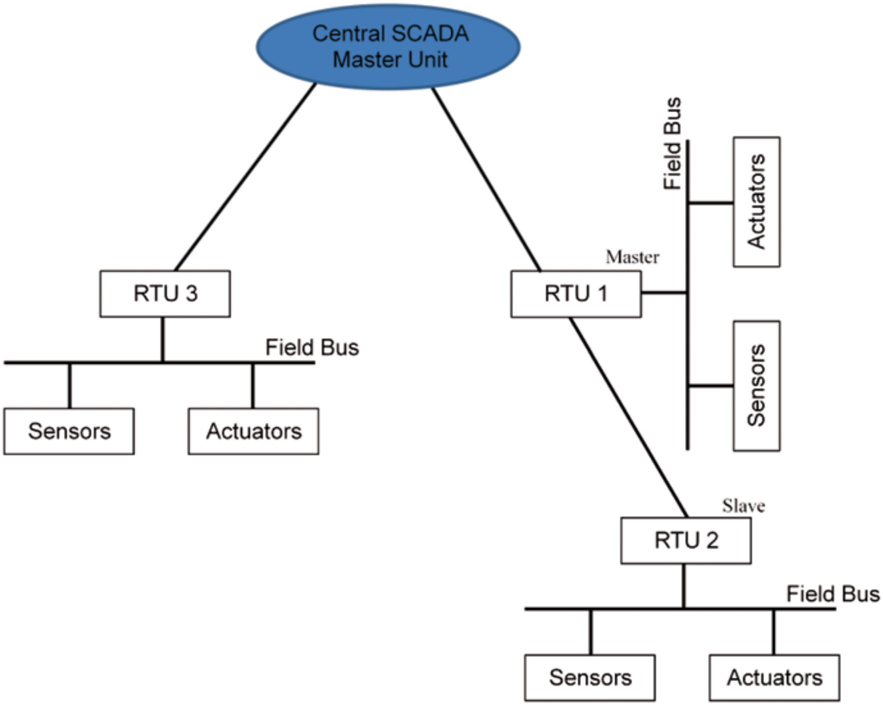

Fig. 2.2 Remote terminal unit in SCADA systems

Currently, power grids are monitored by legacy Supervisory Control And Data Acquisition (SCADA) [1] systems that are composed of control devices, generally called remote terminal units (RTUs), as depicted in Fig. 2.2. The RTU represents a contact point with field sensors and actuators through a field bus. It allows the SCADA system to collect measurements from sensors such as current sensors, and to send control commands to actuators, such as relay points and circuit breakers. In addition, the SCADA system comprises a central Master Unit computer, which is usually composed of one or more servers that represents the interface between the operator and the SCADA system. The role of the central host computer is primarily the processing of data collected from different field-based control devices and presenting them in a readable format to the operator. The communication network is central to this process as it allows data transfer between the control center and the field-based devices, and it comprises typical IT equipment such as routers, switches, modems, etc. These legacy systems were built around a hierarchical and centralized communication approach, where an RTU sends its messages to its direct one-hop RTU neighbor that acts as its master, usually using a multi-drop communication mode. This process is repeated until the data reaches the master processing unit of the SCADA system.

However, as the power grid scales up, particularly with regard to the number and type of monitoring devices being deployed, it is clear that this system may run into a number of issues. First, this type of SCADA system is not designed to handle the number of connected devices being envisioned. If one considers that the number of devices deployed into such a network might realistically be expected to grow by several orders of magnitude then it is easy to appreciate the problem of aggregating data at master RTUs close to the Master Unit. Moreover, such a monitoring network will need to support the much richer information supplied by modern devices, necessitating the provision of dedicated high bandwidth links. Finally, as we have seen, failures in such equipment are entirely possible and hence and system must be designed to be robust. Current systems are not designed in this way and new approaches may well look to adopt the lessons learnt from Internet engineering for managing the communication infrastructure.

2.2 Distributed Generation and Active Control

The integration of small renewable generators into power networks will offer a cheaper supply option to consumers and help supply isolated consumers, hence increasing the reliability of the power grid and reducing its operation costs. However, it is clear that managing this new system will also require a new control system to effectively manage it. This new system will require utilities to move away from the traditional centralized approach and adopt a more distributed, collaborative, and dynamic paradigm.

The introduction of DER into the power grid will create new issues for the distribution network operators (DNOs) [2, 3]. While in traditional power grids the electricity usually flows from the central power stations to the consumers, in a smart power grid incremented with DER, the electricity now flows in two directions, either from the station to the consumer or from the consumer DER back into the grid, as shown in Fig. 2.3. To introduce DER, DNOs will therefore be faced with the challenge of making their power distribution networks more flexible and dynamic. For example, the loads in distribution lines have strict thermal and voltage capacities, which cannot be exceeded. As such, the connection of small generators with variable output rates, such as wind turbines, will represent a risk to the stability of the network unless it is managed carefully.

Despite this challenge, this new paradigm offers some very powerful features that could be used to improve grid performance and reliability. Figure 2.4 depicts an example of an area isolated and cut from the power supply due to a fault that occurred on a feeder which resulted in the opening of the breaker B1. Under this new model, the isolated area could be re-supplied with electricity through generator G1, once breaker B2 is closed. In this case, DER represents a cheaper and more robust solution to deliver energy closer to the consumer than with only the centralized DNO power grid.

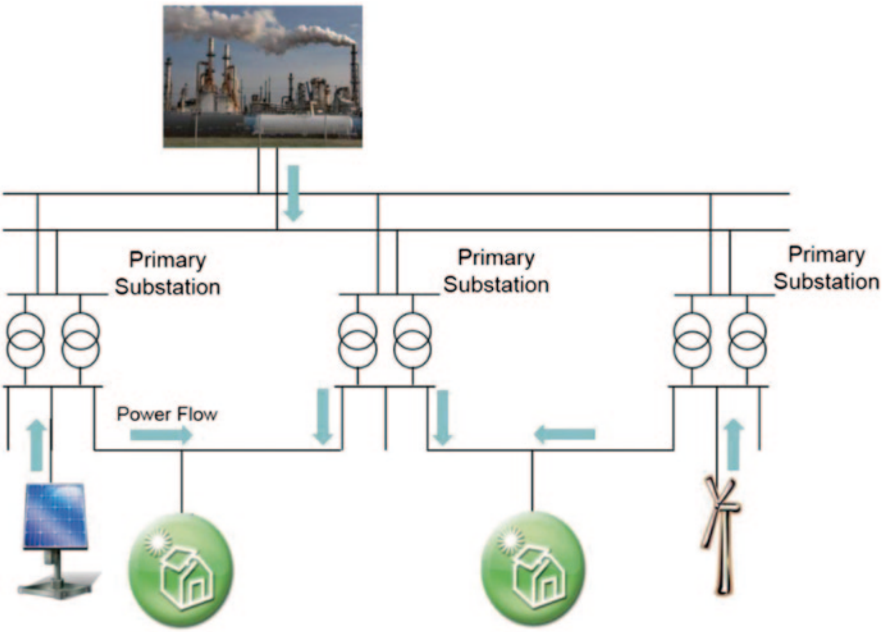

Fig. 2.3 Power grid with distributed generation

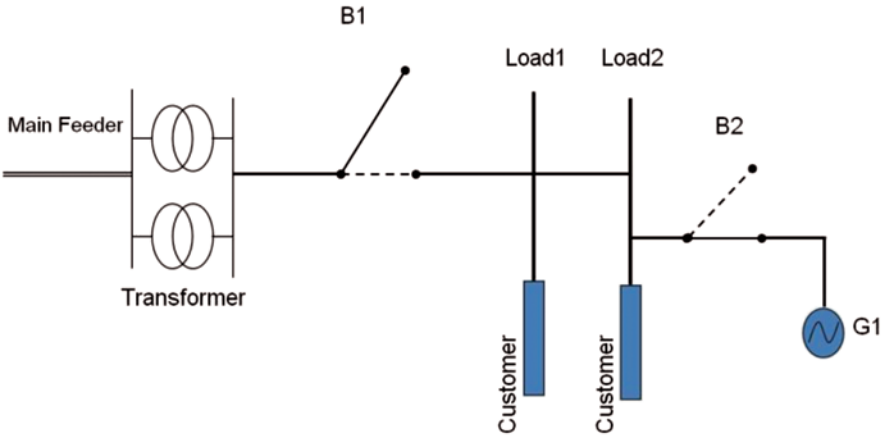

Fig. 2.4 Power re-supply with distributed generation

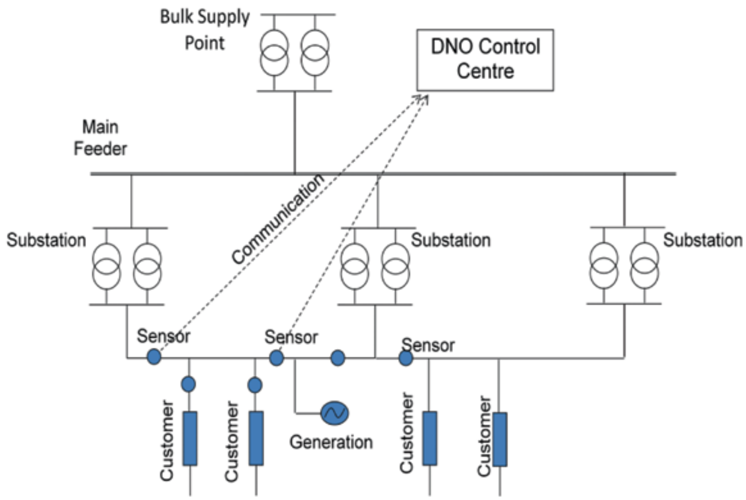

Fig. 2.5 Communication in centralised active control system

More broadly speaking, the distribution network therefore needs to be flexible enough to redirect the flow of excess electricity to other grid segments, or find alternative paths to supply the designated consumers [4, 5]. In such a case, the actual topology of the network will require modification and DNOs' control systems will therefore need to move from passive control to a more active control model whereby the distribution network can be modified and re-configured dynamically according to changes in the power flow [6].

Active control is predicated on continuous real time monitoring and management of the power network. Therefore, sensors need to be deployed in far larger numbers than are currently in order to efficiently monitor the power network conditions. These measurements will need to be taken across the entire distribution network, as illustrated in Fig. 2.5.

Moreover, many works in the area of active control are advocating the move from the current centralised active control model towards a more autonomous active control paradigm [7–9]. In this model, distribution networks are divided into micro-grids, where each micro-grid is formed by the interconnection of distributed generators and autonomous intelligent controllers that are deployed to manage them. In this case, rather than report to the central controller, sensor data will be transmitted to the intelligent controllers and local control decisions will be taken there, as illustrated in Fig. 2.6. In this situation, intelligent controllers will also be required to work in collaboration with neighboring micro-grids and will need to exchange control data [10–12]. Therefore, the availability of a high performance and pervasive communication network is crucial for the realisation of an active distributed control system design.

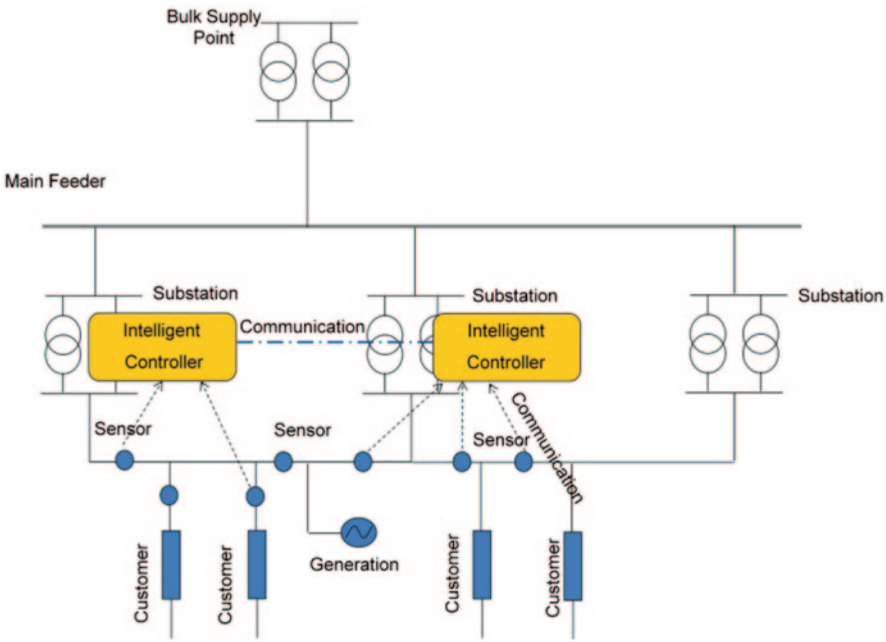

Fig. 2.6 Communication in autonomous active control

2.3 Communications Challenges in Active Control

The realization of a heterogonous power grid that could support distributed renewable generators in addition to traditional bulk power supply therefore requires flexible and active control mechanisms. However, to implement these mechanisms it is important to first understand their communication requirements. The study of active control presented above helps to identify two connectivity requirements:

- *Connectivity between intelligent controllers*: Intelligent controllers need to be interconnected in order to allow for collaborative and distributed control over the power network via micro-grids. This connectivity will allow the controllers to exchange coordination messages before execution of any control action over the power network.
- *Connectivity between intelligent controllers and field-devices*: In order to execute control actions, controllers both need input from sensors in the power network such as measurements, alarms, etc., in addition to the ability to send control commands to actuators in the field.

These requirements show that interconnections will be needed to carry two specific types of data traffic: one will be used to carry inter-controller coordination messages, the other will be used to transmit field-devices monitoring reports. The design of each connection relies on the study of the characteristics of the relevant traffic. This section will help to identify the communication solutions required.

2.3.1 Inter-Controller Coordination Traffic

The implementation of autonomous control with intelligent controllers is predicated on the deployment of a Multi-Agent Systems (MAS) within these intelligent controllers [13, 14] to form a distributed system, akin to modern web services. MAS are characterized by a continuous interaction via entities, usually called agents. Therefore, the collaboration process between these intelligent controllers can effectively be modelled as data exchanges between software agents that form a MAS.

To ensure interoperability between agents, MAS specify the use of a common Agent Communication Language (ACL) that provides a basis for inter-agent communication. The most common ACLs include Knowledge Query and Manipulation Language (KQML) and Foundation for Intelligent Physical Agents (FIPA) [15]. The specifications of ACLs make some assumptions about the underlying transport communication protocols. For instance, in the FIPA specifications, there is an implicit assumption that the underlying data communication network used to transfer information between remote agent platforms is based on the TCP/IP protocol stack, as illustrated in Fig. 2.7. This allows agents to communicate over arbitrary distances with a reasonable degree of reliability.

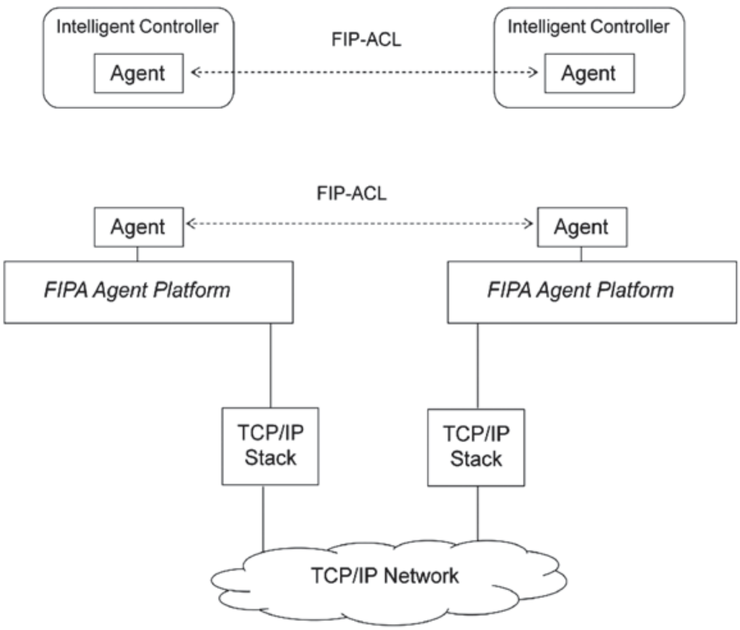

Fig. 2.7 FIPA-ACL communications over TCP/IP

A study published in [15] shows that a simple Request/Agree exchange between two agents based on FIPA-ACL over a communication network generates two messages of sizes: 1408 bytes, and 2854 bytes respectively. Moreover, since the ACL is expected to run over a standard protocol stack, such as TCP/IP, the ACL messages are embedded (encapsulated) into a new message with extra control overhead added at each layer of the protocol stack.

2.3.2 Field-Device Control Traffic

Dense deployment of monitoring devices in the distribution power network is vital to the success of active control. Such dense deployment of control devices, however; will induct extra data traffic that includes all types of measurements and control messages, such as: fault passage indications and reports generated by RTUs deployed in the distribution network. Currently, most of these field devices are using proprietary communication protocols, such as WISP+and Ferranti [16], to send their data however; in the future these devices are expected to use a common communication protocol, which will facilitate interoperability between devices from different manufacturers.

This data traffic includes all measurement, fault passage indications, and reports generated by RTUs deployed at medium and low voltage distribution network (11 kV). The most important issue with this traffic is therefore to have a unified data model for all the RTUs. Such a unified model will make the communication between the RTUs and the intelligent controller easier, and avoid the need for translation gateways at each end of the communication link. There are many standards that have been proposed in this area that aim to provide such a common control model for power network monitoring field devices [17, 18]. For instance, DNP3 [19] was among the first protocols to have been designed to offer an open standard control system for power networks. DNP3 was based on the paradigm of exchanging generic control data while respecting the bandwidth constraints of the physical links. As such, DNP3 protocol could work with a minimum control overhead allowing it to run over communication channels with operating bit rates as low as 1200 bits per second by adjusting the size of the messages sent by control devices and reducing their sampling rates [16].

More recently, the International Electro technical Commission (IEC) proposed a new standard that targets interoperability and fast communication between Intelligent Electrical Devices (IEDs) called IEC61850 [20, 21]. The superiority of IEC61850 over other communication standards in substations is that the functions, the services, and the communication protocols are not mixed together but are defined separately. Moreover, the standard contains the data models of all possible functions in a substation, and standardizes the names of these functions and their data. Similarly, the standard specifies a set of generic abstract services which cover all the data transfers required within a substation and maps these abstract services and the standardized data onto real communication protocols which include Ethernet, TCP/IP and Manufacturing Message Specification (MMS) [22]. A study in [23] show that IEC61850 can use a common data model in substation automation even over low bandwidth networks, by adjusting the control messages sizes and the sampling rates of the IEDs. Hence, coordination traffic, and the field-device data traffic has relatively lower bandwidth requirements. However, recall that distributed control systems are projected for use in future power networks; hence they need to be extensible for future control functionalities. This implies that the communication solution that will be deployed to carry this traffic needs to be scalable both in cost and in performance.

2.4 Conclusion and Open Issues

The smart grid will be characterized by its ability to support heterogeneous energy supply with a mixture of traditional large power stations, and small renewable energy sources. The management of the power flow in this model will therefore become increasingly challenging and will require the modernization of the control and communication systems that govern the power grid. Active control aims to replace the existing passive control systems that govern today's power grid and providing better management of these energy flows. This control paradigm, however, is predicated on the dense deployment of sensors, and seamless coordination between autonomous controllers.

In particular, the implementation of active control for distribution and generation necessitates the introduction of changes in the communication infrastructure that supports control operations in the power grid. This communication infrastructure cannot currently support the control traffic generated by thousands of extra sensors and control devices that will be added to control the power grid. The study published in [24] shows that adding active control systems to manage small distributed generators increases the grid communication traffic overheads which, without proper management, may result in congestion and message loss which in turn will potentially threaten the performance of grid control operations.

Therefore, the existing communication infrastructure first needs to be urgently upgraded in terms of transmission capacity to support this extra control traffic. In addition, new communication links will need to be added in order to connect intelligent controllers and support the coordination of traffic. An upgrade of the communication infrastructure, however, will necessitate a full study of existing communication technologies in terms of performance, ease of deployment, and cost.

References

1. D. Bailey, and E. Wright, *Practical SCADA for industry*. 2003: Newnes.
2. Y. Sun, and N.H. El-Farra, *Integrating control and scheduling of distributed energy resources over networks*, in Advanced Control of Chemical Processes, vol. 7, n. 1: pp. 141–146, 2009.
3. P. Lopes, et al., Integrating Distributed Generation into Electric Power Systems: A Review of Drivers, Challenges and Opportunities, in Electric Power Systems Research, vol. 77, n. 9: pp. 1189–1203, 2007.

Springer

http://www.springer.com/978-1-4939-2183-6

Communication Challenges and Solutions in the Smart Grid

Bouhafs, F.; Mackay, M.; Merabti, M.

2014, IX, 95 p. 25 illus., Softcover
ISBN: 978-1-4939-2183-6