Chapter 2
Smart Grid

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Abstract All over the world, electrical power systems are encountering radical change stimulated by the urgent need to decarbonize electricity supply, to swap aging resources and to make effective application of swiftly evolving information and communication technologies (ICTs). All of these goals converge toward one direction; 'Smart Grid.' The Smart Grid can be described as the transparent, seamless, and instantaneous two-way delivery of energy information, enabling the electricity industry to better manage energy delivery and transmission and empowering consumers to have more control over energy decisions. Basically, the vision of Smart Grid is to provide much better visibility to lower-voltage networks as well as to permit the involvement of consumers in the function of the power system, mostly through smart meters and Smart Homes. A Smart Grid incorporates the features of advanced ICTs to convey real-time information and facilitate the almost instantaneous stability of supply and demand on the electrical grid. The operational data collected by Smart Grid and its sub-systems will allow system operators to quickly recognize the best line of attack to protect against attacks, susceptibility, and so on, sourced by a variety of incidents. However, Smart Grid initially depends upon knowing and researching key performance components and developing the proper education program to equip current and future workforce with the knowledge and skills for exploitation of this greatly advanced system. The aim of this chapter is to provide a basic discussion of the Smart Grid concept, evolution and components of Smart Grid, environmental impacts of Smart Grid and then in some detail, to describe the technologies that are required for its realization. Even though the Smart Grid concept is not yet fully defined, the chapter will be helpful in describing the key enabling technologies and thus allowing the reader to play a part in the debate over the future of the Smart Grid. The chapter concludes with the experimental description and results of developing a hybrid prediction method for solar power which is applicable to successfully implement the 'Smart Grid.'

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2.1 Introduction

The majority of the world's electricity delivery system or 'grid' was built when energy was reasonably low cost. While minor upgrading has been made to meet rising demand, the grid still operates the way it did almost 100 years ago—energy flows over the grid from central power plants to consumers, and reliability is ensured by preserving surplus capacity [1]. The result is an incompetent and environmentally extravagant system that is a foremost emitter of greenhouse gases, consumer of fossil fuels, and not well suited to distributed, renewable solar and wind energy sources. Additionally, the grid may not have ample capacity to meet future demand.

Continued economic growth and fulfillment of high standards in human life depends on reliable and affordable access to electricity. Over the past few decades, there has been a paradigm shift in the way electricity is generated, transmitted, and consumed. However, fossil fuels continue to form a dominant initial source of energy in the industrialized countries. The steady economic growth of some of those industrialized countries gradually exposed the unsustainable nature of the energy policy that is highly dependent on foreign fossil fuels. On the other hand, an aging power grid that faces new challenges posed by higher demands and increasing digital and nonlinear loads has placed new reliability concerns as observed with frequent outages in the recent years. Sensitivity of digital equipment, such as data centers, and consumer electronics, into intermittent outages has redefined the concept of reliability. As a result, power generation, transmission, and consumption has been the focus of investigations as to see what remedies will address the above challenges, thereby transforming the power grid into a more efficient, reliable, and communication-rich system [2]. Smart power grid is a host of solutions that is aimed to realize these lofty goals by empowering customers, improving the capacity of the transmission lines and distribution systems, providing information and real-time pricing between the utility and clients, and higher levels of utilization for renewable energy sources to name a few.

The present revolution in communication systems, particularly stimulated by the Internet, offers the possibility of much greater monitoring and control throughout the power system and hence more effective, flexible, and lower-cost operation. The Smart Grid is an opportunity to use new information and communication technologies (ICTs) to revolutionize the electrical power system [3]. However, due to the huge size of the power system and the scale of investment that has been made in it over the years, any significant change will be expensive and requires careful justification.

The consensus among climate scientists is clear that man-made greenhouse gases are leading to dangerous climate change. Hence, ways of using energy more effectively and generating electricity without the production of CO_2 must be found. The effective management of loads and reduction in losses and wasted energy need accurate information, while the use of large amounts of renewable generation requires the integration of the load in the operation of the power system in order to help balance supply and demand. Smart meters are an important element of the Smart Grid as they can provide information about the loads and hence the power flows throughout the network. Once all the parts of the power system are monitored, its state becomes observable and many possibilities for control emerge. In the future, the anticipated future de-carbonized electrical power system is likely to rely on generation from a combination of renewables, nuclear generators, and fossil-fuelled plants with carbon capture and storage. This combination of generation is difficult to manage as it consists of variable renewable generation and large nuclear and fossil generators with carbon capture and storage that, for technical and commercial reasons, will run mainly at constant output [3]. It is hard to see how such a power system can be operated cost-effectively without monitoring and control provided by a Smart Grid.

2.2 Smart Grid: The Definitions

The concept of Smart Grid combines a number of technologies, customer solutions and addresses several policy and regulatory drivers. Smart Grid does not have any single obvious definition. The European Technology Platform [4] defines the Smart Grid as:

> A Smart Grid is an electricity network that can intelligently integrate the actions of all users connected to it—generators, consumers and those that do both—in order to efficiently deliver sustainable, economic and secure electricity supplies.

In Smarter Grids: The Opportunity [5], the Smart Grid is defined as:

> A smart grid uses sensing, embedded processing and digital communications to enable the electricity grid to be observable (able to be measured and visualised), controllable (able to manipulated and optimised), automated (able to adapt and self-heal), fully integrated (fully interoperable with existing systems and with the capacity to incorporate a diverse set of energy sources).

According to the U.S. Department of Energy [6]:

> A smart grid uses digital technology to improve reliability, security, and efficiency (both economic and energy) of the electrical system from large generation, through the delivery systems to electricity consumers and a growing number of distributed-generation and storage resources.

From the aforementioned definitions, the Smart Grid can be described as the transparent, seamless, and instantaneous two-way delivery of energy information, enabling the electricity industry to better manage energy delivery and transmission and empowering consumers to have more control over energy decisions. A Smart Grid incorporates the benefits of advanced communications and information technologies to deliver real-time information and enable the near-instantaneous balance of supply and demand on the electrical grid. One significant difference between today's grid and the Smart Grid is two-way exchange of information between the consumer and the grid. For example, under the Smart Grid concept, a smart thermostat might receive a signal about electricity prices and respond to higher demand (and higher prices) on the grid by adjusting temperatures, saving the consumer money while maintaining comfort. Figure 2.1 shows a snapshot of the deliverance of the Smart Grid.

Introducing Smart Grid to the electrical power grid infrastructure will:

- ensure the reliability of the grid to levels never thought possible
- allow for the advancements and efficiencies yet to be envisioned
- exerting downward pressure on electricity prices
- maintain the affordability for energy consumers
- provide consumers with greater information and choice of supply
- accommodate renewable and traditional energy resources
- enable higher penetration of intermittent power generation sources
- revolutionizing not only the utility sector but the transportation sector through the integration of electrical vehicles as generation and storage devices
- finally, the Smart Grid will promote environmental quality by allowing customers to purchase cleaner, lower-carbon-emitting generation, promote a more even deployment of renewable energy sources, and allow access to more environmentally friendly central station generation. Furthermore, the Smart Grid will allow for more efficient consumer response to prices, which will reduce the need for additional fossil fuel-fired generation capacity, thereby reducing the emission of CO_2 and other pollutants.

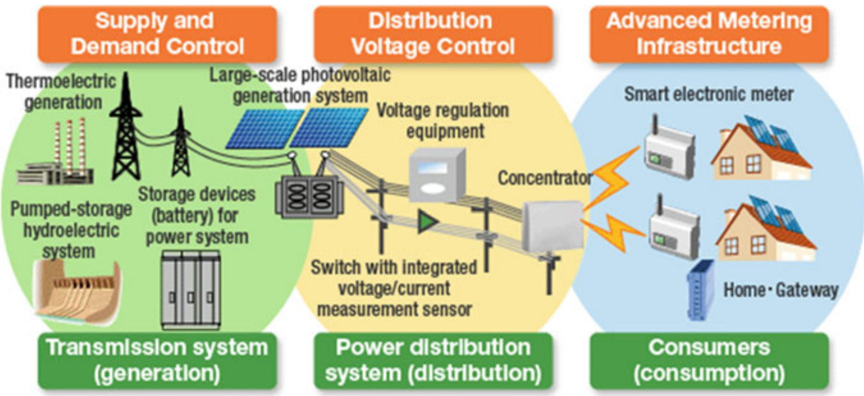

Fig. 2.1 Smart Grid [7]

2.2.1 Characteristics of Smart Grid

In short, a Smart Grid employs innovative products and services together with intelligent monitoring, control, communication, and self-healing technologies.

The literature [7–10] suggests the following attributes of the Smart Grid:

- Smart Grid allows consumers to play a part in optimizing the operation of the system and provides consumers with greater information and choice of supply. It enables demand response and demand-side management through the integration of smart meters, smart appliances and consumer loads, micro-generation, and electricity storage (electrical vehicles) and by providing customers with information related to energy use and prices. It is anticipated that customers will be provided with information and incentives to modify their consumption pattern to overcome some of the constraints in the power system.
- It better facilitates the connection and operation of generators of all sizes and technologies and accommodates intermittent generation and storage options [11]. It accommodates and facilitates all renewable energy sources, distributed generation, residential micro-generation, and storage options, thus significantly reducing the environmental impact of the whole electricity supply system. It will provide simplified interconnection similar to 'plug-and-play.'
- It optimizes and efficiently operates assets by intelligent operation of the delivery system (rerouting power, working autonomously) and pursuing efficient asset management. This includes utilizing assets depending on what is needed and when it is needed.
- It operates resiliently in disasters, physical or cyber attacks and delivers enhanced levels of reliability and security of supplying energy. It assures and improves reliability and the security of supply by anticipating and responding in a self-healing manner, and strengthening the security of supply through enhanced transfer capabilities.
- It provides power quality of the electricity supply to accommodate sensitive equipment that enhances with the digital economy.
- It opens access to the markets through increased transmission paths, aggregated supply and demand response initiatives, and ancillary service provisions.

2.2.2 Traditional Grid Versus Smart Grid

Many issues contribute to the incapability of traditional grid to competently meet the demand for consistent power supply. Table 2.1 compares the characteristics of traditional grid with the preferred Smart Grid.

Table 2.1 Comparison between the traditional and Smart Grid

Traditional grid	Smart Grid
Electromechanical, solid state	Digital/Microprocessor
One-way and local two-way communication	Global/integrated two-way communication
Centralized generation	Accommodates distributed generation
Limited protection, monitoring and control systems	WAMPAC, Adaptive protection
'Blind'	Self-monitoring
Manual restoration	Automated, 'self-healing'
Check equipment manually	Monitor equipment remotely
Limited control system contingencies	Pervasive control system
Estimated reliability	Predictive reliability

2.3 Evolution of Smart Grid

The existing electricity grid is a product of rapid urbanization and infrastructure developments in various parts of the world in the past century. Though they exist in many differing geographies, the utility companies have generally adopted similar technologies. The growth of the electrical power system, however, has been influenced by economic, political, and geographic factors that are unique to each utility company [12]. Despite such differences, the basic topology of the existing electrical power system has remained unchanged. Since its inception, the power industry has operated with clear demarcations between its generation, transmission, and distribution subsystems and thus has shaped different levels of automation, evolution, and transformation in each step.

According to Fig. 2.2, the existing electricity grid is a strictly hierarchical system in which power plants at the top of the chain ensure power delivery to customers' loads at the bottom of the chain. The system is essentially a one-way pipeline where the source has no real-time information about the service parameters of the termination points. The grid is therefore over-engineered to withstand maximum anticipated peak demand across its aggregated load. And since this peak demand is an infrequent occurrence, the system is inherently inefficient. Moreover, an unprecedented rise in demand for electrical power, coupled with lagging investments in the electrical power infrastructure, has decreased system stability [2]. With the safe margins exhausted, any unforeseen surge in demand or anomalies across the distribution network causing component failures can trigger catastrophic blackouts. To facilitate troubleshooting and upkeep of the expensive upstream assets, the utility companies have introduced various levels of command-and-control functions. A typical example is the widely deployed system known as supervisory control and data acquisition (SCADA).

Given the fact that nearly 90 % of all power outages and disturbances have their roots in the distribution network, the move toward the Smart Grid has to start at the bottom of the chain, in the distribution system. Moreover, the rapid increase in the cost of fossil fuels, coupled with the inability of utility companies to expand their generation capacity in line with the rising demand for electricity, has accelerated

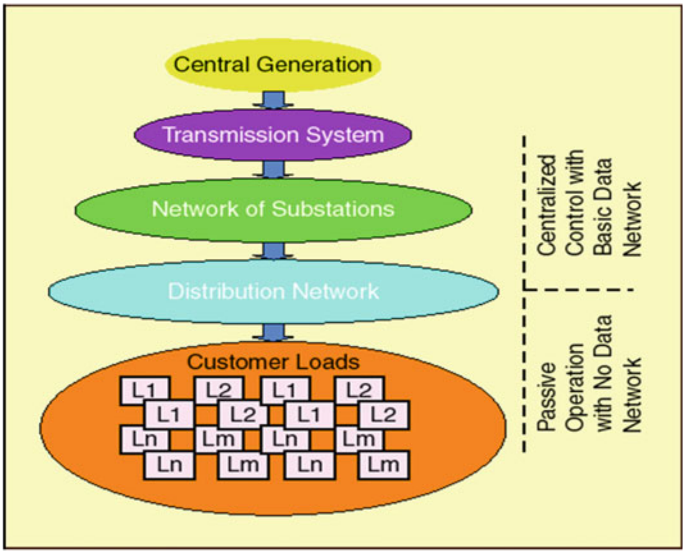

Fig. 2.2 The existing grid [12]

the need to modernize the distribution network by introducing technologies that can help with demand-side management and revenue protection.

As Fig. 2.3 shows, the metering side of the distribution system has been the focus of the most recent infrastructure investments. The earlier projects in this sector saw the introduction of automated meter reading (AMR) systems in the distribution network. AMR lets utilities read the consumption records, alarms, and status from customers' premises remotely.

Figure 2.4 suggests, although AMR technology proved to be initially attractive, utility companies have realized that AMR does not address the major issue they

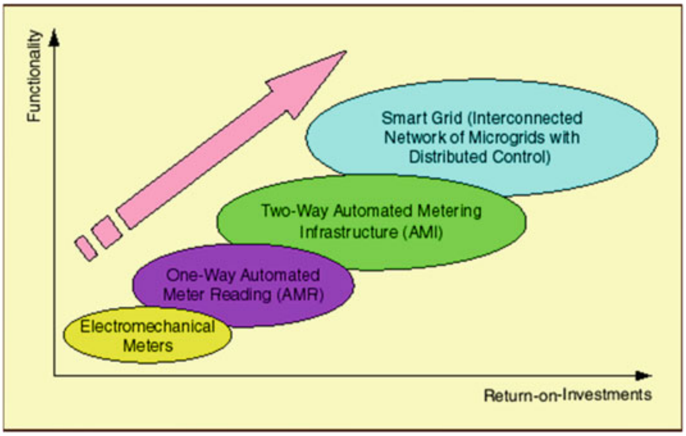

Fig. 2.3 The evolution of the Smart Grid [12]

need to solve: demand-side management. Due to its one-way communication system, AMR's capability is restricted to reading meter data [2]. It does not let utilities take corrective action based on the information received from the meters. In other words, AMR systems do not allow the transition to the Smart Grid, where pervasive control at all levels is a basic premise. Consequently, AMR technology was short-lived. Rather than investing in AMR, utilities across the world moved toward advanced metering infrastructure (AMI). AMI provides utilities with a two-way communication system to the meter, as well as the ability to modify customers' service-level parameters. Through AMI, utilities can meet their basic targets for load management and revenue protection. They not only can get instantaneous information about individual and aggregated demand, but they can also impose certain caps on consumption, as well as enact various revenue models to control their costs. The emergence of AMI heralded a concerted move by stakeholders to further refine the ever-changing concepts around the Smart Grid [2]. In fact, one of the major measurements that the utility companies apply in choosing among AMI technologies is whether or not they will be forward compatible with their yet-to-be-realized Smart Grid's topologies and technologies.

2.4 Components of Smart Grid

For the generation level of the power system, smart enhancements will extend from the technologies used to improve the stability and reliability of the generation to intelligent controls and the generation mix consisting of renewable resources.

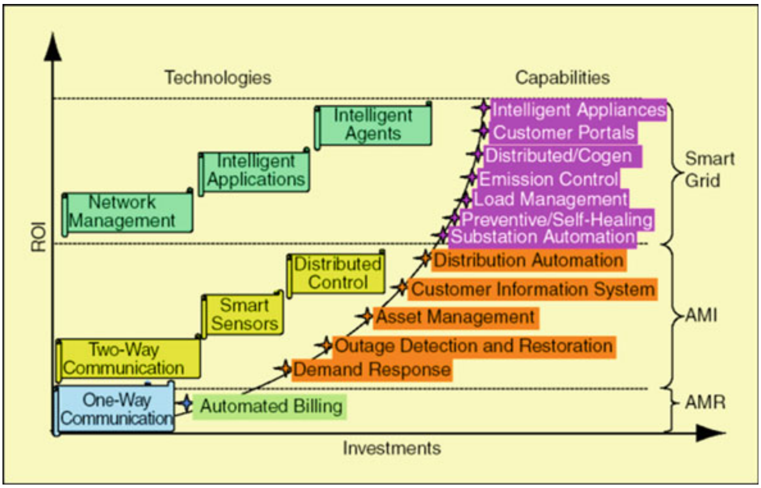

Fig. 2.4 Smart Grid returns on invesments [12]

2.4.1 Monitoring and Control Technology Component

In a conventional power system, electricity is distributed from the power plants through the transmission and distribution networks to final consumers. Transmission and distribution networks are designed to deliver the electricity at the consumer side at a predefined voltage level. Photovoltaic power generation is in general connected at the distribution level of the power system. For this reason, it is possible for the power produced by the PV to cause a 'counter' power flow from the consumer side to be delivered to other consumers through the distribution network. This phenomenon may present two challenges: an increase in the voltage in areas with high PV production and voltage fluctuation throughout the system due to the intermittency characteristics of the PV production [13]. Intelligent transmission systems include a smart intelligent network, self-monitoring and self-healing, and the adaptability and predictability of generation and demand robust enough to handle congestion, instability, and reliability issues. This new resilient grid has to resist shock (durability and reliability), and be reliable to provide real-time changes in its use. Taking these issues into consideration, voltage control systems that incorporate optimal power flow computation software are developed. These systems have been designed to rapidly analyze power flow to forecast the voltage profile on the distribution network, and, in some cases, control voltage regulation equipment to ensure the appropriate voltage. The optimal control signal is developed through optimal power flow calculation. Figure 2.5 overviews the distribution and automation system for electrical power companies.

2.4.2 Transmission Subsystem Component

The transmission system that interconnects all major substation and load centers is the backbone of an integrated power system. Transmission lines must endure dynamic changes in load and emergency without service interruptions. Strategies to achieve Smart Grid performance at the transmission level include the design of analytical tools and advanced technology with intelligence for performance analysis such as dynamic optimal power flow, robust state estimation, real-time stability assessment, and reliability and market simulation tools [13].

Real-time monitoring based on PMU, state estimators sensors, and communication technologies are the transmission subsystem's intelligent enabling tools for developing smart transmission functionality.

2.4.3 Smart Devices Interface Component

Smart devices for monitoring and control form part of the generation components' real-time information processes. These resources need to be seamlessly integrated in the operation of both centrally distributed and district energy systems. Apart

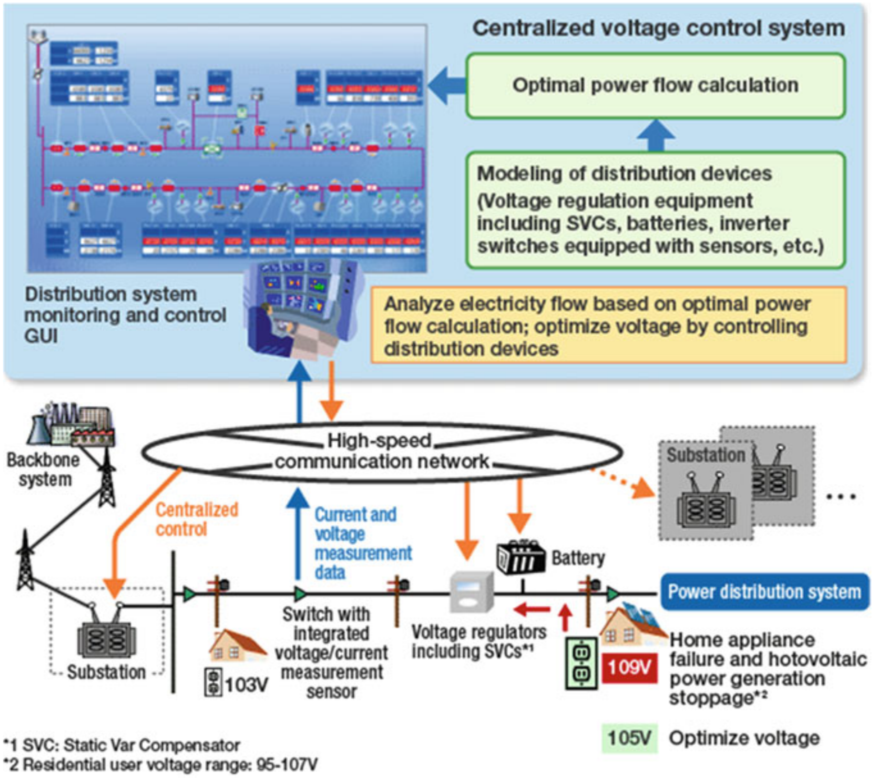

Fig. 2.5 Distribution and automation system for electrical power companies [7]

from a physical model of a smart device, there is also a need for a logical model for a smart device. Such a model must outline what a smart device offers to a smart space with regard to the services it can provide to the environment. The model must also outline interactions between smart devices, changes in the state of smart device operation, and smart services within a smart space. There are various models present today that have similar approaches to modeling device [13]. Two such models would include Home Plug and Play (HPnP), which is slightly out-of-date but still applicable, and the newer Universal Plug and Play (UPnP), which is an open standards body. These two standards bodies have modeled devices by the services that they offer and have also developed interaction models for device communication. Another emerging standard for defining services in an abstract way is with the use of the Web Services Definition Language (WSDL). Along with describing services a smart device can provide, there must also be a way of representing changes in states of smart devices and how devices react to these changes within a smart environment.

2.4.4 Intelligent Grid Distribution Subsystem Component

The distribution system is the final stage in the transmission of power to end users. At the distribution level, intelligent support schemes will have monitoring capabilities for automation using smart meters, communication links between consumers and utility control, energy management components, and AMI [13]. The automation function will be equipped with self-learning capability, including modules for fault detection, voltage optimization and load transfer, automatic billing, restoration and feeder reconfiguration, and real-time pricing. Electrical companies are accelerating efforts to develop an advanced meter infrastructure (AMI) to improve customer services and reduce meter reading costs. An essential element in this AMI is the smart meter. A smart meter is a device that not only measures the electricity consumption but also able to communicate with a center. Developing the communication network between the meter and the center presents several challenges, including costs and reliability. AMI technologies and systems need to be developed to ensure reliability and flexibility in measuring and controlling electricity meters through next-generation wireless mesh networks [13]. Wireless mesh networks provide a transmission method that links electrical meters to relay data by each meter through other meters, using a multi-hop network scheme. This network is helpful reduce the time required to acquire data while at the same time curtailing costs. While wireless mesh networks present cost benefits, some challenges have to be overcome to ensure practical application. Simultaneous transfer of data between meters at the same frequency can cause signal collision, preventing reliable data collection. Figure 2.6 represents the advanced metering infrastructure those are being used in present days for electrical power companies.

2.4.5 Storage Component

Due to the unpredictability of renewable energy and the disjoint between peak availability and peak consumption, it is important to find ways to store the generated energy for later on use. Options for energy storage technologies include pumped hydro, advance batteries, flow batteries, compressed air, super-conducting magnetic energy storage, super-capacitors, and flywheels [13]. Associated market mechanism for handling renewable energy resources, distributed generation, environmental impact, and pollution has to be introduced in the design of Smart Grid component at the generation level.

2.4.6 Demand-side Management Component

Demand-side management (DSM) and energy efficiency options were developed for effective means of modifying the customer demand to cut operating expenses

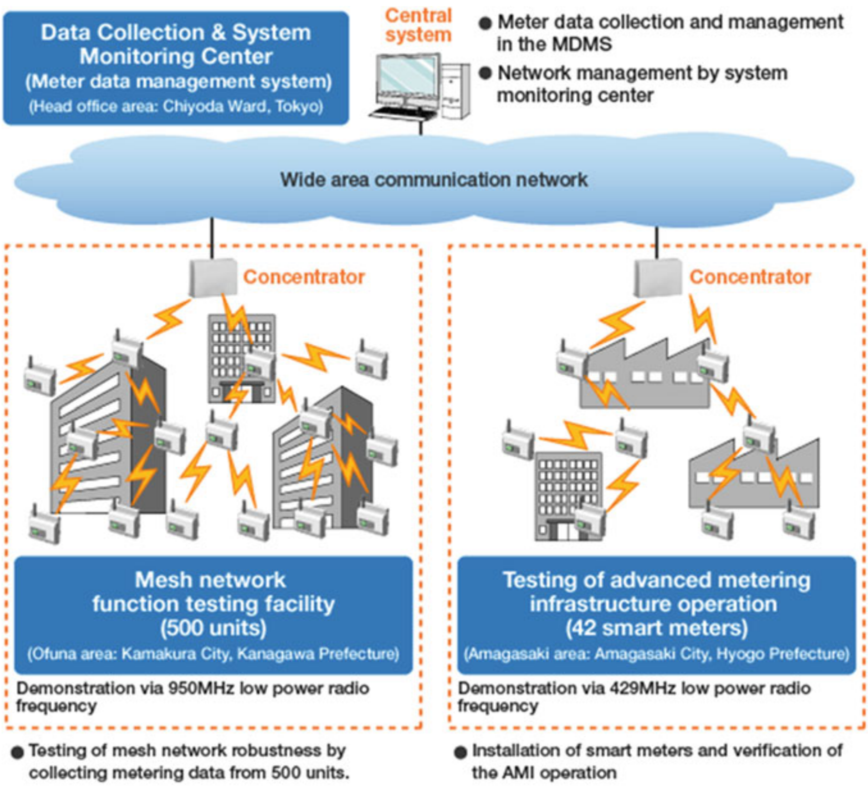

Fig. 2.6 Advanced metering infrastructure for electrical power companies [7]

from expensive generators and suspend capacity addition [13]. DSM options provide reduced emissions in fuel production, lower costs, and contribute to reliability of generation. These options have an overall impact on the utility load curve. Electrical power companies are obligated to maintain constant frequency levels and the instantaneous balance between demand and supply by adjusting output through the use of thermoelectric and pumped storage generation. With the expected increase in photovoltaic power generation, the supply power may fluctuate considerably due to changes in the weather. Imbalance between demand and supply causes fluctuation in the system frequency that may, in turn, affect negatively user appliances and, in a worst case, lead to a power outage [13]. In order to resolve this issue, optimal demand–supply control technologies are required to develop to control not only conventional generators but also batteries and other storage devices. Figure 2.7 demonstrates the advanced demand and supply planning and control system for electrical power companies and transmission system operators.

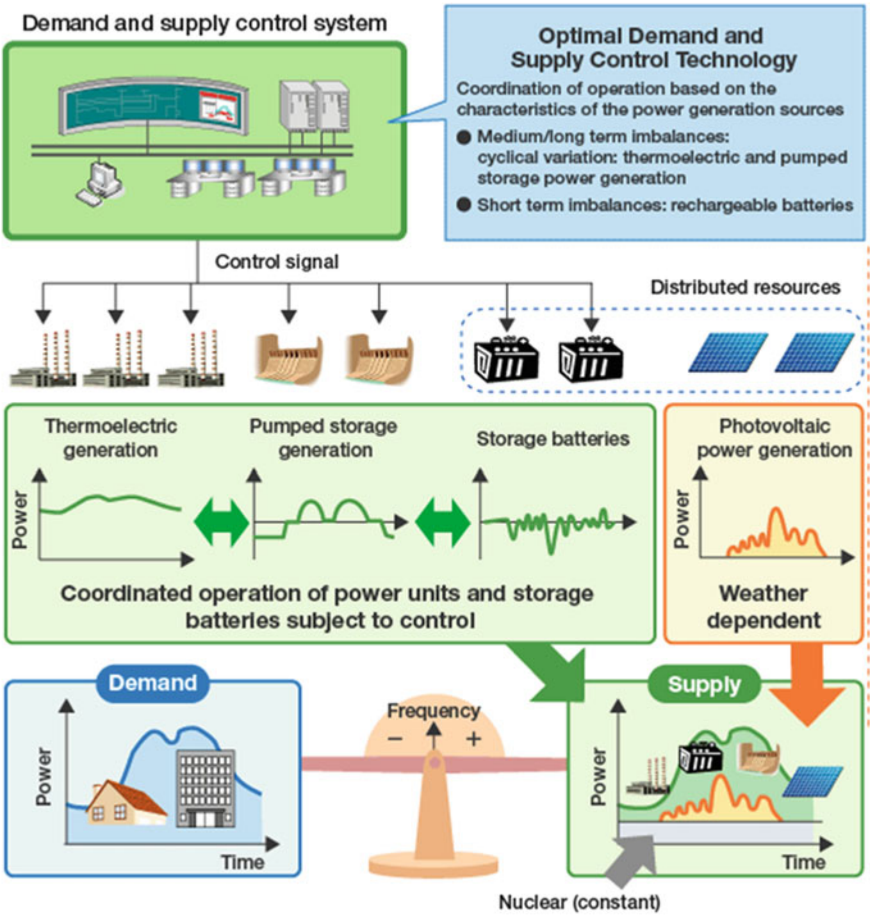

Fig. 2.7 Demand and supply planning and control system for electrical power companies and transmission system operators [7]

2.5 The Environmental Impacts of Smart Grid

The resulting forecasts of global power sector CO_2 emissions are illustrated in Fig. 2.8. The conservative scenario leads to 5 % reduction in annual power sector CO_2 emissions by 2030, with the average annual growth rate in CO_2 emissions dropping from 0.7 to 0.5 % [2]. The expanded scenario produces even further reductions. Power sector CO_2 emissions in 2030 drop by 16 % relative to the business-as-usual (BAU) case. CO_2 emissions are essentially flattened under this scenario, with the annual change in CO_2 emissions becoming an average decrease of 0.1 % per year.

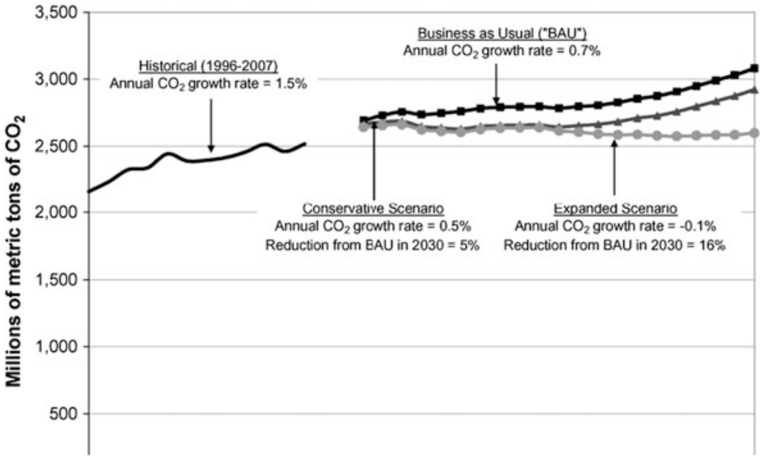

Fig. 2.8 Global power sector CO_2 emissions projections [2]

Figure 2.9 highlights the challenge to deliver future deep cuts in greenhouse gas emissions. Australia's green house gas (GHG) emissions are rising and this trend is projected to increase until at least 2020.

By 2020, national emissions are projected to reach 22 % above 1990 levels, even with current measures delivering significant abatement. Most of this increase will come from the stationary energy sector which is projected to rise to 170 % of

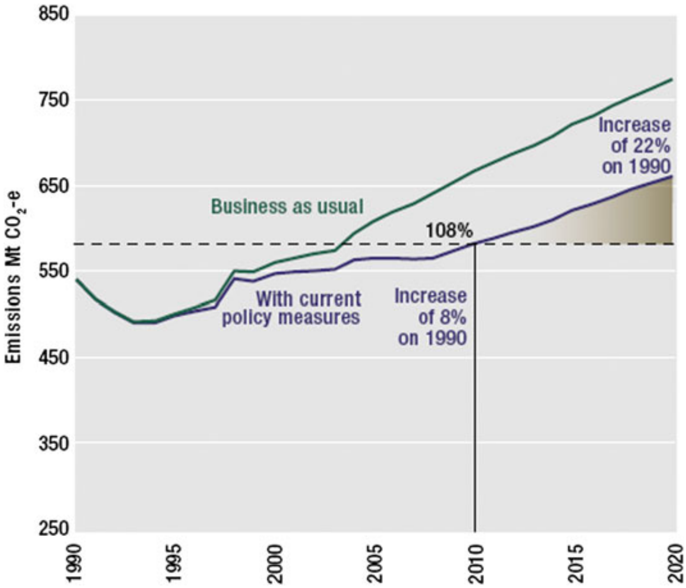

Fig. 2.9 Australian GHG emissions projected to 2020 [2]

1990 levels by 2020 [2]. These reductions are the product of several changes to the power system. Fewer coal and natural gas plants are built, because there is generally a lower need for new capacity due to the decreased demand for electricity. In the expanded scenario, much of this capacity is displaced with cleaner renewable resources. The reduction in line losses also reduces the amount of electricity that must be produced by power plants in order to meet demand.

2.5.1 Reduce Greenhouse Gas Emissions

Worldwide demand for electrical energy is expected to rise 82 % by 2030 (Energy Information Administration, US [14]). Unless revolutionary new fuels are developed, this demand will be met primarily by building new coal, nuclear, and natural gas electricity generation plants. Not surprisingly, world CO_2 emissions are estimated to rise by 59 % by 2030 as a result. The Smart Grid can help offset the increase in CO_2 emissions by slowing the growth in demand for electricity.

- Enable consumers to manage their own energy consumption through dashboards and electronic energy advisories. More accurate and timely information on electricity pricing will encourage consumers to adopt load-shedding and load-shifting solutions that actively monitor and control energy consumed by appliances.
- In deregulated markets, allow consumers to use information to shift dynamically between competing energy providers based on desired variables including energy cost, greenhouse gas emissions, and social goals. Users could include utility companies, homeowners with rooftop solar panels, and governments with landfills that reclaim methane gas. This open market approach could accelerate profitability and speed further investments in renewable energy generation [1].
- Broadcast demand–response alerts to lower peak energy demand and reduce the need for utility companies to start reserve generators. Remote energy management services and energy control operations will also advise consumers, giving them the choice to control their homes remotely to reduce energy use.
- Allow utility companies to increase their focus on 'Save-a-Watt' or 'Mega-Watt' programs instead of producing only power. These programs are effective because offsetting a watt of demand through energy efficiency can be more cost-effective and CO_2-efficient than generating an extra watt of electricity [15].

2.6 Overview of the Technologies Required for Smart Grid

To accomplish the diverse necessities of the Smart Grid, the following enabling technologies must be developed and implemented:

Sensing, measurement, control, and automation technologies: These include

- Phasor measurement units (PMU) and wide area monitoring, protection and control (WAMPAC) to ensure the security of the power system [3].
- Intelligent electronic devices (IED) to provide advanced protective relaying, measurements, fault records, and event records for the power system, integrated sensors, measurements, control and automation systems, and information and communication technologies to provide rapid diagnosis and timely response to any event in different parts of the power system [3]. These will support enhanced asset management and efficient operation of power system components, to help relieve congestion in transmission and distribution circuits and to prevent or minimize potential outages and enable working autonomously when conditions require quick resolution.
- smart appliances, communication, controls, and monitors to maximize safety, comfort, convenience, and energy savings of homes.
- smart meters, communication, displays, and associated software to allow consumers to have better choice and control over electricity use. Those will provide consumers with accurate bills, accurate real-time information on their electricity use, and enable demand management and demand-side participation.

Information and communications technologies: These include

- two-way communication technologies to provide connectivity between different components in the power system and loads [3].
- open architectures for plug-and-play of home appliances; electrical vehicles; and micro-generation.
- communications and the necessary software and hardware to provide customers with greater information enable customers to trade in energy markets.
- software to ensure and maintain the security of information and standards to provide scalability and interoperability of information and communication systems [3].

Power electronics and energy storage: These include

- High-voltage DC (HVDC) transmission and back-to-back schemes and flexible AC transmission systems (FACTS) to enable long-distance transport and integration of renewable energy sources [3].
- different power electronic interfaces and power electronic supporting devices to provide efficient connection of renewable energy sources and energy storage devices.
- series capacitors, unified power flow controllers (UPFC) and other FACTS devices to provide greater control over power flows in the AC grid [3].
- HVDC, FACTS, and active filters together with integrated communication and control to ensure greater system flexibility, supply reliability, and power quality [3].
- power electronic interfaces and integrated communication and control to support system operations by controlling renewable energy sources, energy storage, and consumer loads.
- energy storage to facilitate greater flexibility and reliability of the power system.

2.7 The Future: The Key Challenges

- Strengthening the grid—ensuring that there is sufficient transmission capacity to interconnect energy resources, specially renewable resources, across Europe [2]
- Moving offshore—developing the most efficient connections for offshore wind farms and for other marine technologies
- Developing decentralized architectures—enabling smaller-scale electricity supply systems to operate harmoniously with the total system
- Communications—delivering the communications infrastructure to allow potentially millions of parties to operate and trade in the single market [2]
- Active demand side—enabling all consumers, with or without their own generation, to play an active role in the operation of the system [2]
- Integrating intermittent generation—finding the best ways of integrating intermittent generation including residential micro-generation [2]
- Enhanced intelligence of generations
- Capturing the benefits of distributed generation and storage [2]
- Preparing for electrical vehicles—whereas Smart Grids must accommodate the needs of all consumers, electrical vehicles are particularly emphasized due to their mobile and highly dispersed character and possible massive deployment in the next years, which would yield a major challenge [2].

2.8 Experiments to Select the Base Regression Algorithms of the Hybrid Prediction Method for Smart Grid

Computational intelligence (CI) holds the key to the development of Smart Grid to overcome the challenges of planning and optimization through accurate prediction of renewable energy sources (RES), managing data and communications, control and protection of power plants. It was observed that the hybrid prediction method or ensemble model (i.e. a set of different regression algorithms or machine learning techniques whose discrete predictions are united to generate an ultimate aggregated prediction [16]) is suitable for a reliable Smart Grid energy management. The following experiments investigate the applicability of heterogeneous regression algorithms for 6-h ahead solar power hybrid prediction using historical data of Rockhampton, Australia. Prediction reliability of the proposed hybrid prediction method is carried out in terms of error validation metrics such as *Correlation Coefficient* (*CC*), *Mean Absolute Error* (*MAE*), *Mean Absolute Percentage Error* (*MAPE*), *Root Mean Squared Error* (*RMSE*), *Root Mean Squared Percentage Error* (*RMSP*), *Mean Absolute Scaled Error* (*MASE*), *Root Relative Squared Error* (*RRSE*) and *Relative Absolute Error* (*RAE*). The experimental results show that the proposed hybrid method achieved acceptable prediction accuracy. This potential

Table 2.2 Results of applying 10-fold cross-validation method on the data set

		CC	RMSE	MAE	RRSE	RAE
10-Fold cross-validation	LR	0.89	150.14	66.35	46.30	27.44
	RBF	0.13	321.58	240.09	99.16	99.30
	SVM	0.88	164.18	46.58	50.63	19.26
	MLP	0.99	14.81	9.74	4.57	4.03
	PR	0.89	150.14	66.31	46.30	27.42
	SLR	0.87	158.56	83.15	48.89	34.39
	LMS	0.88	165.15	47.94	50.92	19.83
	AR	0.94	108.94	80.99	33.59	33.50
	LWL	0.81	190.26	146.09	58.67	60.42
	IbK	0.93	124.41	90.86	38.36	37.58

hybrid model is applicable as a local predictor for any proposed hybrid method in real-life application for 6 h in advance prediction to ensure constant solar power supply in the Smart Grid operation.

2.8.1 Experiment Design

Ten popular regression algorithms namely Linear Regression (LR), Radial Basis Function (RBF), Support Vector Machine (SVM), Multilayer Perceptron (MLP), Pace Regression (PR), Simple Linear Regression (SLR), Least Median Square (LMS), Additive Regression (AR), Locally Weighted Learning (LWL), and Instance Based K-nearest neighborhood (IbK) Regression have been used to find out ensemble generation. A unified platform is used with WEKA release 3.7.3 for all of the experiments. The WEKA 3.7.3 Developer Version is a Java-based learning tool and data mining software which is issued under the GNU General Public License [17]. WEKA is an efficient data pre-processing tool which encompasses a comprehensive set of learning algorithms with graphical user interface as well as command prompt. Regression, classification, and association rule mining, clustering, and attribute selection all are integrated in WEKA.

To estimate model accuracy precisely, the wide-ranging practice is to perform some sort of cross-validation method as well as training and testing method for error estimation. For this chapter, both the 10-fold cross-validation method and training (70 %) and testing (30 %) method are exercised. In Table 2.2, the results of applying 10-fold cross-validation method on initially selected regression algorithms are demonstrated.

The above results obtained from applying 10-fold cross-validation method on the data set clearly show that in terms of the *MAE,* the most accurate one is the MLP regression algorithm. Next to the MLP, SVM is in the second best position and LMS regression algorithm is in the third best position. In Table 2.3, the results of applying training and testing error estimator method on initially selected regression algorithms are illustrated.

Table 2.3 Results of applying training and testing method on the data set

		CC	RMSE	MAE	RRSE	RAE
Training (70 %) and testing (30 %)	LR	0.88	150.84	66.91	47.21	27.75
	RBF	0.12	317.38	239.64	99.34	99.40
	SVM	0.87	165.56	47.19	51.82	19.58
	MLP	0.99	16.90	11.73	5.29	4.87
	PR	0.88	150.88	66.65	47.22	27.65
	SLR	0.87	159.22	82.74	49.83	34.32
	LMS	0.87	164.69	48.69	51.55	20.19
	AR	0.93	114.90	83.97	35.96	34.83
	LWL	0.80	190.39	146.48	59.59	60.76
	IbK	0.92	128.82	94.23	40.32	39.09

Table 2.4 Six-hour ahead prediction errors of different regression algorithms

Six hours in advance prediction error summary

	CC	MAE	MAPE	RMSE	RMSPE	MASE	RANK
LMS	0.96	77.19	17.65	107.94	29.19	0.63	1
MLP	0.99	91.02	20.17	119.73	31.62	0.74	2
SVM	0.96	126.88	21.72	135.15	24.01	1.03	3
LR	0.96	148.41	24.07	155.82	25.12	1.21	4
LWL	−0.15	213.33	46.86	271.22	72.39	1.73	5
IbK	0.88	275.00	47.90	290.18	53.66	2.24	6
AR	0.93	298.45	48.21	306.03	49.05	2.43	7

The above results obtained from applying training (70 %) and testing (30 %) method on the data set clearly show that in terms of the *MAE,* the most accurate one is the MLP regression algorithm. Next to the MLP, SVM is in the second best position and LMS regression algorithm is in the third best position as well. Both the 10-fold cross-validation and training and testing methods suggest the top-most three accurate and potential regression algorithms for this research are MLP, SVM, and LMS in descending order. Afterward, six-hour ahead solar radiation prediction with the potential regression algorithms were performed to compare the errors of the individual prediction to select three decisive regression algorithms for the ensemble generation. In Table 2.4, the summary of six hours in advance prediction error for different regression algorithms with various prediction accuracy validation metrics is presented.

From the individual prediction results, the regression algorithms are ranked. According to [46], MAE is strongly suggested for error measurement. Hence, the ranking is done based on the *Mean Absolute Error* (*MAE*) of those regression algorithms' predictions. Based on the *MAE* and the *MASE* the top-ranked three regression algorithms for ensemble generation are LMS, MLP, and SVM. In Figs. 2.10, 2.11, 2.12, the comparison between the actual and predicted values of the LMS, MLP, and SVM regression algorithms is graphically presented. In all

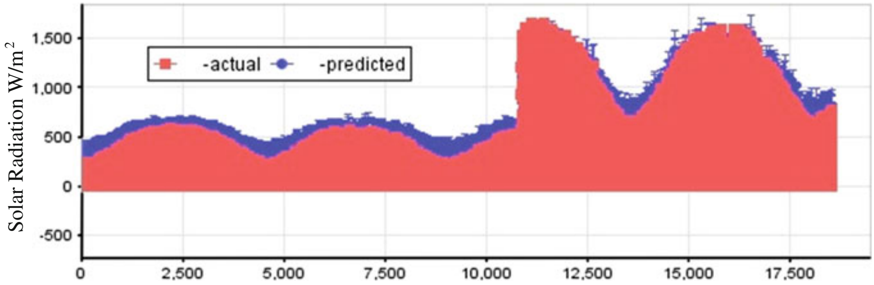

Fig. 2.10 Prediction performance of LMS

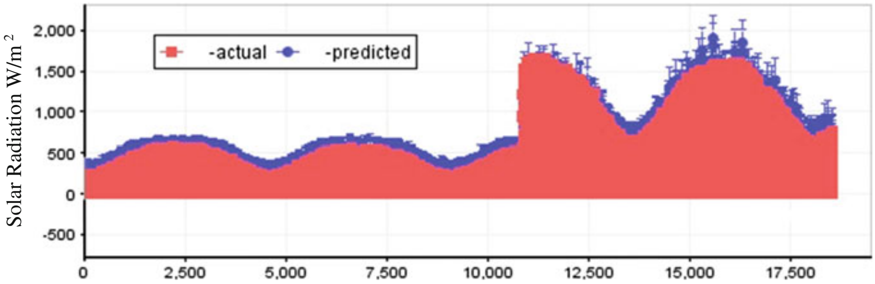

Fig. 2.11 Prediction performance of MLP

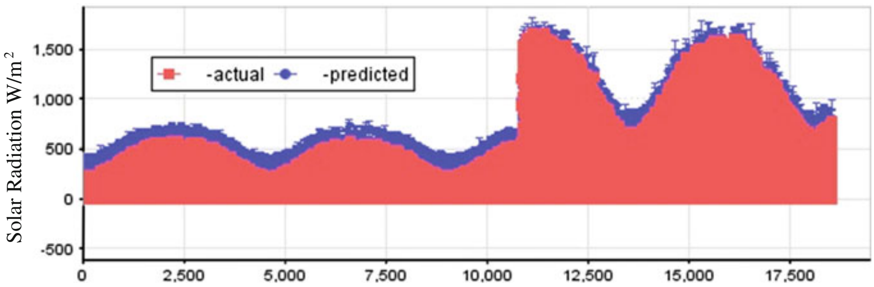

Fig. 2.12 Prediction performance of SVM

those figures, x axis represents the number of instances and y axis represents the solar radiation measured in W/m^2.

Sophisticated intelligent techniques are mandatory to handle the Smart Grid operation in an efficient and economical way. The strengths of CI paradigms have been demonstrated to resolve the ensemble generation confront for the proposed hybrid method for solar power prediction. Such hybrid solar power prediction methods are promising solutions to convey the expectations of a Smart Grid.

2.9 Summary

The aim of this chapter is to provide a basic discussion on the background of the Smart Grid; its concept and definition. Even though the Smart Grid concept is not yet fully defined, a working definition of the Smart Grid was given. Characteristics of Smart Grid and comparison between traditional or existing grid and Smart Grid are also included in this chapter. Afterward the history of the evolution of Smart Grid and the specific components of prospective Smart Grid function were provided. Environmental impact of implementing Smart Grid, particularly the way it can be used to reduce greenhouse gas emissions, and the overview of the technologies required for Smart Grid are discussed in this chapter. Directions of some future key challenges those need to be resolved for the successful implementation of Smart Grid are also depicted in this chapter. The chapter concludes with the experimental description and results of developing a hybrid prediction method for solar power which is applicable to successfully implement the 'Smart Grid.'

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