SMART GRID: A feasible solution to India's energy security

By

PRITHWISH KARURI

(SAP ID 500025240)

Guided By

Sk. Maruf Hossain

Senior Manager (PS), STPS, WBPDCL

A DISSERTATION REPORT SUBMITTED IN PARTIAL FULFILLMENT OF

THE

REQUIREMENTS FOR

MBA (Power Management)

OF UNIVERSITY OF PETROLEUM & ENERGY STUDIES, INDIA

CENTRE FOR CONTINUING EDUCATION

UNIVERSITY OF PETROLEUM & ENERGY STUDIES, DEHRADUN

Acknowledgement

This is to acknowledge with thanks the help, guidance and support that I have received during the Dissertation.

I have no words to express a deep sense of gratitude to the management of WBPDCL-STPS for giving me an opportunity to pursue my Dissertation, and in Particular Surajit Mandal, for his able guidance and support.

I must also thank Amit Baran Jha for his valuable support.

I also place on record my appreciation of the support provided by Librarian and other staffs for helping me to complete the dissertation.

Prithwish Karuri,

(Signature of student)

Name of the Student: Prithwish Karuri

Residential Address: 116/1, Brindaban Mallik Lane. Howrah-711101

Telephone/Mobile: 09883035244

E-mail: karuriprithwish.27@gmail.com

Date: 13.11.15

Place: Santaldih.

The West Bengal Power Development Corporation Limited
(A Government of West Bengal Undertaking)

Santhaldih Thermal Power Station
P.O. Santhaldih Thermal Plant
Dist. Purulia (W.B.) Pin - 723146
Fax : (03251) 260217
Phone : (03251) 260227, 260221, 260226, 260341, 260218, 260228,260222

Date: 24.08.15

Declaration by the Guide

This is to certify that the Mr Prithwish Karuri, a student of (MBA (Power Management)), Roll No 500025240 of UPES has successfully completed this dissertation report on **"Smart Grid: A feasible solution to India's Energy Security"** under my supervision.

Further, I certify that the work is based on the investigation made, data collected and analyzed by him and it has not been submitted in any other University or Institution for award of any degree. In my opinion it is fully adequate, in scope and utility, as a dissertation towards partial fulfillment for the award of degree of MBA.

Signature

Sk. Maruf Hossain

Name: Sk. Maruf Hossain
Designation: Senior Manager (PS),
Address: STPS, WBPDCL,
Mobile: 8336926291
E-mail: smhossain@wbpdcl.co.in

D Y.O.S.
Mechanical Operation
S.T.P.S, Purulia

Date: 24.08.15
Place: Santaldih

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ACRONYM

AMI	Advanced metering infrastructure
APDRP	Accelerated Power Development and Reform Programme
AT&C	Aggregate technical and commercial
BIS	Bureau of Indian Standards
CEA	Central Electricity Authority
CER	Certified emission reduction
CERC	Central Electricity Regulatory Commission
CRM	Customer relations management
DMS	Distribution management systems
DNO	Distribution network operator
DR	Demand response
DSM	Demand-side management
EE	Energy efficiency
EPRI	Electric Power Research Institute
GIS	Geographic information system
ICT	Information and communications technology
IEEE	Institute of Electrical and Electronics Engineers
IED	Intelligent electronic device
O&M	Operations and maintenance
PLC	Power line carrier
PLC	Programmable logic controller
R-APDRP	Restructured Accelerated Power Development and Reform Programme
RE	Renewable energy
ROI	Return on investment
RTU	Remote terminal unit
SCADA	Supervisory control and data acquisition
SERC	State Electricity Regulatory Commissions
T&D	Transmission and distribution
TOU	Time of use

EXECUTIVE SUMMARY

India is truculent to meet the electric power demands of a fast expanding economy. Restructuring of the power industry has only several challenges for the power system engneers. The proposed vision of introducing viable smart grid (SG) at various levels in the indian power systems has recommended that an advanced automation mechanism needs to be adapted. Smart grids are introducedto make the grid operation smarter and intelligent. Smart grid operations, upon appropriate deployment can open up new avenues and opportunities with significant financial implications. The adaptation of the smart grid vision to the Indian context offers the potential to revolutionize electricity supply and increase the probability of achieving the Government of India's electricity sector goals sooner and more effectively. The immediate beneficiaries would be the people of India. The design of a sustainable smart grid model would also provide a blueprint for developing nations. This work presents various Smart grid initiatives and implications in the context of power market evolution in India. Various examples of existing structures of automation in India are employed to underscore some of the views presented in this report. It also reviews the progress made in Smart grid technology research and development since its inception. Attempts are made to highlight the current and future issues involved for the development of Smart Grid technology for future demands in Indian perspective.

CHAPTER 1

OVERVIEW AND BACKGROUND

Smart Grid: Utilities around the world are rapidly making the terms as the centerpiece of their infrastructure development plan. But the term "Smart Grid" seems to have many different meanings.

This chapter begins with an overview of the key forces driving the smart grid's development. It also touches on the role of smart grids in enabling sustainable, low-carbon/high-growth economies.

In the United States, the electric industry emerged as a grid-connected, central station network during the 1920s and 1930s. In the following fifty years, technological advances enabled ever-larger power plants to be built at ever lower unit costs. As the industry expanded, the enormous fixed costs of the grid-connected central station network could be spread over many more units of production, further reducing unit costs. The new electricity technology turned night into day by providing a better source of illumination and made it possible to locate power sources — and work that needed it — at great distances from rivers that for most of human existence had served as the most important source of motive power.

After its financing needs were resolved either through the advent of regulated monopolies or direct government ownership, the electric supply industry enjoyed decades of almost uninterrupted growth.

After that economies of scale, spurred by a string of technological breakthroughs, produced step-function improvements in productivity and continuous reductions in unit cost result a string of ever-lower costs per megawatt to build ever-larger power plants.

Each reduction in the price of electricity opened up new uses for it, which led to further reductions in unit prices because the high fixed costs of plant investment could be spread over greater sales volumes. This led to a continuing expansion in the application of electricity that resulted in historic growth in customers and sales. The parallels with today's growth in IT are compelling.

Next, the joint and reinforcing results of the OPEC cartel, coupled with high inflation and high interest rates, rocked the capital-intensive electricity business. The industry's then-latest technological development (nuclear power) failed to produce lower unit costs. The sharp run up in prices triggered by the OPEC oil embargo but compounded by the failure of nuclear power combined to reduce the average rate of sales growth to a fraction of what it had been. Sales growth plunged from roughly 7% to 9% a year to 2% or less. This led to a severe over capacity situation and, thus, upward pressure on unit costs. What followed was a massive breakdown in pricing. Regulators and politicians found it difficult to raise prices to cover sharply higher costs. Keeping prices below economic levels contributed to the uneconomic consumption of electricity, the wasteful deployment of high-cost assets, and mounting economic losses.

Those companies operating as regulated monopolies discovered that regulation works better in declining cost environments than when conditions require successive and substantial price increases. Where governmental ownership was the norm, the industry discovered that governmental ownership and financing may have been a good at stimulating the development of early-stage growth but, here too, there was a massive failure in the pricing mechanism. If regulators had difficulty in imposing the necessary increases in tariffs, government-owned utilities found it almost impossible.

The OPEC oil embargo also signaled the finite nature of oil and gas, and unleashed a frenzy of inventiveness aimed at conservation and load management, as energy efficiency and demand-side management (DSM) were then known. Initially, in the face of industry resistance, DSM programs were mandated by regulators. Likewise, energy efficiency (EE) had a tumultuous beginning and many electric industry executives resisted it because it would reduce corporate revenues. As Upton Sinclair famously said, "It is difficult to get a man to understand something when his salary depends on his not understanding it." Ultimately, this too changed.

Today, these revolutionizing technologies — electricity and information and communications technology (ICT) — are converging with the descendents of DSM (now considered a sophisticated marketing tool known as "demand response" or DR) and energy efficiency know-how. Collectively, cost-effective, small-scale distributed generation monitored by sophisticated electronic sensors and managed by advanced metering and control systems (all enabled by advances in ICT) are spurring more innovative and cost-effective applications of DR and EE to radically transform the way electricity is produced delivered and used.

1.1Key drivers of Smart Grid

The global energy deficiency has directly foiled the economics, society, development of the nations, and environments through greenhouse gases (GHGs) and by gaining carbon credits. The growing demand of power across the globe is being envisaged and logged to be exponential. Lack of asset with outdated network infrastructure, climate change, rising fuel costs, has resulted inefficient and increasingly unstable electric system. With this, the global concern has raised certain critical points upon which the energy revolution for a green and sustainable future are guaranteed and ensued.

Fossil fuel dead lock: Raising energy demand is knocking pressure on fossil fuel supply and now oil exploration towards "unconventional" oil resources. Switching from fossil fuels to renewable also offers substantial benefits such as independence from world market fossil fuel prices and the creation of millions of new green jobs. It can also provide energy to the two billion people currently without access to energy services. A closer look at the measures required to phase-out oil faster in order to save the Arctic from oil exploration, avoid dangerous deep sea drilling projects and to leave oil shale in the ground are well thought- out. The changeover from the fossil-driven based energy sources to the renewable energy sources

(RES) is being addressed globally according to significant benchmarks. The dynamic characteristics of the RESs and its developing sparingly sustainable means to produce energy with less environmental challenges, is one of its foremost.

Climate change threat: The threat of climate change, caused by rising global temperatures, is the most significant environmental challenge being encountered by the world since the beginning of the 21st century. It has major implications for the world's social and economic stability, its natural resources and in particular, the way we produce our energy. In order to avoid the most catastrophic impacts of climatic change, the global temperature increase must be kept as far below 2°C as possible. The main greenhouse gas is carbon dioxide (CO_2) produced by using fossil fuels for energy and transport. Keeping the global temperature until 2°C is often referred to as a 'safe level' of warming; beyond which unacceptable risks to the world's key natural and human systems might occur. Even with a 1.5°C warming, increase in drought, heat waves and floods, along with other adverse impacts such as increased water stress for up to

1.7 billion People, wildfire frequency and flood risks, are projected in many regions. Partial de-glaciations of the Greenland ice sheet, and possibly the West Antarctic ice sheet, could even occur from additional warming within a range of 0.8 – 3.8°C above current levels. If rising temperatures are to be kept within acceptable limits then we need to significantly reduce our GHG emissions.

Global negotiations: In 1961 to stimulate economic progress and world trade, a forum of countries committed to democracy and the market economy, providing a platform to compare policy experiences, seek answers to common problems like global warming, and identify good practices and co-ordinate domestic and international policies of its members, like fortification of renewable energy. This lead to the formation of the Organization for Economic Co-operation and Development (OECD), and the member nations are high income economies with a very high Human Development Index (HDI) and are regarded as developed countries. Also, recognizing the global threats of climate change, the signatories to the 1992

UN Framework Convention on Climate Change (UNFCCC) agreed to the Kyoto Protocol in 1997. The

Protocol entered into force in early 2005 and its 193 members meet continuously to negotiate further refinement and development of the agreement. In 2009, the UNFCCC were not able to deliver a new climate change agreement towards ambitious and fair emission reductions. At the 2012 Conference, there was agreement to reach a new agreement by 2015 and to adopt a second commitment period at the end of

2012. The proposed mitigation pledges put forward by governments are likely to allow global warming to at least 2.5 to 5 degrees temperature increase above pre-industrial levels.

Nuclear issues: To both climate protection and energy security, however their claims are not supported by data. The most recent Energy Technology Perspectives report published by the International

Energy Agency (IEA) includes a Blue Map scenario including a quadrupling of nuclear capacity between current years and 2050. To achieve this, the report says that on average 32 large reactors (1,000 MW each) would have to be built every year from now until 2050. According to the IEA's own scenario, such massive nuclear expansion would cut carbon emissions by less than 5%. More realistic data analysis shows the past development history of nuclear power and the global production capacity make such expansion extremely unviable. With a temperament of its catastrophic aftermath and its indispensable biohazard activities, during the past situations and the future valuations, many reactors has been terminated and slowdown in various expanses across the sphere. Japan's major nuclear accident at Fukushima in March

2011 following a tsunami came 25 years after the devastating explosion in the Chernobyl Nuclear Power Plant, illustrating the inherent risks of nuclear energy. Nuclear energy is simply unsafe, expensive, has continuing waste disposal problems and cannot reduce emissions by a large enough amount. In contrast, renewable energy is also a viable solution for replacing the world's elusive, hazardous and intolerably expensive nuclear energy.

Climate change and Security of supply: Access to both supplies and financial stability is now at the top of the energy policy agenda. Rapidly fluctuating oil prices are lined to a combination of many events, however one reason for these price fluctuations is that supplies of all proven resources of fossil fuels are becoming infrequent and more expensive to produce. Some 'non-conventional' resources such as shale oil have become economic, with devastating consequences for the local environment. Uranium, the fuel for nuclear power, is also a finite resource. By contrast, the reserves of renewable energy that are technically accessible globally are large enough to provide more than 40 times more energy than the world currently consumes, forever, according to the latest IPCC Special Report Renewable (SRREN). Cost reductions in just the past two years have changed the economics of renewable fundamentally, especially wind and solar photovoltaic (PV) along with the common features like, emission of little or no GHG and are a virtually inexhaustible fuel. Some technologies are already competitive; the solar and the wind industry have maintained double digit growth rates over 10 years now, leading to faster technology deployment worldwide.

Energy efficiency: The most cost competitive way to reform the energy sector. There is enormous potential for reducing our consumption of energy, while providing the same level of energy services. New business models to implement energy efficiency must be developed and must get more political support.

The challenge ahead will require an innovative power system architecture involving both new technologies and new ways of managing the network to ensure a balance between fluctuations in energy demand and supply. The key elements of this new power system architecture are micro grids, smart grids and an efficient large scale super grid, which could play a dynamic role in remodeling the global energy scenario with factors like policies, regulation, and efficiency of market with costs, benefits and services which also normalizes the power and energy market with the reduction of carbon footprints and foot dragging the GHG emissions.

Drivers in INDIA

India has limited experience with smart grid deployments and advanced metering, especially for small consumers and farmers. The factors that will drive India's adoption of smart grids include the need to reduce technical and commercial losses, resolve it's the chronic supply-demand gap, and find a way to "leapfrog" into a more advanced electricity supply solution to satisfy its sustainable, low-carbon, high-growth economic development goals. The drivers for India are also discussed in this section.

Six factors will drive the adoption of the smart grid in India:

Supply shortfalls: Demand, especially peak demand, continues to outpace India's power supply. The increasing affordability of household appliances is adding to the burden on the grid. Official estimates of India's demand shortfall are 12% for total energy and 16% for peak demand. Managing growth and ensuring supply is a major driver for all programs of the Indian power sector.

Loss reduction: India's aggregate technical and commercial losses are thought to be about 25-30%, but could be higher given the substantial fraction of the population that is not metered and the lack of transparency. While a smart grid is not the only means of reducing losses, it could make a substantial contribution.

Managing the "human element" in system operations: Labor savings is not a prime driver for the smart grid in India as contracts for outsourcing are inexpensive. However, automated meter reading would lower recording and other errors-including what are known elsewhere as "Curbstone readings" or "shade tree" readings- or even deliberate errors which are thought to be significant reasons for losses.

Peak load management:_ India's supply shortfalls are expected to persist for many years. A smart grid would allow more "intelligent" load control, either through direct control or economic pricing incentives that are communicated to customers in a dynamic manner. Such measures would help mitigate the supply-demand gap.

Renewable energy: India has supported the implementation of renewable energy. Spurred by environmental concerns and the desire to tap into all available sources of power, this move can also be a smart grid driver.

Technological leapfrogging: Perhaps the most intriguing driver for India is the potential to "leapfrog" into a new future for electricity, as it did with telecommunications.

1.2 What is Smart Grid?

A smart grid is the integration of information and communications technology into electric transmission and distribution networks. The smart grid delivers electricity to consumers using two-way digital technology to enable the more efficient management of consumers' end uses of electricity as well as the more efficient use of the grid to identify and correct supply demand-imbalances instantaneously and detect faults in a "self-healing " process that improves service quality, enhances reliability, and reduces costs. Thus, the smart grid concept is not confined to utilities only; it involves every stage of the electricity cycle, from the utility through electricity markets to customers' applications.

The emerging vision of Smart Grid encompasses a broad set of applications, including software, hardware,, and technologies that enable utilities to integrate, interface with, and intelligently control innovations. Some of the technologies that make smart grid deployment possible includes:

- Meters
- Storage devices
- Distributed generation
- Renewable energy
- Energy efficiency
- Home area networks
- Demand response
- IT and back office community
- Security
- Integrated communication system
- Superconductive transmission lines.

1.3 Potential benefits of Smart Grid

The smart grid presents a wide range of potential benefits, including:

1. Optimizing the value of existing production and transmission capacity
2. Incorporating more renewable energy
3. Enabling step-function improvements in energy efficiency
4. Enabling broader penetration and use of energy storage options
5. Reducing carbon emissions by increasing system, load and delivery efficiencies
6. Improving power quality
7. Improving a utility's power reliability, operational performance, asset management and overall productivity
8. Enabling informed participation by consumers by empowering them to manage their energy usage
9. Promoting energy independence.

1.4 Smart Grid and Environment

There is a broad consensus that smart grid deployments will provide environmental benefits, including significant reductions in greenhouse gas emissions. EPRI has projected that by 2030, the implementation of a smart grid across the United States would reduce annual greenhouse gas emissions by 60-211 metric tons of carbon dioxide equivalent compared to "business as usual." This is equal to 2.5 to 9% of the greenhouse gas emissions of the US in 2006. More than half of the potential emission reductions can be achieved through improvements in end-use efficiency and increased energy conservation enabled by the smart grid, as well as the integration of large-scale renewable energy projects into the grid. Smart grids can bring about environmental improvements by:

1. **Managing peak load** through demand response rather than spinning reserves.

2. **Reducing transmission losses** through better management of transmission and distribution networks.

3. **Monitoring equipment in real time,** which will enable the redirection of power flows in response to early warnings of system problems, detect and remedy faults in a "self-healing" mode and keep important system components operating at high efficiency

4. **Increasing transparency in electricity prices** to help consumers understand the true cost of electricity by time of day. Giving continuous feedback on electricity use could reduce annual CO_2 emissions by 31-114 million metric tons of CO_2 equivalent in 2030 as consumers adjust their usage in response to pricing and consumption information.

5. **Reducing new infrastructure construction** by helping optimize the use of existing generation and transmission and distribution capacity. Together with energy efficiency and conservation savings, this will reduce the pace at which new supply and delivery infrastructure must be built to satisfy increasing demand

6. **Integrating more renewable energy sources and energy storage** to support system operators by providing more real-time information to make decisions on selecting generation from clean energy sources, thus substituting renewable energy when possible.

Table 1: Smart Grid mechanisms for reducing CO_2

Mechanisms	Reduction in Electric Sector Energy and CO_2 Emissions (%)[Assumes 100% penetration of Smart Grid technologies]	
	Direct	Indirect
Conservation effect of consumer information and feedback systems	3	--
Joint marketing of energy efficiency and demand response programs	--	0
Deployment of diagnostics in residential and small/medium commercial buildings	3	--
Measurement and verification for energy efficiency programs	1	0.5
Shifting load to more efficient generation	□0.1	--
Support for additional electric vehicles and plug in hybrid electric vehicles	3	--
Conservation voltage reduction and additional voltage control	2	--
Support the penetration of renewable wind and solar generation (25% renewable portfolio standard)	□0.1	5
Total reduction	12	6

Source: R.G. Pratt et al., Smart Grid; an Estimation of the Energy and CO_2 Benefits, Pacific Northwest National Laboratory, January 2010.

Also, smart grid deployments could provide added value for the utility industry due to the prospects of the costly emission control measures that many governments are now discussing.

Challenges to quantifying smart grid benefits: Environmental benefits will be difficult to quantify due to the complex dimensions of the smart grid and the fact that benefits are often dispersed and therefore not readily identifiable or easily quantifiable. Some other reasons for this concern include:

- Environmental benefits tend to occur due to avoided emissions or offset impacts, which are often difficult to quantify
- The benefits cannot always (or easily) be traced to a single organization
- Benefits will occur outside the boundary of the firm implementing the program
- Environmental benefits accrue over very long time periods

The Indian Context: Even with a population of over a billion, India is a relatively low carbon economy ranking 63rd worldwide in per capita emissions and 48th in CO_2 emissions per unit of GDP. Furthermore, recent studies commissioned by the Ministry of Environment and Forests have found evidence that India is improving the energy intensity of its GDP: in 1980, it used 0.30 kilograms of oil equivalent per \$ of GDP in purchasing power parity terms; today, the comparable figure is 0.16. Most independent projections indicate that India's CO_2 intensity is likely to continue to decline over the 2030-2050 timeframe.

Nonetheless, the potential for offsetting CO_2 emissions in India is high owing to the large opportunities to both lower energy intensity and improve the carbon intensity of its fuel mix. India's commitment to a low-carbon economy will involve major changes to the way it supplies and uses energy. Modernizing and improving the operational efficiency and increasing the proportion of renewable energy in its fuel mix while reducing peak demand (especially for electricity created from fossil fuels) will remain central to achieving the objective of a lower carbon footprint.

Meeting this objective will require a development strategy to design smart grids at the outset, spur more consumer-driven energy efficiency, optimize the sector's fuel mix, and speed the deployment of grid-connected renewable energy sources.

The ideal outcome would be a plan to enable India to "leapfrog" into an advanced electricity supply system without going through the life cycle of the power sectors in mature industrial and post-industrial economies.

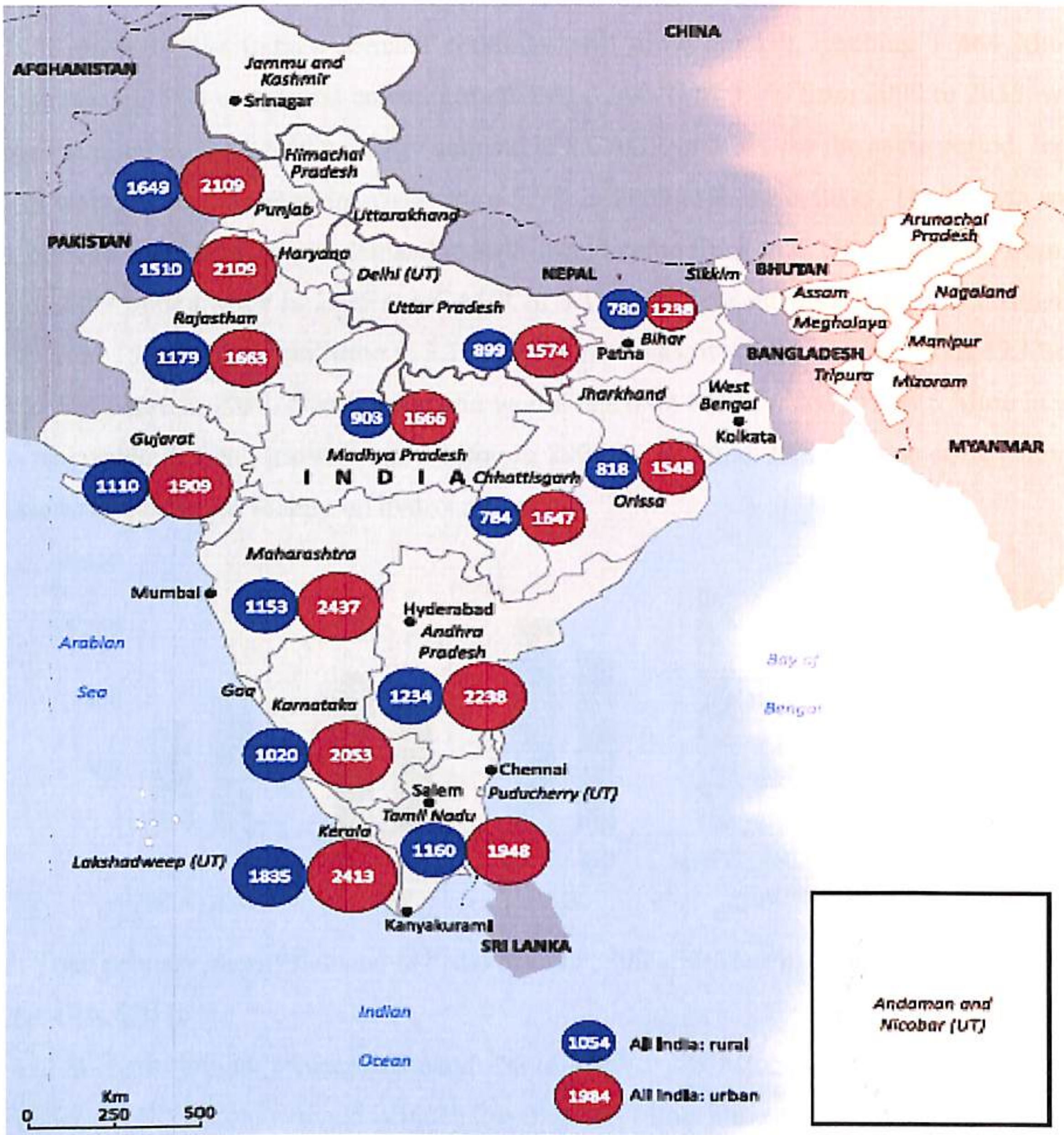
CHAPTER 2

INDIAN ENERGY SCENARIOS

Overview of the Energy Sector

In 2009, India had the third largest energy demand in the world after China and the United States and just ahead of Russia. As World Energy Outlook (WEO) 2011 shows, India's energy demand more than doubled from 319 million tons of oil equivalent (Mtoe) in 1990 to 669 Mtoe in 2009. Notably, India's per-capita energy consumption is still at a much lower level than that of developed countries and even of some developing countries. Its per-capita energy consumption is 0.58 (toe/capita), compared to the world average of 1.8, OECD of 4.28, China of 1.7 and Africa of 0.67 in 2009 (IEA, 2011b). The low per-capita energy consumption level indicates that India's energy demand still has a long way to reach saturation. With a growing economy and a 1.24 billion population aspiring for a better quality of life, India's energy demand growth is inevitable. The question is at what scale and speed India's energy demand will expand and which fuels and technologies it will use. This is the key for understanding the future landscape of India's and eventually the world energy market.

Figure 1: Average monthly per-capita expenditure: major states (INR)



Source: MOSPI, 2011

Energy Demand

The New Policies Scenario (NPS), the central scenario of WEO 2011, shows how the future might look on the basis of the incorporation of broad policy commitments and plans announced by countries to tackle energy security, climate change and other pressing energy-related challenges. The 450 Scenario of WEO 2011 sets out an energy pathway consistent with a 50% chance of meeting the goal of limiting the increase in average global temperature to 2°C, compared with pre-industrial levels.

The NPS projects that India's demand continues will grow quickly, reaching 1 464 Mtoe in 2035, increasing by a compound annual growth rate (CAGR) of 3.1% from 2009 to 2035, which is more than double the world's energy demand at a CAGR of 1.3% for the same period. India's share in world energy demand increases from 5.5% in 2009 to 8.6% in 2035. The growth would come from all fuels. The largest demand growth would come from coal, almost tripling from 280 Mtoe in 2009 to 618 Mtoe in 2035 at a CAGR of 3.1%. Oil demand would show a considerable growth from 159 Mtoe to 356 Mtoe at 3.1%. For natural gas, it would increase from 49 Mtoe in 2009 to 154 Mtoe in 2035. Nuclear demand would reach 48 Mtoe in 2035 from 5 Mtoe in 2009 while renewable demand grows from 2 Mtoe in 2009 to 36 Mtoe. India's huge energy demand increase would be based mainly on hydrocarbons.

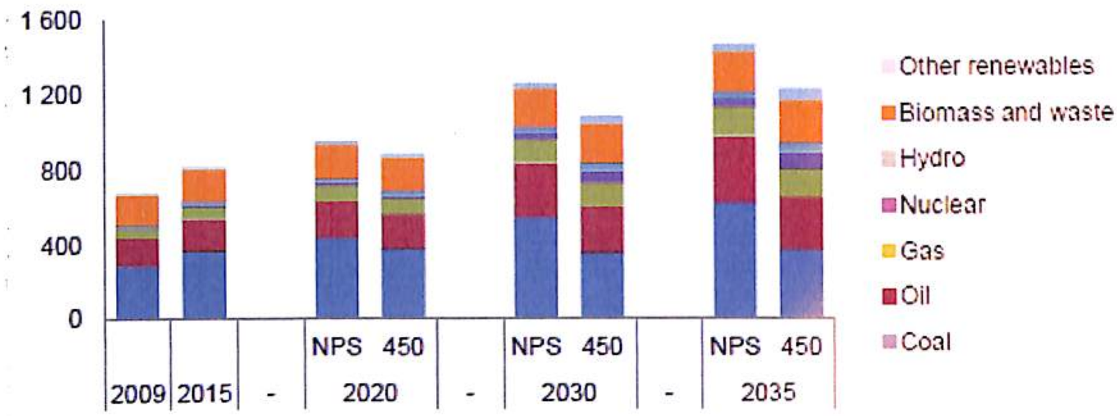


Fig 2: Total primary energy demand (TPED) in India, 2009-35(Mtoe)

Source: IEA, 2011a

The 450 Scenario project's energy demand would reach 1 223 Mtoe in 2035, which is 17% less than under the NPS. Coal demand is much lower at 365 Mtoe, almost half of the NPS projection. The demand for nuclear energy would double in the 450 Scenario to 90 Mtoe, growing at a CAGR of 11.9% from 2009 to 2035, and renewable demand would increase to 57 Mtoe.

However, even under the 450 Scenario, which implies greater expansion of renewable and nuclear, the growth of hydrocarbon energy at 311 Mtoe from 2009 to 2035 remains substantial.

It is important to note that in 2009, 289 million Indians lived without access to electricity and 836 million people without modern fuel for cooking and heating (IEA 2011a). Unsatisfied energy demand is the key source of projected growth of demand in India, which will accelerate in tandem with the country's economic growth.

Energy mix

The energy mix is the snapshot of a country's dependency on each energy source and provides a good indication of a country's energy challenges. Since economic reforms in 1991, India has experienced a major transformation of its energy mix. The most notable change in the country's energy mix since then was the shift from biomass to other energy sources, particularly coal. The reduction of biomass consumption coincides with India's economic development and growing urbanization over the past two decades. Biomass and other wastes such as fuel wood and animal waste are widely used for cooking and heating purposes by low income households, primarily in rural areas.

In 2009, India's largest primary energy source was coal, with a share of 42%. The second largest source was biomass at 25%, decreased from 42% in 1990. In 2009, oil represented 24% and natural gas 7%. Other fuels, such as nuclear, hydro and other renewable, have a rather small share in the total fuel mix. The current energy mix would not experience a dramatic change by 2035, with coal remaining the dominant fuel at the same 42% share. The share of biomass would decrease to 15%, as an outcome of poverty reduction, urbanization and increasing demand for modern fuels. Other fuels would maintain similar shares in 2035. On the contrary, a declining share of coal to 30% in 2035 with a greater share of nuclear and renewable of 7% and 5% in the energy mix.

Sectored energy demand

Sectored energy demand reflects the economic structure of a country. In 1990, the building sector was India's largest energy consumer, representing 42% of India's total primary energy demand, using biomass as the major fuel. The share of buildings dropped to 29% in 2009 and will decrease to about 18% in 2035. The industry sector consumed approximately 22% of TPED in1990 and will remain similar until 2035.

The power sector has been the primary force behind energy demand growth in India. Its share expanded from 23% to 38% of TPED from 1990 to 2009. This was attributable to soaring demand for electricity for industry uses and residential/commercial activities. With this trend, the share of the power sector will continue growing to almost 42% in 2035 under NPS. The transport sector represented 8% of energy in 1990 and will reach 14% in 2035 under NPS, a small but significant growth, as 90% of transport energy consumption will be based on oil.

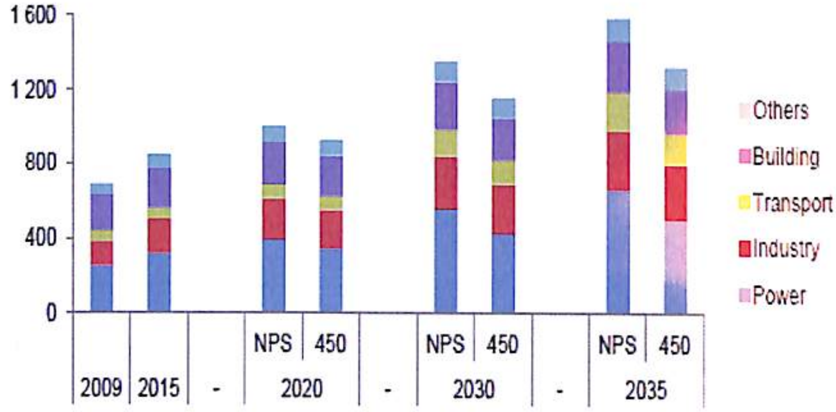


Fig 3: Sectored demand 2009-2-35(Mtoe)

Source: IEA, 2011a

Energy Supply

Domestic energy production in India grew from 291 Mtoe in 1990 to 502 Mtoe in 2009 at a CAGR of 2.9%. Considering India's demand growth at a CAGR of 4% for the same duration, domestic supply could not keep up with the demand. Biomass was the largest production source with 46% share in 1990, but dropped to 33% in 2009. The largest production volume addition came from coal production, which increased from 104 Mtoe in 1990 to 244 Mtoe in 2009 at a CAGR 4.6%. Coal also represented almost half of total domestic energy production. The fastest growing fuel is, however, natural gas, which increased domestic energy production to 38 Mtoe in 2009 from 10 Mtoe in 1990 at a CAGR of 7.0%. On the other hand, crude oil production growth remained at CAGR 0.5% for the same period, whilst crude demand increased by 5.1%.

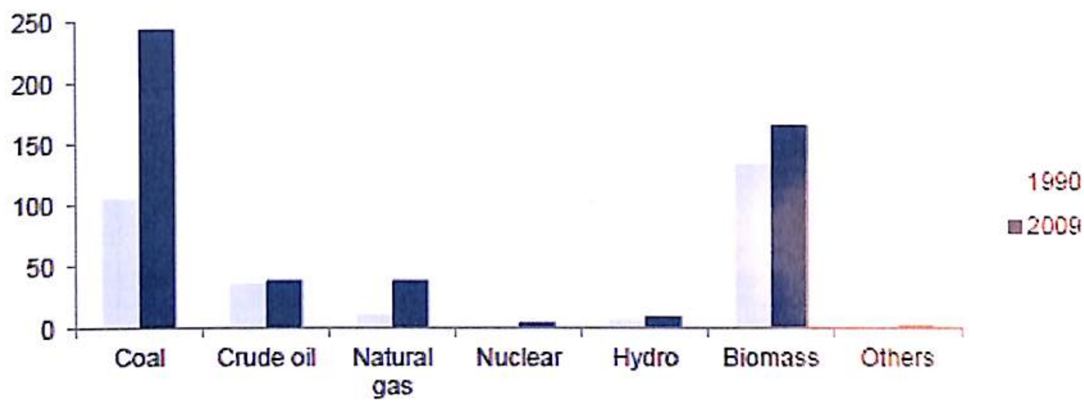


Fig 4: Energy production (Mtoe)

Source: IEA database

Carbon Emission

India was the third largest CO2 emitter in the world in 2009, following China and the United States and slightly ahead of Russia. Its carbon emissions of 593 million tones carbon dioxide (MtCO2) or 2.8% of global emission in 1990 almost tripled to 1 548 MtCO2 or 5.4% in 2009. This growth rate is much higher than the world's average; India's emissions between 1990 and 2009 grew by a CAGR of 5.2% vis-à-vis 1.7% for the world. This is due to increased coal consumption, which represented 67% of the emissions increase from 1990 to 2009. Under the NPS, India's carbon emissions increase to 3 535 MtCO2 in 2035 at a CAGR of 3.2%, responsible for 8% of global emission of 43 320 MtCO2. Emissions from coal combustion would be 2227 MtCO2 or 63% of India's total emissions. Under the 450 Scenario, India's emissions growth would slow to a CAGR of 1.3%, reaching 2 159 MtCO2 in 2035. The share of coal-based emissions would decrease to 51%, decreasing dramatically to 1 093 MtCO2, which is near to the same level as in 2009. Such projections of a massive increase of carbon emissions in India raise concerns about their impact on global climate change.

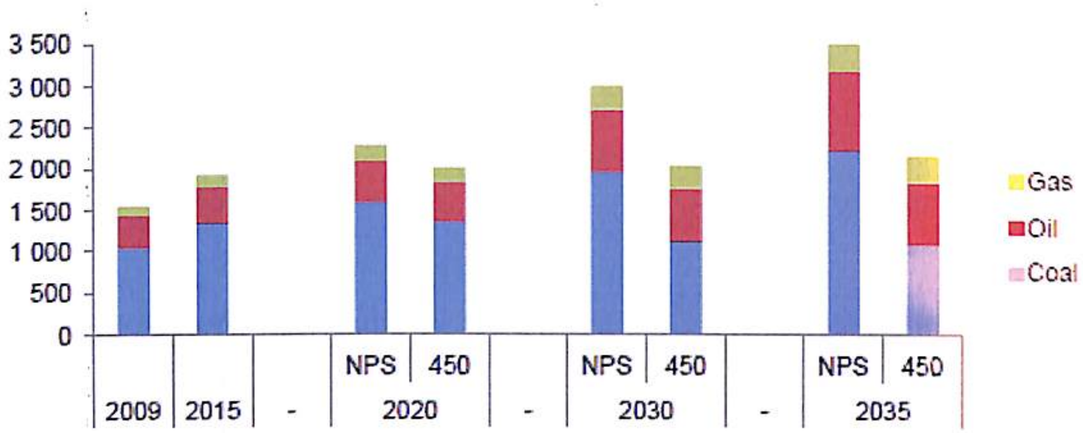


Fig 5: Carbon emission in India, 1990-2035(Mtoe)

Source: IEA, 2011a

It is important to mention that India's per-capita carbon emissions of 1.37 tones carbon dioxide (tCO_2/capita) were much lower than those of other countries in 2009. The world average was 4.29 (tCO_2/capita), compared to China at 5.14 and the United States at 16.90. The WEO 2011 NPS assumes that in 2035, when India is projected to be the world's most populous nation with 1.511 billion people, India's per-capita carbon emissions could reach 2.34 (tCO_2/capita), which is higher than at present but still substantially lower than the world average of 4.25, with China's per-capita CO_2 emissions at 7.39 and the United States' at 12.03 in 2035. The 450 Scenario projects that they would be 1.43 (tCO_2/capita) for India, 3.59 for China, 5.98 for the United States and 2.52 globally.

2.1 Challenges and Opportunities in Power sector

First of all it is worth mentioning that the power sector has been at the centre of India's energy policy. The development of the power sector is closely tied with India's energy policy objectives of universal energy access and energy security. The Indian power sector is one of the most demanding and diversified sector in the world today. Various sources for power generation range from conventional sources like coal, lignite, natural gas, oil, hydro and nuclear power to non-conventional sources like wind, solar, tidal, agriculture and domestic wastes. The demand for the electricity in the country is growing at a faster pace and expected to grow further in the ensuing years. In order to meet the increasing demand of the electricity, a massive addition to the existing capacity is required. Simultaneously, commensurate augmentation in the Transmission and Distribution segments is also required, which require a massive infrastructure with skilled and un-skilled manpower resources.

There is no doubt that the Power sector is the most important among all infrastructure sectors in the country. As power is a prerequisite input to all industrial and commercial sectors, the development and maintenance of commensurate power infrastructure is essential for the sustained growth of the economy. Thus, it is imperative that the growth in Power Sector should be broadly at par with the GDP growth rate, say around 9%.

The Indian Power sector has grown significantly since independence and the generation capacity has increased from 1,362 MW in 1947 to over 250,257 MW in July, 2014. Despite significant increase in electricity generation, the shortage of Power continues to persist primarily on account of the growth in electrification and demand for Power outsmarting the growth in generation and capacity addition. Even after considerable growth in the Power sector and improvement in the electricity supply, many parts of the country continue to face Power shortages.

The Power sector is highly capital intensive with long gestation periods before commencement of revenue streams with a construction period of about 4-5 years in case of the Thermal Projects and 7-8 years for the Hydro Projects. This excludes a considerable time required for seeking statutory clearances like environment and forest clearance, land acquisition and achieving financial closure for the project. Since the projects have a long time-frame, this involves several inherent risks too in both the internal & external environment.

The Power sector has made considerable progress over the past few years with several reforms for progressive changes. The erstwhile state electricity boards have been restructured and independent regulatory institutions in the form of central and state regulatory commissions have been established. Setting up of an electricity tribunal, forums for redressal of consumer grievances and ombudsman have proved to be significant milestones for conflict resolution among stakeholders. Government has distanced it with tariff determination and there is greater public participation in Tariff-setting exercise. Tariff distortions are getting minimized over a period of time. Despite all these measures, the sector is facing considerable problems and new challenges cropping up. In a way, the sector is witnessing a turbulent phase and the investors are wary of the challenges that need prompt addressal. Besides, per capita annual consumption of electricity wise, the country with its per capita consumption of about 914 kWh in 2012-13, is still lagging behind in comparison to many other developing and developed countries.

Table 2: Per capita energy consumption

Serial No.	Country	kWh (For the year 2011)
1.	United States	13227
2.	Japan	7847
3.	China	3298
4.	South Africa	4694
5.	Brazil	2441
6.	India	884

Source: Indian Smart grid forum

The major issues and challenges that India is facing in various segments of power development are briefly indicated in the following paragraphs.

Challenges in Generation

Of the existing 250,257 MW capacity, about 172,986 MW (69.1%) is under the thermal generation i.e. coal, gas and diesel based, 40,798 MW (16.3%) under the hydro, 31,692 MW (12.7%) under the renewable energy sources and remaining 4,780 MW (1.9%) under the nuclear energy. Despite this huge capacity, there is still severe shortage of power in the country which compels utilities to resort to large scale load shedding in both the urban and rural areas.

In order to meet the ever growing demand of the electricity and to enhance the economic growth of the country, a large scale addition to the installed generation capacity and commensurate development of associated transmission and distribution infrastructure is required. The current 12^{th} Five Years Plan has an ambitious target of the capacity building of an additional 88,537 MW with another about one hundred thousand MW in the following five years plan with an objective to meet growing power demands with 24x7 supply to consumers.

However, the Generation segment is facing certain serious issues including the availability of coal and gas which is a serious challenge for augmentation of generation of electricity. These issues are briefly given in the following paragraphs.

(1) Shortage in Coal supply: At present, of the total generation capacity about 60% is coal/lignite based and around 76% of the generation comes from the coal-fired power stations making it back-bone of the power sector. The PLF of the thermal power stations remained about 65.5% during the year 2013-14 and one of the major factors has been the widening gap between the demand and supply of coal. Coal India Limited (CIL), a public sector company of the Government of India, and its subsidiaries are main source of production and supply of coal besides some captive coal mines and coal imports. The coal supply to the thermal power plants is assured through the coal linkage and signing of fuel supply agreements (FSAs) between the CIL and power plants.

While there has been a rapid growth in the generation capacity, mostly coal based, with large scale private sector participation in the recent years but coal production has not increased with commensurate pace. Developers are not so keen for the imported coal, though of superior quality, due to its high cost fearing this may lead to high tariff making it unviable for sale to already cash deficient distribution utilities. Available options to remedy this situation are a) steps to be taken by CIL to augment its coal mining capacity to match the growing demand of coal; b) government may consider opening the coal mining sector for private players; c) of late international coal prices are showing fall in prices, opportunity may be availed by developers to make use of the imported coal.

Another dimension has been added to the already deteriorating coal supply position. In the recent Supreme Court landmark decision, the majority of coal blocks allotted by the government to public and private companies since 1993 have been cancelled. This cancellation would have several repercussions in the days ahead and the government is required to promptly act to minimize its adverse impact on several ongoing projects. Similarly, several gas based projects are also stuck up with the problem of inadequate or non-supply of gas.

(2) Availability of natural gas: Gas based power plants currently contribute less than 10 percent of the total power generation installed capacity in India. The preference of Natural gas as fuel source for power generation is increasing due to its lower environmental impact in comparison to coal. Current natural gas production in India stands at 132.5 mmscmd which dropped from 143 mmscmd in 2009-10. The allocation of natural gas to Power and Fertilizer sector contributes a lion's share of approximately 70 percent, and with the current domestic production there exists a deficit in the supply of natural gas.

(3) Statutory Clearances: Though delicensing of generation and transmission was a significant step in power development, there are still many delay prone government approval and statutory clearances at various levels making the process lengthy and cumbersome. Securing land and environment & forest clearances continue to be difficult and time-consuming processes. Land is first and foremost necessity for setting-up a Power project. A lot of projects get either cancelled or delayed due to non-availability of land or difficulties in transfer of land. Sometimes, environment and forest clearance takes three to five years or even more leading to considerable time and cost overruns. Securing fuel linkage or captive mines too is a rather long-drawn process and has led to a scam like Coalgate. It is understood the present government is working on how to make streamline processes and expedite clearances in a fair and transparent manner.

(4) Investor Friendly Climate: Private investment has steadily grown in the country since the liberalization of the Power sector by allowing hundred percent foreign direct investments. However, many major international companies are still apprehensive and reluctant to invest in India's energy sector due to several restrictive policies and cumbersome procedures. Moreover, the coal mining sector continues to remain monopoly of one government owned company almost closed for the private participation. In terms of the general investment environment, the doing business index (DBI) by the World Bank in 2012 ranked India at 132nd out of 183 countries. Clearly, the country needs to go a long way to create investment friendly business climate to attract greater investment.

(5) High Ash Content Coal: About 80% of Indian Coal reserves have ash content between 25-45%. The absence of adequate numbers and location of Coal washeries in the Country makes it necessary to import low-ash Coal. Low ash Coal is largely imported as high ash content in Indian Coal makes washing necessary before it is supplied to Power plants. Besides, the disposal of ash also poses several problems.

(6) Dipping Power Load Factor (PLF): Availability of Coal and Gas for Power generation has been a major cause of concern. The Gas supply to gas based Power plants has been quite uncertain and erratic. Due to reduced availability coal and of gas, many existing Power plants in the country are operating at low PLF and some have even been closed.

(7) Uncertainty of Imported Coal : The recent change in international markets, most notably among which being the enactment of the new mining laws in Indonesia, has significantly impacted the cost of imported coal for Indian companies, many of which were relying on supply of coal from this south-east Asian nation. Securing fuel from the import Coal market is turning out to be increasingly costly and uncertain. Krishnapatnam UMPP (4,000 MW) has remained a non-starter while Mundra UMPP (4,000 MW) and Adani MTPP (4620 MW) are facing litigation over rising cost of imported coal. Recently, coal prices in the international market are showing a down trend but due to price uncertainties and high transportation cost, it has so far failed to create a favorable impact on Indian importers.

Challenges in Transmission

At the time of Independence with meager overall generation capacity, Power systems in the country were essentially isolated systems developed in and around urban and industrial areas with the highest transmission voltage of 132 kV. The state-sector network grew at voltage level up to 132 kV during the Fifties and Sixties and then to 220 kV during the Sixties and Seventies. Subsequently, in many states substantial 400 kV network was also added as large quantum of power was to be transmitted over long distances.

While generating power, the evacuation of this power with proper transmission and distribution is also equally important which again require a massive infrastructure with skilled and un-skilled manpower resources. For smooth and efficient transportation of electricity from one part to another part of the country, a national grid is in place. The country is divided into five electrical regions, namely northern, southern, western, eastern and north-Eastern regions for the purpose of grid operation. In the past, they were operating in asynchronous mode but now all these regions are synchronously connected which means power can now smoothly flow from one part of the country to another.

In addition to the national grid, the respective states have their own state grid for transmission of electricity. Inter-State (and Inter-regional) transmission system is mainly owned by Power Grid Corporation Limited, a Government of India Undertaking. Planning and developing Inter-state transmission system for many private projects is a challenging task because of the uncertainty about their actual materialization, commissioning schedule and their beneficiaries are most often not known at the time of transmission planning. The process of transmission planning and development is becoming increasingly dynamic in the market driven environment.

The major issues and challenges in development of the Transmission segment in the country are as under:

(1) Inter-State Transmission Capacity Building: The current cumulative Inter-regional Power transfer capacity of National Grid stands to about 28,000 MW and frequent congestion in Inter-State Transmission of electricity have been noticed. Commissioning of Inter-regional links has strengthened the Inter-regional grid capacity of Eastern Region with Western Region and Northern Region. To further strengthen the National Grid, various high capacity HVDC and EHVAC Inter-regional links with total capacity of 38,400 MW have been planned to take care of Inter-regional Power transfer requirement of various planned generation projects including Independent Power Producers (IPPs) scheduled for commissioning in XII Plan. The Inter-regional power transfer capacity of National Grid is thus envisaged to be enhanced to about 66,400 MW by the end of XII Plan.

The augmentation of inter-regional capacity shall also facilitate the integration of a large renewable Power generation in the southern region with the rest of the country.

(2) Grid Failure: With the ever expanding transmission network in the Country, complexities of Grid operation have also increased. Currently there are five Regional Load Dispatch Centers (RLDCs) under the National Load Dispatch Centre (NLDC) which are being upgraded continuously through deployment of latest technology. However, the Grid experienced two major disturbances consecutively on 30th July & 31st July, 2012. While the first disturbance affected only Northern Region, the second one affected Northern, Eastern and North Eastern Regions. However, the essential loads were restored quickly within few hours of the incidents and power supply was restored progressively. Other than this, there has not been any other major failure during the last ten years.

Ever since several measures have been taken at national level to ensure uninterrupted supply and reliability of the Power system in the country which *inter alia* include heavy penalties for violation of grid code by any utility.

(3) Islanding Scheme: In any power system, the transmission network is designed to be adequate for normal load flows and also for certain reasonable contingencies. However, in the event of a major disturbance with considerable loss of network/generating capacity; the remaining network may not be in a position to cater to the load and such overloading may have cascading effect in tripping of the remaining network following the disturbance.

In order to provide another layer of system protection and prevent collapse of the entire system leading to total black out consequent to a major system disturbance, a scheme called islanding scheme was conceptualized in 2013 and is being developed for the major cities and pockets. This protection is a system protection of the last resort. This scheme pre-supposes that the integrity of the system cannot be maintained in spite of the automatic load shedding. Instead of allowing the system to disintegrate by the tripping of generators and transmission lines as the disturbance develops, the islanding scheme itself sectionalizes the whole system into sustainable small systems each consisting of a group of generating stations and a group of load centers that can be sustained by these generating stations. In effect each group becomes a sustainable island and hence the name islanding scheme. Initially, such scheme is being implemented for cities like Delhi and Mumbai.

(4) Smart-Grid: Smart Grid is confluence of Information, Communications & Electrical/Digital technologies. Smart Grid, apart from facilitating real time monitoring and control of power system will also help in reduction of AT&C losses, peak load management/demand response, integration of renewable energy, power quality management, outage management etc. In this way Smart Grid technology shall bring efficiency and sustainability in meeting the growing electricity demand with reliability and quality of the Power system.

In India, it is still in a nascent stage yet the PGCIL has taken pioneering steps in bringing Smart Grid technology to various facets of power supply value chain. It has undertaken a smart grid pilot project at Puducherry through open collaboration covering all attributes of smart grid in distribution.

Challenges in Distribution Segment

Distribution of the electricity is largely a state subject in India. The responsibility for the distribution of electricity to the end consumer is undertaken by the state owned Distribution companies. The private sector has limited presence in distribution segment in certain parts of country including Delhi, Mumbai, and Odisha etc. Incidentally, this happens to be weakest link among various segments associated with the power industry. Distribution infrastructure largely consists of sub-stations, low voltage lines, transformers and associated paraphernalia. A large number of the distribution utilities are running into losses due to issues like obsolete and outdated infrastructure, energy losses in transmission, distribution and theft, inefficient metering, billing and collection, subsidy and cross-subsidy, non-implementation of cost reflective tariff, and so on so forth.

There is no doubt that any service sector cannot deliver on its social responsibilities unless it is financially and commercially viable. The Distribution segment plays a crucial role in the overall functioning of the Power Sector as it provides the last mile connectivity of Power to the consumer. The recent years have been a witness to growing concerns over the financial health of Distribution Utilities. The low collection efficiencies and cash deficit scenario of the Distribution utilities, in a way, are impacting the financial viability of Generation and Transmission segments as well.

Distribution segment has major bottlenecks in terms of inadequate investment, metering of consumers, aggregate technical and commercial (AT&C) losses, rising gap between the cost of supply and revenue realized, LT-HT line ratio and overloading of transformers, skewed tariff structure, accountability, management structure and practices. The major challenges before the Distribution segment are highlighted in the following paragraphs.

(1) High Aggregate Technical & Commercial Losses: Existing high AT&C losses are one of the biggest problems in the Distribution segment. At present, national average annual AT&C loss is estimated to be around 25.38% for the financial year 2012-13. However, there is a wide variation in the loss levels for different states. In states like Jammu & Kashmir and Bihar, it is as high as 60.87% and 54.63% respectively, while some others like Himachal Pradesh (9.53%) and Andhra Pradesh (13.63%) and have been able to bring down these losses significantly. High levels of AT&C losses pose a major challenge as a significant portion of the generated power is lost or goes unaccounted. This has largely been on account of old and outdated sub-transmission, poor distribution leakages, theft etc.

The scale of losses in the Distribution segment of Power sector is simply unsustainable to maintain the financial viability of the sector. A number of technical and non-technical factors contribute to the high Transmission and Distribution losses. These include populist measures of granting free or subsidized power supply to agricultural users, lack of consumer education, theft and inefficient use of electricity. Inadequate investments in the sector over the years have also resulted in overloading the distribution system elements. Apart from above problems, the Distribution segment is affected by poor billing and collection efficiency in most of the States.

The Transmission and Distribution (T&D) losses in the developed countries vary in the range of 4 to 8%. Countries in Europe and United States of America have T&D losses of about 6 to 8 %. Developed countries have far lower loss levels compared to India. China with a T&D loss level of approximately 6% is ahead of many developing countries.

Main reasons for AT&C Losses are both technical and commercial. Technical losses are on account of the overloading of existing lines and substation equipment, lack of up-gradation of old lines and equipment, low high tension – low tension lines ratio, poor repair and maintenance of equipment and inadequate or non-installation of capacitors/reactive power equipment. On the other hand, commercial losses include low metering, billing and collection efficiency, theft, pilferage of electricity, tampering of meters, lack of energy accounting and auditing further compounded with low accountability of concerned employees.

The responsibility of reduction of AT&C losses in the distribution network primarily rests with the State Governments and the Power Departments/Utilities. However, to address the issues related to the high AT&C losses and reforms in the distribution sector of the States, the Government of India had launched the Accelerated Power Development and Reforms Programme (APDRP) during 10th Plan and it was restructured (R-APDRP) during the 11th Plan. The scheme has been continued in the 12th plan (2012 – 2017) with emphasis on actual demonstrable performance in terms of sustained loss reduction, establishment of a reliable and automated system for collection of accurate base line data and adoption of Information Technology (IT) for energy accounting.

(2) Financial Health of Distribution Utilities: The financial health of Distribution utilities in the country is a matter of serious concern. The total Aggregate losses of utilities under various states were estimated to be about 190,000 crore as by end of March, 2012. Factor responsible for this condition are continuing high AT&C losses, unrealistic tariff structure, poor revenue collection, non-payment of subsidy, poor infrastructure, planning and implementation.

To bail out state owned Distribution utilities, the Central Government has formulated and approved a scheme for financial restructuring in October, 2012 to enable the turnaround of the state distribution companies and ensure their long term viability. Under the scheme, 50% of the outstanding short term liabilities corresponding to accumulated losses as on 31st March, 2012 shall be taken by the state government. The balance 50% liability will be rescheduled by lenders on best possible terms with initial moratorium on principal. The Central government will, in turn, incentivize States by giving capital reimbursement support @ 25% on the liability taken over by the state government and grant equal to the value of energy saved by way of accelerated AT&C loss reduction, subject to fulfillment of certain reform measures. These steps are likely to improve financial health of participating utilities in due course.

(3) Tariff Rationalization: The main reason for the poor financials of Distribution utilities is the continuing revenue gap between the cost of supply of electricity and tariff fixed. Such a gap is left by the regulators mostly under influence of state governments as populist measure in an endeavor to keep tariff low for certain categories of consumers including agriculture and domestic consumers. This compromises the sustainability of Distribution companies. It is necessary that the tariff structure is commensurate with the cost of supply and, in case, any State governments desires to give relief to any category of consumers, they should do so by upfront payment of subsidy as provided under the Act.

(4) 100% metering of Consumers: Metered supply to consumers leads to correct estimates of losses, subsidies, incentives, and effective planning and implementation. There is an urgent need to identify an action plan for 100% metering of consumers and implementation by all Distribution utilities. The existing provision is to have pre-paid meters for all government consumers and high end consumers of one MW and above. In many states, a large number of domestic and agriculture consumers are un-metered. It is necessary to have a time bound metering plan for all consumers in the following manner.

- Identifying all unmetered consumers
- Metering of consumers should be completed in phases depending on prioritization such as Urban, Rural etc.
- Implementation of prepaid metering for the designated category of consumers.

(5) Lack of credible database: Majority of the Distribution utilities do not have IT enabled information system and thus struggle to maintain a comprehensive database of all consumers and related information. Lack of accurate information hinders decision making especially in curtailing theft, making investments and estimating losses. IT based information system can be a key enabler in electricity distribution business to set baseline and measure performance. For this, initiative taken by the Central Government in the form of R-APDRP should be utilized in full by the respective state utilities in a time bound manner.

(6) Energy accounting & auditing covering all feeders and Distribution Transformers (DTs): Despite the focus given to proper energy accounting and auditing, metering especially for rural, domestic and agriculture consumers is still to be completed. This in turn puts a question mark on the veracity of the Distribution loss figures in itself as reported by the utilities based on estimated consumption taken for unmetered consumers. Again R-APDRP would be of tremendous help in addressing these issues.

(7) Other Measures for Distribution segment: Multipronged approach has been adopted for swift recovery and overall improvement of the Distribution segment. Some of the important measures are briefly indicated here:

- Privatization of distribution by out-rightly giving it to private companies and Franchisees is being attempted. Odisha and Delhi are example of privatization while franchisee model was successfully implemented in Bhiwandi, Maharashtra. Franchisee model is being experimented in certain other major towns like Nagpur, Aurangabad and Jalgaon in Maharashtra, and Agra and Kanpur in Uttar Pradesh.

- A National Electricity Fund has been created which is basically an interest subsidy scheme for the states interested in improving their High Voltage Distribution System (HVDS) in the towns not covered under the R-APDRP.
- Supervisory Control and Data Acquisition System (SCADA) is being implemented at large scale for the real time communication, information storage and energy loss calculations.
- Smart metering i.e. the use of remote meters for automatic meter reading is at cards. This will be very useful for effective energy management, energy accounting and problems of manual reading.
- There is need for segregation of agriculture and rural feeders. By separation of agriculture and rural feeders, agricultural load can be given supply during off peak hours while eventually a continuous supply could be given to rural homes. In 2014-15 Central Budget, Deen Dayal Upadhyaya Gram Jyoti Yojana has been announced for feeder separation and strengthening of sub-transmission and distribution infrastructure in rural areas.
- There is a need for promoting energy efficient equipment and appliances. Regulatory Commissions can play meaningful role by introducing components in the tariff structure for incentivizing energy efficiency.

2.2 Renewable energy scenarios

Large scale electrification and consumption of the fossil fuel based electricity featured only in 20th Century in the history of civilization. Till late 20th century, more developed West, like industrialization and modern technology, took lead in this sector too but the rest of the countries including India are now catching up fast to meet their growing energy needs in the modern age living. Fossil based fuels like coal, gas, diesel etc. are exhaustible energy sources which are fast depleting globally due to large scale mining world over to meet growing energy needs. Hence the future of the humanity seems viable only with the growth of new and renewable energy sources.

Fossil fuels are basically hydrocarbons such as coal, lignite, oil and natural gas formed from the organic remains of the prehistoric organisms – plants and animals. While coal and lignite were usually formed under the land mass from the remains of land vegetation, the oil and natural gas represent the fossilized remnants of the marine organisms which became encased within the sea-floor sediments over the millions of years. When these fuels are extracted and burnt in controlled conditions, the entrapped energy is released which is harnessed to generate electricity for human use. The formation of these reserves under land or sea has taken millions of years and it is obvious that there is no way that these can be replenished in any timeframe that the man can visualize to match his growing needs. Hence the express need to look for the alternative renewable sources of energy.

Besides, the combustion of large scale fossil fuels has adverse impact on global warming and human health too. The discharge of carbon dioxide consequent to the burning of coal is a major contributor to the global warming and its harmful effects on human health worldwide. Besides coal combustion also releases particulate matter (fly ash), nitrogen oxides, sulfur dioxide, mercury and many other substances which pollute environment and are hazardous to human health, particularly for the respiratory system, the cardiovascular system, and the nervous system. Hence minimizing the impact of the green house gas emissions with carbon footprints have been the major concern worldwide necessitating to look for alternative sources of cheap, green and clean energy. Needless to mention, this alternative has been found in the renewable energy sources of the planet.

By definition, the renewable energy falls in the category of energy which is constantly replenished in the nature. For illustration, the sunlight, wind, tides, waves, rain, biomass and biofuels and geothermal heat are everlasting resources which have potential to serve as alternative of conventional fossil fuels in areas like electricity generation, motor fuels, water heating and rural energy needs. The added advantage of these sources is that they are abundantly available and can be tapped over a large geographical area as against the fossil fuels which are localized only in certain countries and areas.

Though sunlight, wind, tide power etc. were known to mankind for long as source of energy and were being tapped in a limited way by countries but concerted efforts to tap it have been started only with the dawn of the 21st century. In fact, the world's first government level international conference was held in June 2004 in Bonn, Germany which was attended by participants from as many as 154 countries. The global outlook on renewable energy has considerably changed for good during the last ten years. This period has witnessed continuous technological advances, rapid expansion and deployment of technology in various countries to exploit full potential of the renewable energy sources. Towards the end of 2012, renewable energy constituted about 19% of the global energy consumption and it is continuously growing. Of course world leaders continue to be countries like China, USA, Germany, Spain, Japan, UK, Canada etc.

Fortunately, India is geographically placed in a region where there is no dearth of wind and sun light. Besides, the country generates a tremendous amount of biomass annually. The country is now seriously endeavoring to tap these energies and is perhaps one of the few countries which have an exclusive Ministry for New and Renewable Energy Sources to pursue unhindered progress of renewable energy as popular means of futuristic affordable power.

Currently it has one of the largest programs in the world for deploying renewable energy products and systems. Since its formation, the Ministry has launched one among the world's largest and ambitious projects and schemes through various promotional efforts. Besides, the north and north-eastern region of the country have tremendous big and small hydro potential of which even 25% have not been tapped so far. Efforts are also on to utilize the hydro potential by removing existing barriers and bottlenecks in the development of Hydro Power Plants.

Towards the end of July, 2014, the country has total installed capacity of renewal energy from all sources at 33,447 MW. Of this, 32,424 MW (Table-1) is grid-interactive power from the electricity generated through the sources like wind, small hydro, solar, biomass, baggase cogeneration etc., while the remaining 1023 MW is off-grid and captive power. The key drivers for the promotion of the renewable energy are existing demand-supply gap, large untapped potential, growing concern for the environment, imperative need to strengthen India's energy security, pressure on high-emission industry sectors and need for a foreseeable and viable solution for rural electrification. In the following paragraphs, we shall briefly see the position of major renewable energy sources and their emerging trends in the country.

Table 3: Grid interactive power (Capacity in Mega watts)

Serial No.	Category	As on July,2013	As on July, 2015
1.	Wind power	19661.15	21692.98
2.	Solar power	1839.00	2753.00
3.	Small hydro power	3706.15	3826.18
4.	Biomass power and Gasification	1264.80	1365.20
5.	Baggase Cogeneration	2337.43	2680.35
6.	Waste to power	96.08	106.58
	Total	28905.21	32424.29

Source: Indian Smart Grid forum

Solar Power

India's geographical location between the Tropic of Cancer and the Equator enables it to have an average annual temperature range not below the range of 25-27 Centigrade with almost the entire central and southern peninsula with high solar potential. India has a vast solar energy potential. About 5,000 trillion kWh per year energy is incident over India's land area with most parts receiving 4-7 kWh per sq. m per day. Hence both technology routes for conversion of solar radiation into heat and electricity, namely, solar thermal and solar photovoltaic, can effectively be harnessed. Sunlight also provides the ability to generate power on a distributed basis and enables rapid capacity addition with a short lead time. Off-grid decentralized and low-temperature applications could be advantageous from a rural electrification perspective. From an energy security perspective too, solar is the most secure of all sources, since it is abundantly available.

Currently, India has a total capacity of about 2753 MW of solar power with grid connectivity. Solar energy is tapped by deploying photovoltaic (PV) cells on the roof top of houses and commercial buildings and collectors like mirrors or parabolic dishes to move and track the sun during the day. The Government had launched Jawaharlal Nehru National Solar Mission (JNNSM) in January, 2010 with an objective to develop and promote the solar energy technologies in the country.

Solar PV systems are taken as viable option by many users as well as generators because of its reasonable cost and ability to install in various capacities (kW to MW). The Ministry of New and Renewable Energy has come out with various schemes for promoting solar power projects from off-grid applications of 100 kW to utility scale megawatt size projects of various capacities. Even roof-top systems provide that generated power is consumed by the owner and excess power is fed to the grid. The scheme is implemented through the Solar Energy Corporation of India (SECI) by providing part subsidy (30%) to developers with the specific objective of reducing the dependence on the consumption of diesel during the day as also dependency on the grid power. Under the scheme, all buildings of the government, PSUs, commercial establishments, industries, hospitals, cold storage, warehouses and educational institutions are covered. Usually the projects of 100 kW to 500 kW are covered under the scheme. Besides, the government's own PSUs and private developers have undertaken several projects of the size of 5 MW and above.

Wind Energy

India has a vast potential of wind energy of an estimated 48,500 MW across the country especially in north-west and southern states like Rajasthan, Gujarat, Maharashtra, Karnataka, Kerala, Tamilnadu and Odisha. The wind energy is particularly favored because it one of the most environment friendly, clean and safe energy source. Besides it has many other advantages like a) a low gestation period compared to the conventional energy sources; b) equipment erection and commissioning is completed only in a few months; c) low operating and maintenance costs since any fuel is not required, and d) the capital cost (Rs 50-60 million/MW), unlike solar, is almost in the range of conventional power plants.

The Wind Resource Assessment Programme which is being coordinated by the Centre for Wind Energy Technology (C-WET) under the aegis of the government has so far covered 31 States and Union Territories involving establishment of about 1244 wind monitoring and wind mapping stations. The cost of setting up a wind monitoring station is shared between Central and State Governments in ratio of 80:20 and 90:10 in the North Eastern Region and hilly States. Usually, two types of wind turbines namely 'stall regulated' and 'pitch regulated' are being deployed in the country for the grid-interactive power. The stall regulated wind turbines have fixed rotor blades whereas pitch regulated wind turbines have adjustable rotor blades that change the angle of attach depending upon wind speed.

The total installed capacity of wind power in the country towards the end of July, 2014 is about 21,693 MW. Wind energy has a vast potential in India. The wind station/farm is ideally suited at sites with high wind resource, adequate available land with suitable terrain and good soil conditions, maintenance access to the site and nearby power grid for connectivity. The government is in favor of promoting more and more wind stations because of its categorical advantages over the fossil fuel based power stations which inter alia include its being inexhaustible resource, zero emission and no adverse impact on environment being pollution free and environment friendly.

Biomass Energy

Biomass has always been an important energy source in the country considering the benefits it offers. It is renewable, widely available, and carbon-neutral and has the potential to provide significant employment in the rural areas. Biomass is also capable of providing firm energy. About 32% of the total primary energy use in the country is still derived from biomass and more than 70% of the country's population depends upon it for its energy needs.

Biomass includes solid biomass comprising of the organic material of biological origins, biogas mainly methane and carbon dioxide produced by anaerobic digestion of biomass and combusted to produce power and/or heat, bio-based liquid fuel from biomass transformation used in transportation, and municipal wastes generated by the residential, commercial and public services sectors to produce power and/or heat.

Solid biomass resources such as cattle dung, agriculture wastes and many other organic wastes have been known energy sources for the mankind since ancient times. These are converted to biogas which is a clean low carbon technology for the efficient management and conversion of fermentable organic wastes into clean, cheap and versatile fuel for various applications including electricity generation, heating, cooking and refrigeration etc. The country ranks second with its capacity of biomass power and gasification at about 1365 MW as in July, 2014. Biomass based power has an added advantage that the biogas can be generated round the clock as against the solar and wind power which are intermittent in nature.

Another very successful form of biomass is sugar cane baggase from the agriculture, pulp and paper residues. Currently, India has installed baggase cogeneration capacity of about 2680 MW. The country is rich in biomass. As per an estimate, the country has a potential of over 20,000 MW of which baggase cogeneration alone accounts for about 3,500 MW. Thus a vast biomass potential remains untapped even now.

Small Hydro Power

Ministry of New and Renewable Energy has the responsibility of developing Small Hydro Power (SHP) projects up to 25 MW. The estimated potential of power generation in the country from small hydro is about 20,000 MW. Most of the potential is in Himalayan States as river-based projects and in other States on irrigation canals. The government facilitates statutory clearances and the private sector is showing a lot of interest in SHP projects which are essentially private investment driven. The Ministry aims to harness at least 50% of the potential in the country in the next 10 years.

India has a vast potential of hydro power in the country and the installed capacity of major hydro projects up to July, 2014 is about 40,798 MW which works out to 16.3% of the total installed capacity. However, despite being restorable energy source, the hydro power has traditionally been accounted for in India with the conventional energy sources largely comprising of fossil fuels.

In the country, the small hydro projects as renewable energy source for power generation have an estimated more than 4,000 identified potential sites. Besides, it has added advantage of old and reliable technology. As against the estimated potential of 20,000 MW, the total installed capacity stands at about 3826 MW up to July, 2014 and thus a vast potential still remains untapped. Besides encouraging and setting of new small hydro projects, the MNRE is also engaged in renovation and modernization of old projects and industry based research and development to improve technology.

CHAPTER 3

THE TECHNOLOGY OF SMART GRID

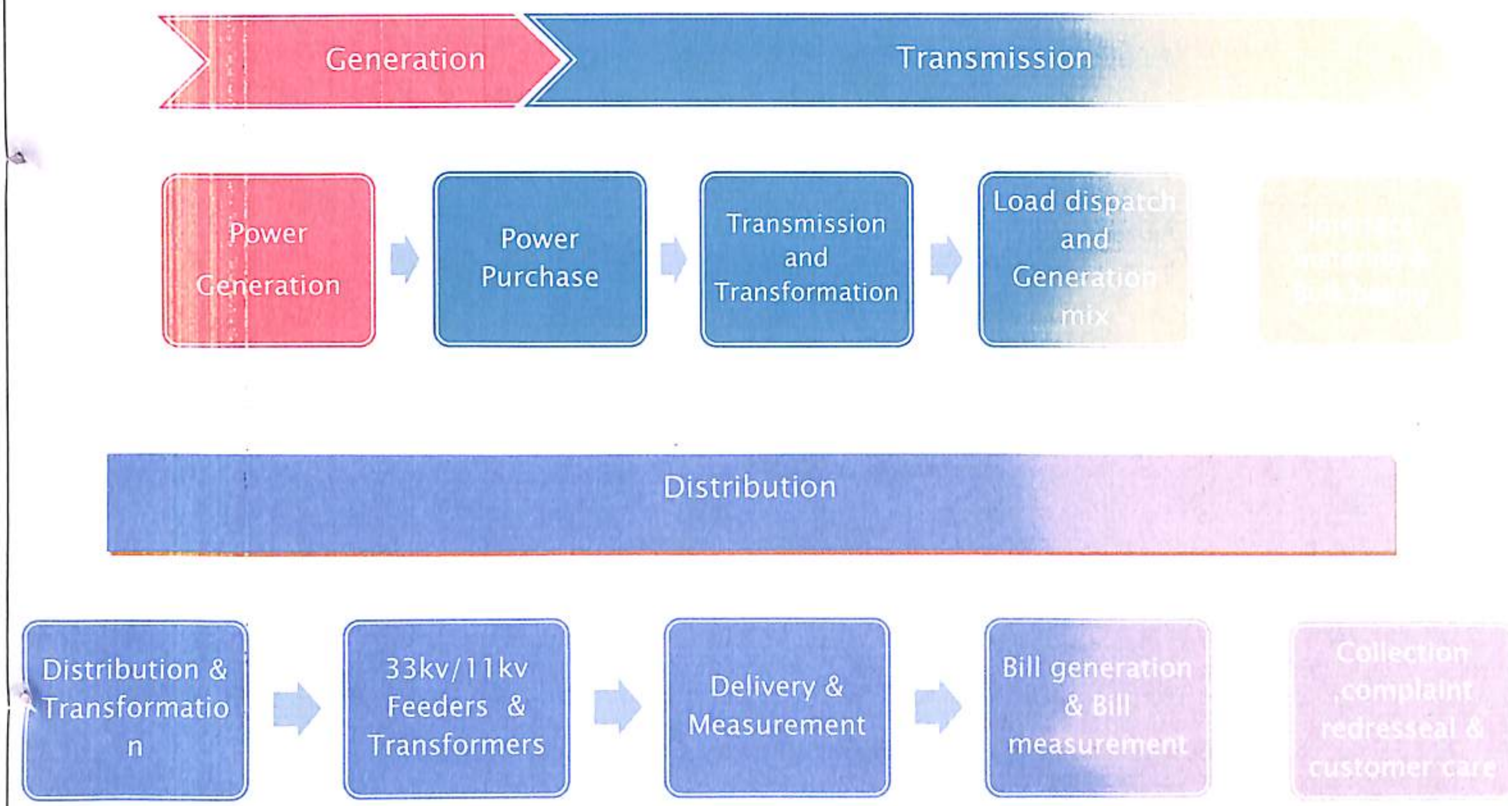
With the growing ultimatum of electrical power, Quality of Service (QoS) and continuity of supply has been the utmost primacy for all major power utility sectors across the world, prior to the global market strategy. Smart Grid is predominantly proposed as the quantum leap in harnessing communication and information technologies to enhance grid reliability, and to enable integration of various smart grid resources such as renewable energy, demand response, electric storage and electric transportation. It allow greater competition between the providers, enabling greater use of intermittent power resources, establishing the wide area automation and monitoring capabilities needed for both bulk transmission over wide distances and distributed power generation, empowering more efficient outage management, streamline back office operations, aiding the use of market forces to drive retail demand response and energy conservation.

After a brief overview of the electricity value chain and a review of the evolving role of the independent system operator (ISO), this chapter's discussion of smart grid technologies follows the path data will take within the utility systems architecture: from the field device to the computer system at a central location (e.g., the data management system at the utility's headquarters, the customer information and billing system, the dispatch center). For some applications, such as control, data also flow in the opposite direction, from the head of the system to the field device.

3.1 The Electricity Value Chain

The process for generating electricity and transporting it through the bulk power supply network (the transmission grid) has been in place for many decades. A critical early step was the adoption of AC power to enable the cost-effective transportation of bulk power over long distances. This enabled the technical structure of the electric industry that was set almost 100 years ago, namely, large, central-station power plants connected to a transmission grid (the superhighway of the electric system) to move power to load centers where transformers reduced voltage levels to distribution levels for use by customers. Following figure 5 shows the major elements of electricity value chain:

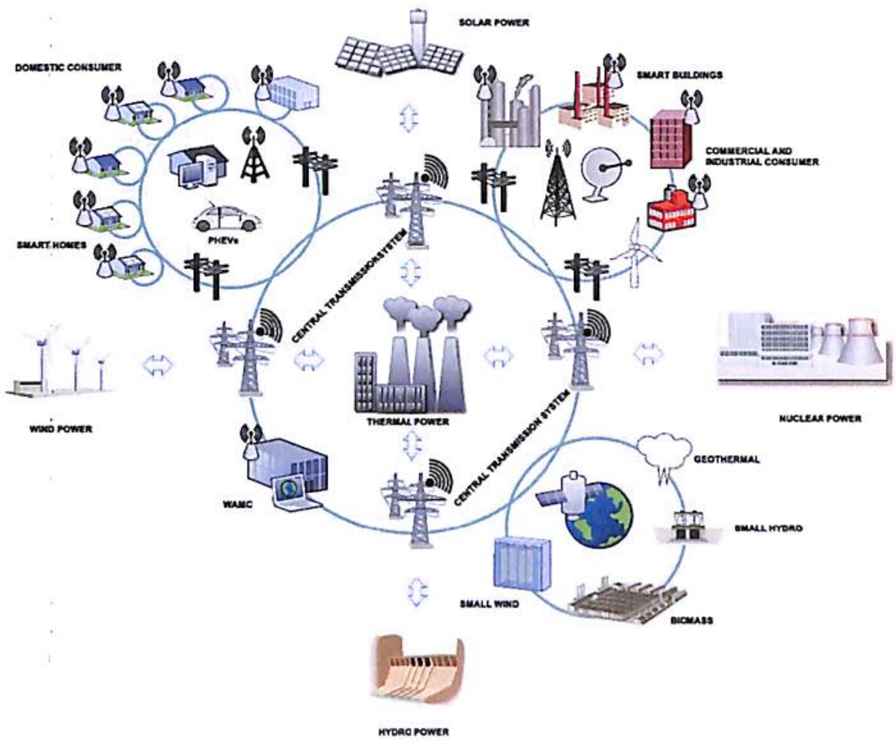
Fig 5: The major elements of electricity value chain



Some of individual and vertical integrated companies hold the ownership of all the elements of value chain for more than half century. This enabled the industry to optimize the economies of scale inherent in the capital-intensive electric supply industry.

Today the convergence of several major forces is changing the historical structure of the industry. These include: technological advances in ICT, the growing scarcity and increasing price of fuel, and the advent of cost-effective, small-scale distributed generation. The increasing technical efficiency and cost-effectiveness of renewable energy sources, coupled with growing public concern about the effects of climate change, have also brought about change. These are the underpinnings of what is known as smart grid. Following picture visualizes a typical paradigm of Smart Grid technology & its distinctive feature:

Fig 6: A typical paradigm of Smart Grid Technology



Source: Generation Dispatch, AREVA – IEEE Smart Grid Conference January 2010.

Nonetheless, the way an integrated smart grid will operate will be operate will be different-radically different in the view of many –from the way industry operated historically. One feature that will change but remain central to the smooth functioning of the electricity supply industry is network operations, or system operations and dispatch, as it was commonly known in the past.

Network Operations

The most visible differences between today's networks and the smart gid of tomorrow will be in the distribution area at the customer/network interfaces. However, in the generation and transmission areas, the role of the system operator (which today is already complex) will become even more complex and critical as it will have to ensure the reliable, efficient, and more integrated operation of many additional energy resources. These additional energy resources include increasing amounts of intermittent solar and wind generation, distributed generation and demand response options (DR) that are expected to become an integral part of the power system of tomorrow, thanks to the smart grid enabling technologies currently under development and implementation.

Evolutionary changes in network operations

The traditional system network operation model has evolved from the cost-based, supply-side system dispatch paradigm when companies operated as vertically-integrated utilities. Electric utilities operated large, remote power stations, long transmission lines, and a distribution system primarily designed to deliver power to a fairly static load.

This will change to a more sophisticated market driven system dispatch with multiple asset owners with a wide range of commercial interests. This evolution has been underway for several decades and will continue; the pace of change may accelerate new approach will have to accommodate more demand-side resources, generation and storage resources on the distribution system, and considerably higher levels of wind, solar and other types of renewable generation.

The traditional or classical system dispatch focused mainly on:

- Unit commitment schedule.
- Economic dispatch.
- Automatic generation control.
- Grid security.
- Local dispatch with some regional implication.

The evolution into a smart grid system dispatch environment will add more dimensions, which include the following:

- Dynamic balancing of centralized and distributed resources.

- Integration of distributed energy resources and demand response resources.

- Integrating large-scale intermittent renewable generation.

- Increased coordination of renewable generation and storage resources. Given the variability of some renewable generation (e.g., wind, solar), more real-time control will be needed to instantaneously balance supply and demand. New forms of storage resources, such as plug-in electric vehicles, could provide a critical buffer.

- Shifting loads to more efficient generation using demand response and distributed generation and storage with the aim of saving energy and reducing carbon emissions, depending upon the mix of base, intermediate, and peak load generating resources in use at any given time.

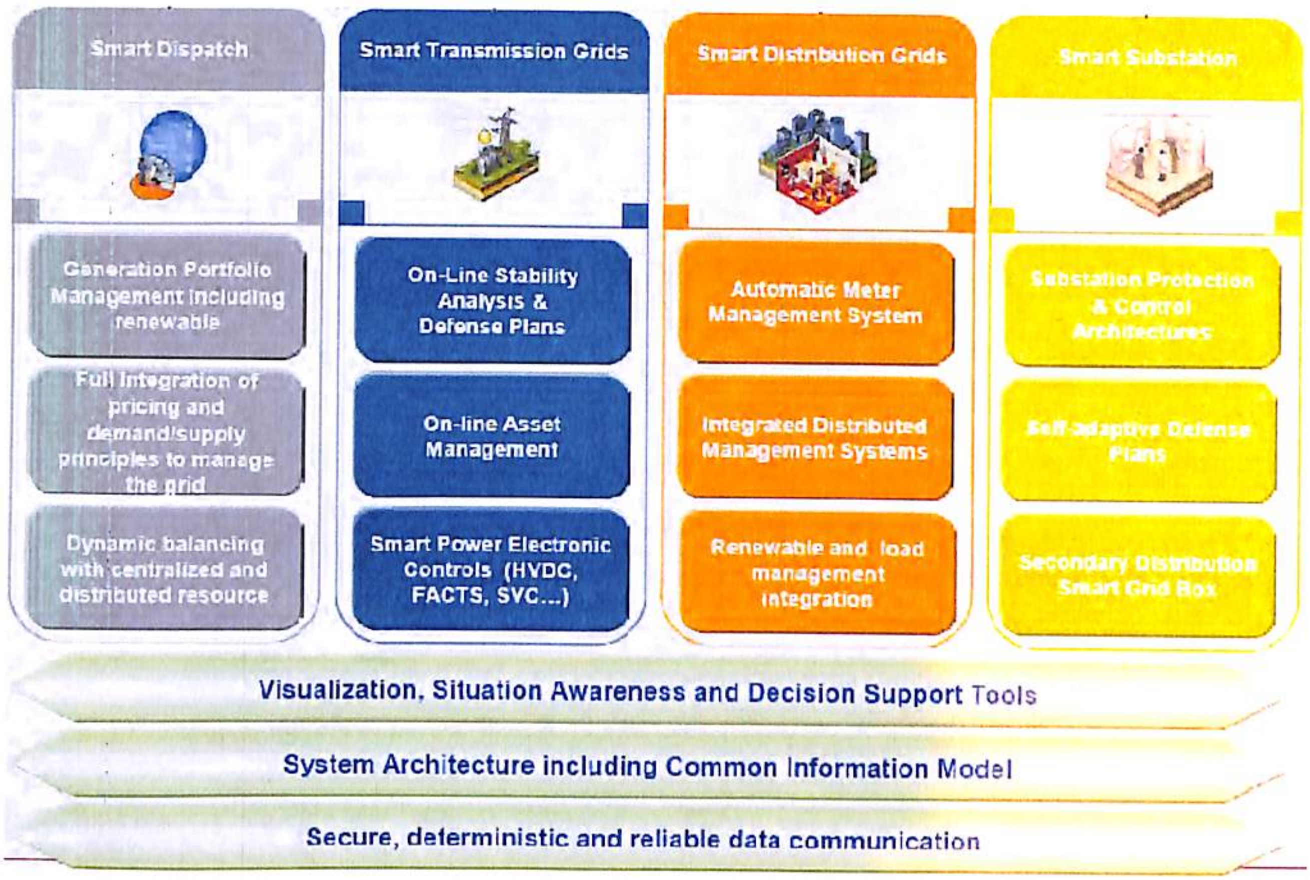
- Integrating technological advances in transmission to control power flows (FACTS, SVC, etc.).

Figure 7 illustrates the smart grid environment in which transmission and generation operations are evolving. It provides a view of the supply chain from generation, through transmission and distribution without getting into the purely customer end of the smart grid spectrum.

These changes may require changes to the power system capacity and capabilities. They will also have a significant impact on systems operators and the IT needed to monitor and control the reliable operation of the power system in an optimal economic manner.

In the future, the range of possible scenarios that system operators face will increase dramatically. Electrical variables such as current and voltage will need to be monitored extensively across the network, even at the lowest voltages, and on-line network analysis will have to be included so that automatic or manual actions can be taken to ensure that circuit capacities are not exceeded. These network data will be used locally or regionally to balance generators and demand response resources in real-time.

Figure 7: The Smart Grid environment



Source: Generation Dispatch, AREVA – IEEE Smart Grid Conference January 2010.

Smart grid technologies will allow better management of network flows. Table 2 summarizes how smart grid could affect some of the generation and transmission functions of systems operators to ensure reliable and efficient performance of the network:

Table 4: How the smart grid can affect generation and transmission

Primary function	Description of function	How the functions effects these functions In generation	How an intelligent communications infrastructure enables and amplifies the smart grid impact
Load control & dispatch	Economical load dispatch scheduling and optimization help to select the right dispatch for the right load at the right time, reducing the cost of generation (startup, operations, and wind down)	The smart grid helps with the scheduling of committed generating units so as to meet the required load demand at minimum operating cost while satisfying all units and system equality and inequality constraints	Economic load dispatch during unforeseen events warrants robust real-time communication infrastructure between the demand and generation functions
Load shaping	Shaping the load during peak demand times reduces the idle and standby generating	Demand-side management helps to manage and accurately estimate demand to as to	Load shaping with DSM involves reliable communication between AMI and CIS (customer

	capacity	meet demand without extra generation	information systems) and generation functions
Distributed renewable, generation	The integration of micro-grids as well as customer premises with the utility infrastructure	The smart grid enables distributed generation and automated adjustment of feed-in tariff regulation to receive premiums in the case of forced switch-off of distributed-generation asset for balancing	Infrastructure is needed to confirm, analyze, and dispatch available load to distribution generation sources
Generation equipments maintenance	Diagnoses and maintenance of the generation equipment reduces faults and prevents their propagation	The smart grid helps asset management and conditioning in preventive maintenance. It also helps accessing newly sensed data.	Data from utilities need to be transferred to the generation control center for better equipment conditioning and monitoring

Primary function	Description of function	How the Smart Grid affects this function in Transmission and distribution	How an intelligent communications infrastructure enables and amplifies the smart grid impact

How an intelligent communications infrastructure enables and amplifies the smart grid impact	Energy management systems and transmission SCADA for data acquisition needed for the following functions: 1) outage management, 2) Volt/VAR management, 3) state estimation, 4) network sensitivity analysis, 5) automatic generation control, and 6) phasor data analysis.	Automatic regulation of load taps changer and capacitor banks for voltage regulation. Wide-area phasor management and control for grid optimization and control. Volt/VAR management using capacitor switches and controls.	Substation automation results in two-way communication between transmission SCADA equipment and the energy management system. Communication between transmission and generation units between is necessary for automatic generation control.
Maintenance of transmission control center	The transmission control center is first line of defense for transmission fault detection and prevention.	Interventions in fault prevention, detection, isolation and correction.	Transmission control center, transmission, distribution and generation units are necessary for control center operations. Security technology development provides for secure data sharing between transmission and other utility functions.

Equipment maintenance	Maintenance of transmission equipment, including breakers, relays, switchers, transformers and regulators, prevention of faults.	The smart grid helps asset management and conditioning for preventive maintenance.	Data from transmission equipment need to be transferred to the generation control center for better equipment conditioning and monitoring.

3.2 Intelligent Electronic Devices

The idea of a "smart grid" has taken center stage — an evolution of advanced technologies that make the availability of a smarter, more efficient electrical power grid possible. These technologies aim to address the complex challenges facing grid systems today, which stem largely from its aging infrastructure and a use case model that has evolved over the years. With power systems over a century old, the field instrumentation on the grid is quickly reaching its life cycle limit, which adversely affects overall grid reliability and efficiency.

With a use case model designed to support the needs of heavy machinery and light bulbs alone, traditional devices on the grid are not prepared to meet modern energy demands, increases in distributed energy sources or changing grid requirements and standards. As a result, there is a lack of support for modern advancements such as computers, fluorescent lights or electric vehicles. This is largely because the grid is based on vendor-defined and closed hardware and software platforms that make it extremely challenging to adapt as grid requirements and standards evolve.

Thus, a re-evaluation of current grid architectures is required where basic automation devices are brought to a higher level of intelligence to enable distributed data acquisition and decentralized decision-making. A new generation of intelligent electronic devices (IEDs) is rapidly being deployed throughout the power system. These devices are equipped with advanced technologies that make two-way digital communication possible where each device on the network is equipped with sensing capabilities to gather important data for wide situational awareness of the grid. Utilizing computer-based remote control and automation, these devices can be efficiently controlled and adjusted at the node level as changes and disturbances on the grid occur. Additionally, these IEDs not only communicate with SCADA systems, but among each other, enabling distributed intelligence to be applied to achieve faster self-healing methodologies and fault location/identification.

At the heart of these advanced devices for the smart grid lies the powerful technology of the FPGA. Once seen as a technology only available to engineers with a deep understanding of digital hardware design, the dramatic advancements in the capabilities and levels of integration of this technology are changing the rules of IED development for smart grid applications.

At the highest level, FPGAs are reprogrammable silicon chips that offer the same flexibility of software running on a processor-based system. However, due to their truly parallel nature, FPGAs are not limited by the number of processor cores available. Additionally, they do not use operating systems and minimize reliability concerns with true parallel execution and deterministic hardware dedicated to every task. Each independent processing task is assigned to a dedicated section of the chip and can function autonomously without any influence from other logic blocks. As a result, the performance of one part of the application is unaffected when additional processing is added.

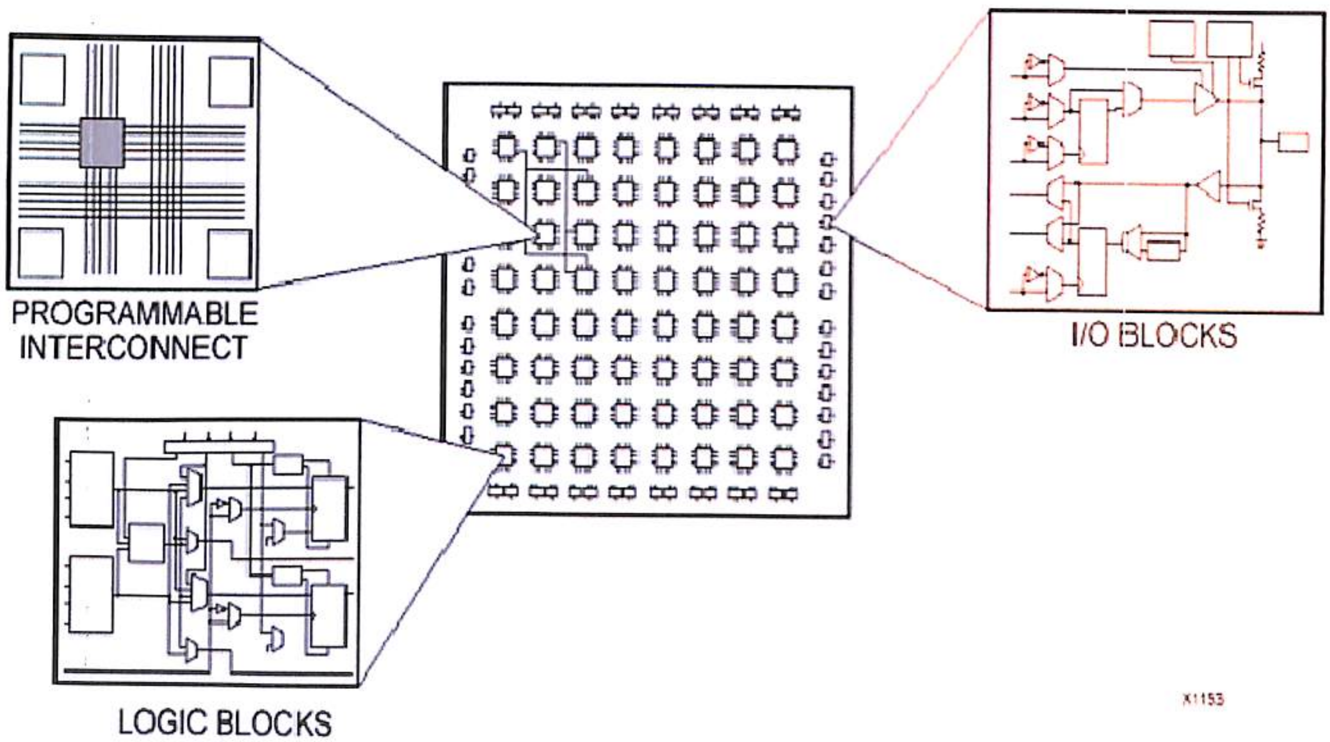


Figure 8: FPGA circuit – includes a flexible hardware architecture with logic functions and DSP blocks

Source: Smart grid evaluation by Rachel Denton

FPGAs exceed the computing power of computer processors and digital signal processors (DSPs) by breaking the paradigm of sequential execution and accomplishing more per clock cycle. With the ability to control inputs and outputs (I/O) at the hardware level, FPGAs provide faster response times and specialized functionality to closely match application requirements.

Furthermore, FPGA technology powers the embedded instrumentation and control systems for the latest generation of IEDs on the smart grid, yielding additional flexibility and reliability, which enables convergence of multiple functional devices into a single unit, lowering the cost of smart grid systems as a whole. As FPGAs are incorporated into virtual instrumentation platforms, this represents a fundamental shift from traditional hardware-centric instrumentation systems to software-centric systems that explore computing power, productivity, display, and connectivity capabilities of popular desktop computers and workstations. Virtual instrumentation platforms that utilize FPGA technology, such as National Instruments Compact RIO hardware, are able to incorporate future modifications to keep pace with power grid requirements that are continuously changing. Thus, as IEDs for the smart grid mature, functional enhancements can be made through the use of open software and modular hardware without the need to modify the board layout or replace the entire device.

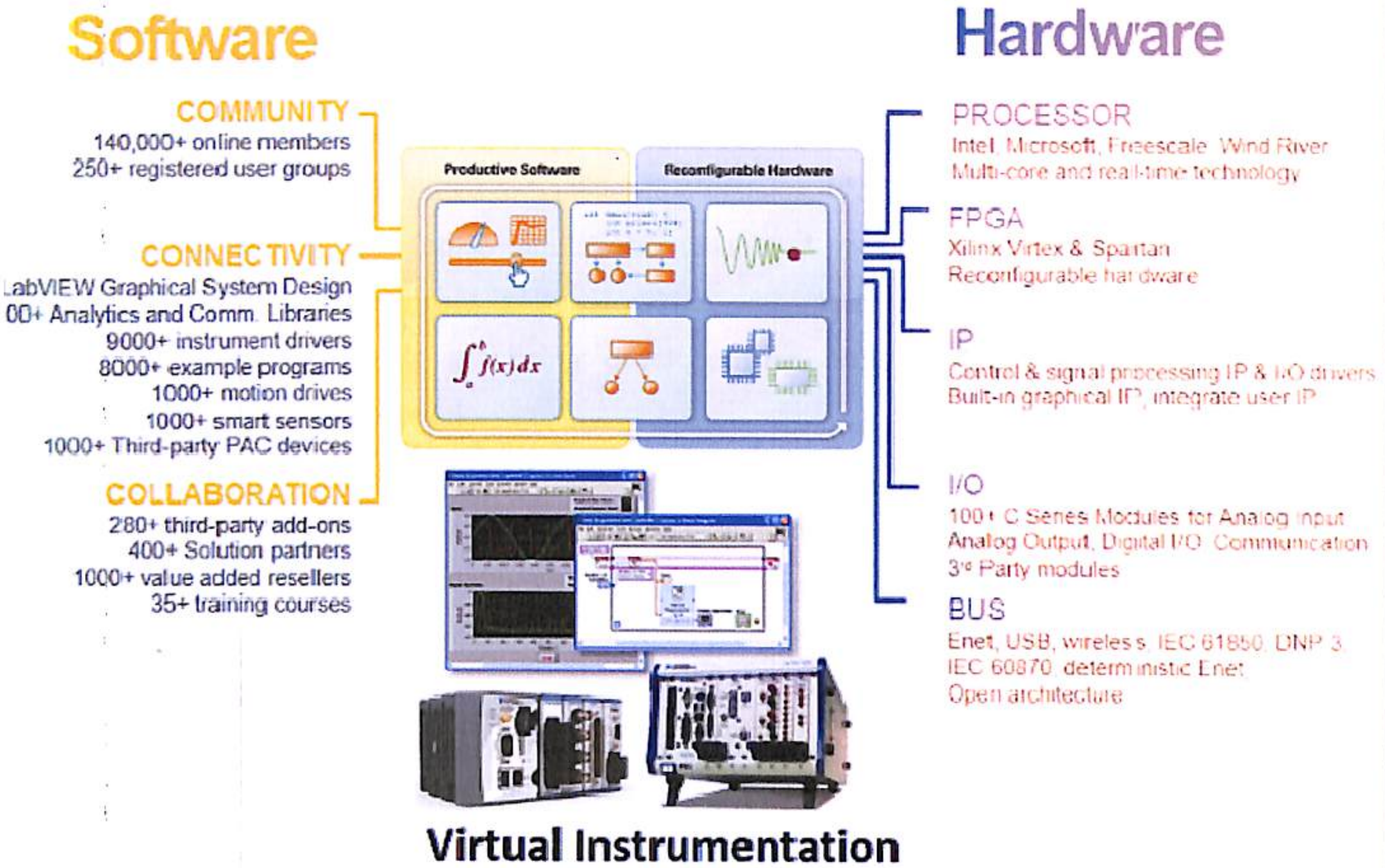


Figure 9: Virtual Instrumentation combines productive software, modular I/O, and scalable platforms to enhance system performance and efficiency.
Source: Smart grid evaluation by Rachel Denton

Virtual instrumentation platforms are being used to develop the latest tools and technologies for the most advanced power quality analysis, which ensures that the power going to electrical power systems are suitable to operate properly. Power quality is critical for the stability of power systems and proper operation of systems/equipment connected to them; without the proper electrical power quality, this systems/equipment can malfunction or fail. Thus, power quality is a major concern for everyone involved in electrical power systems including consumers (domestic and commercial), electrical utilities, industrial facilities, standards and research organizations, and instrument manufacturers.

As an example of a virtual instrumentation device used for electrical power system analysis, the measurement of Synchrophasor has become significantly useful for real-time assessment of grid health. Phasor measurement units (PMUs) quantify the flow and phase separation on the grid by measuring the frequency, amplitude, and phase angle differences from multiple points on the grid as these are synchronized using high precision GPS time references. These synchronized measurements increase situational awareness across wide-area power systems, which makes it possible for grid operators to improve the evaluation of grid stability, detect and react to issues before outages occur, and "heal" the grid quickly when faults take place.

Traditionally small-scale and limited to transmission systems, PMU deployments were hindered by system complexity and other limitations associated with network communication, performance, and data management issues. However, with recent breakthroughs in smart grid technologies, advanced PMUs are being developed for deployment worldwide and for integration into distribution networks.

For example, at the University of Bologna, researchers are actively working to create PMUs that acquire data at higher sample rates and measurement precision/quality to accommodate the reduced line length and lower power flows present on the distribution grid. These PMU designs are based on Compact RIO FPGA technology, which provides the necessary high sampling rates and high-fidelity measurements combined with a real-time processor that can handle multiple tasks in parallel without compromise. Such a platform enables customizability that gives distribution systems the capacity to evolve and adapt to changing requirements down to the silicon gate array-level.

Through the advanced capabilities of the FPGA technology combined with tools such as NI Lab VIEW system design software, developers were able to rapidly implement time-critical algorithms for filtering and signal processing into their designs so that their PMUs could be successfully used in a noisy, low amplitude power distribution infrastructure. Utilizing virtual instrumentation platforms based on FPGA technology and a graphical system design approach, researchers were able to achieve shorter response times, better bandwidth utilization, and faster functionality field upgrades, resulting in decision-making and intelligence that is truly integrated with the grid.

Advanced PMU technology is just one example of how power engineers are finding more effective ways to meet smart grid application challenges by adding more flexible and multifunction IEDs to smart grid systems. As smart grids evolve and continue to require real-time monitoring and control of the electrical power grid, experts around the world predict that in the next 3-5 years there will be an increasing need to embed distributed intelligence into transmission and distribution networks. From protection devices such as smart recloses and sectionalizes to automated metering devices and substation asset monitoring systems, advanced

IEDs will proliferate along power systems. Ultimately, providing additional insight into the real-time health status of the grid, enhancing control power/performance with self-healing capabilities, and optimizing response to grid disturbances with distributed intelligence.

Some of the advances India is making in the area of intelligent electronic devices include:

- The Restructured-Accelerated Power Development and Reforms Programme (R-APDRP) is stimulating progress toward 100% metering on distribution transformers and feeders.
- The conversion from electromechanical to static (electronic) metering is progressing at a low tension level (400/220V) to residential and small commercial customers.
- The Bureau of Indian Standards is scheduled to issue a standardized meter protocol in March 2010 to address meter interoperability. The Meter Inter-Operability Solution being promoted by the Indian Electrical and Electronics Manufacturers Association and Device Language Message Specification are also gaining ground.
- Although meter data acquisition and management are still within the purview of meter vendors, which is hindering the interoperability of the products of different meter suppliers, R-APDRP is working on a holistic approach to meter data management.

3.3 Information and communication technology

In the smart grid, consistent and RT information is the key factor for the reliable delivery of electric power from the generation unit to the end-users. Lack of automated analysis, poor visibility, sluggish response of mechanical switches, and dearth of situational awareness were some of the drawbacks of the classical power system. With the incorporation of advance technologies and applications, the smart grid architecture increases the capacity and flexibility of the network and provides advance sensing and control through modern communication protocols and topologies.

Wired and Wireless modems are being complied for the transmission and communication of data and information between the smart consumers and the utility sectors. Each of the modes of the communication has its own advantages and disadvantages over each other, depending on the various factors such as geographical location, capital investment, economy of use etc. Following exemplifies some of the types of wired and wireless type of communication:

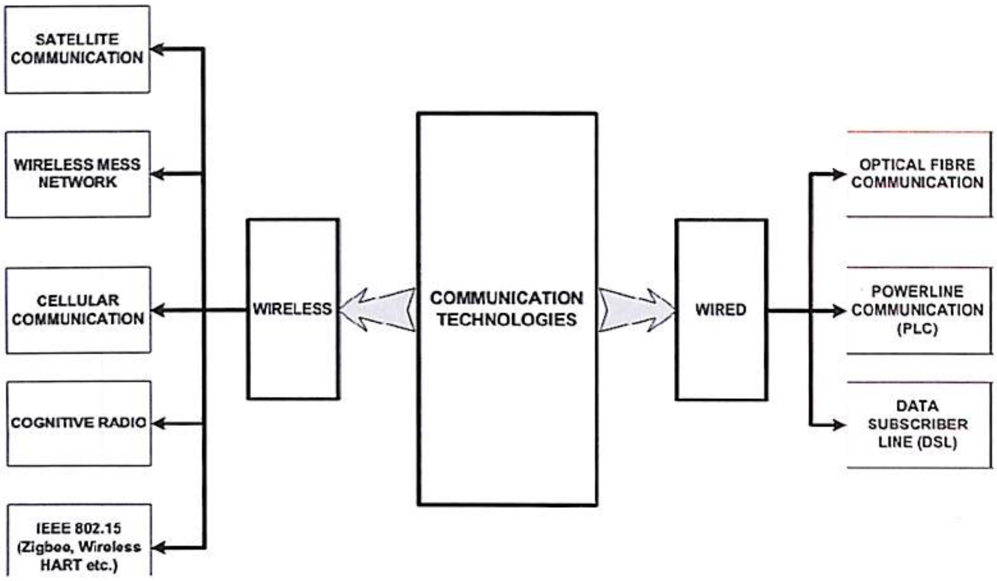


Fig 4: Types of Information and Communication technology

Two-way flows of electricity and information lay the infrastructure foundation for the smart grid. Smart communication subsystem or the ICT are a dynamic sector of the Smart Grid infrastructure. The infrastructure mainly visualizes the communication pattern in two conduits viz. sensor and electrical appliance to smart meters, moreover between smart meters and utility data center. The communication infrastructure between energy generation, transmission, and distribution and utilization requires two-way communications; interoperability between advanced applications and end-to-end reliable and secure communication with low-latencies and sufficient bandwidth. Along with advancement of system security and robustness towards cyber-attacks which provides system stability and reliability with advanced control adds to its essentials. Table articulates some of the important communication topologies along with their brief details, with emphasis on its advantages and disadvantages:

Table 5: Smart Grid network topologies:

Network Topologies	Technical specification	Advantages	Disadvantages	Applications
ZIGBEE COM	2.4 GHz – 915Mhz,	Simplicity, mobility,	Low processing capability,	Advance Metering

	250Kbps, 30-50 m	robustness, low bandwidth requirement, load control and reduction, demand response, real-time pricing, real-time system monitoring and advance metering support	small memory size, small delay requirement, noise and EMI, shares common frequency band ranging from IEEE 802.11 WLANs, Wi-Fi, Bluetooth and Microwave	Infrastructure (AMI) and Home Area Network (HAN)
WIRELESS MESH NETWORK	NA	Cost effective solution, dynamic self-organization, self-healing, self configuration, high scalability services,	Network capacity, EMI, Urban coverage issue, complex infrastructure, bandwidth reduction, high maintenance	Advance Metering Infrastructure (AMI), Home Energy Management and Home Area Network (HAN)

		improved network performance, balanced load network, extended network coverage		
CELLULAR NETWORK	GSM (900-1800MHz, 14.4Kbps, 1-10km) GPRS (900-1800MHz, 170Kbps, 1-10km) 3G (1.92 – 2.17 GHz, 2Mbps, 1-10km) WiMAX (2.5-5.8GHz, 75Mbps, 10-50 km (LOS)	Cost-effective, widespread, sufficient bandwidth, strong security control, excellent coverage, low maintenance cost, quick installation, authentication, demand response	Network congestion, poor emergency response, involvement of various private ventures for use of various spectrum band	Advance Metering Infrastructure (AMI), Home Area Network (HAN), Outage management, Demand side management

	and 1-5 km (NLOS))			
POWERLINE COMMUNICATION	1-30MHz,2-3Mbps,1-3km	Cost-effective, ubiquitous nature, widely available infrastructure, wide range, enhanced system security	EMI, noise, low-bandwidth, device sensitivity towards disturbances and quality of signal, multilevel protocols	Advance Metering Infrastructure (AMI), Fraud Detection, System monitoring and control
DIGITAL SUBCRIBER LINE(DSL)	1.1-4MHz, 256Kbps-40Mbps, 2-16km	Widespread availability, low-cost, high bandwidth data transmission	Distance dependency, lack of standardization, costly set-up, high maintenance	Advance Metering Infrastructure (AMI) and Home Area Network (HAN)

In one hand wired technologies like DSL, PLC, optical fiber, are costly for wide area deployment but they elites communication capacity, reliability and data security. On other hand, wireless technologies aids reduced installation costs, but accolades constrained bandwidth and security. Although reliable and effective information exchange is a key to the success of the future smart grid technologies, as communication infrastructure must gratify QoS of data, reliability in data exchange, wide coverage, fidelity of signal, and security and privacy of information.

3.4 Smart metering technology

Smart metering system has been considered as an effective method for improving the pattern in power consumption and efficiency of energy consumers thus reducing the financial burden of electricity. It is the combination of power system, telecommunication and several other technologies. Indisputably, with the development of science and cutting edge technology, more facilities have been added to this area.

Smart meter is an advance energy meter that measures the energy consumption of a consumer and provides added information to the utility company compared to a regular energy meter. The bidirectional communication of data enables the ability to collect information premeditated with communication infrastructure and control devices. In addition, the meter is used to monitor and control home appliances and devices, collect diagnostics information about the utility grid, support decentralized generation sources, energy storage devices, & consolidate the metering units.

Advanced metering Infrastructure (AMI), an appellation of smart metering technology which consists of set of smart meters, communication modules, LAN, data collectors, WAN, network management system(NMS), Outage Management System (OMS), Meter Data Management Systems (MDMS), and other subsystems. With an advance feature of data collection, the system procures a safe, secure, fast and self-upgradable with developed vision of reliable and flexible access to electricity consumption of the subscribers using power and distribution grid. A proposed architecture of open smart metering system has been illustrated in Fig.5which also gives and brief view of application of AMI and other subsystems. The model planned results and unified system for acquisition and control of power distribution systems. The Data Model shown contains Virtual Meters which is a part of a wider concept called Virtual Power Plant (VPP).

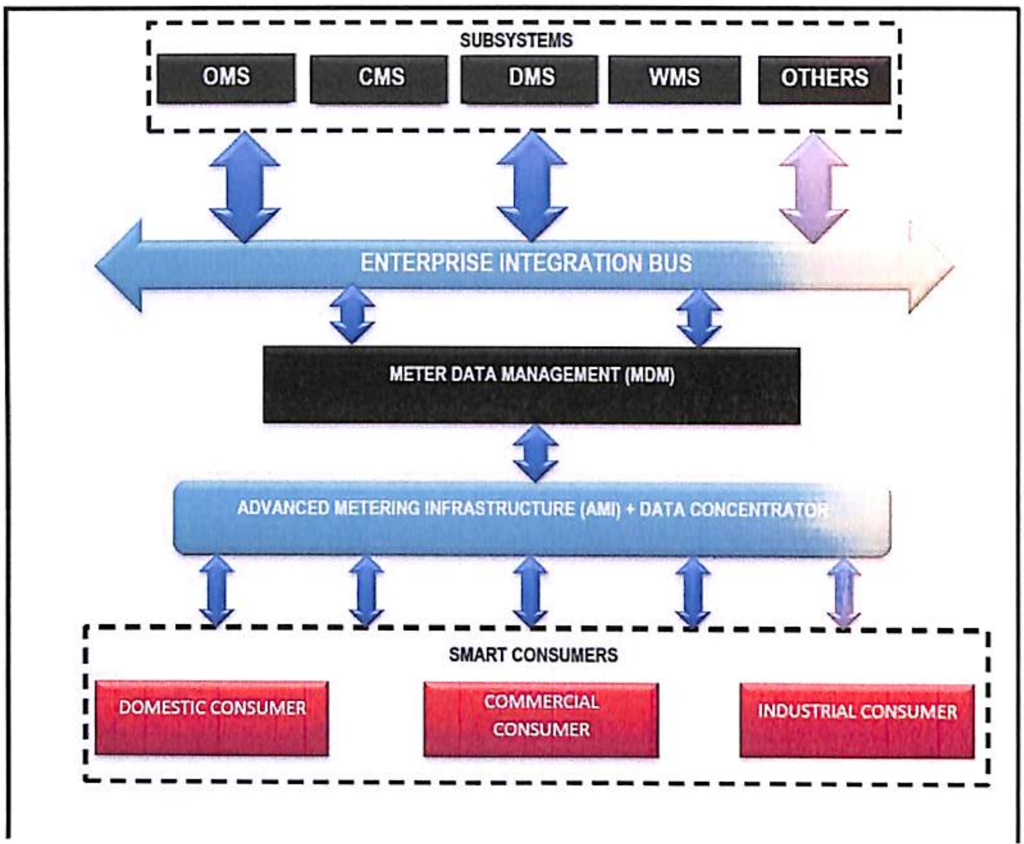


Fig 5: Advanced Metering Infrastructure (AMI)

An important technological device called the In-Home Display (IHD) is an imperative development for the advancement and implementation of smart metering system. A briefing has been revealed in table. The proposed architecture was implemented within a Meter Data Management system, thereby proving it worth.

3.5 Smart control and monitoring technology

With the invasion of very complex adaptive system of smart power grid; a dynamic, stochastic, computational and scalable (DSCS) with innovative control technologies can be a promising trait for a reliable, secure and efficient power network. This complexity and interconnectivity of the electric power grid is aggregating with distributed integration of renewable sources of energy and energy storage of all kinds. In contrary, different approaches to traditional modeling, control and optimization can be augmented or relieved within the grids for rapid adaptation, dynamic foresight, self-healing, power system islanding, fault-tolerance, and robustness to disturbances and randomness. Global Dynamic Optimization

(GDO) is an important aspect to achieve for a DSCS strategy for smart control of the grid, where Computational Intelligence (CI) and Adaptive Critic Designs (ADCs) are referred as the promising and potential approaches. These are an adaptive mechanism inspired from natural phenomena and AI paradigm which facilitates intelligent and smart behavior during complex, uncertain and changing environments. These paradigms of CI inter-combine to form hybrids viz. neuro-fuzzy systems, neuroswarm systems, fuzzy-PSO systems, fuzzy-GA systems, neuro-genetic systems etc., and ensuing superior than any specific paradigm. In addition, the ADCs are based on the combined concept of reinforcement learning and approximate dynamic programming using neural network-based designs for optimization. Following table exemplifies the control technologies using the GDO.

Table 6: Innovative Control Technologies using GDO (CI and ADCs based)

CONTROL TECHNOLOGIES (CI & ADCs based)	OUTCOMES
Neutral Networks and Fuzzy systems	Captures non-linearity in power systems and smart grids
Neural Networks	Behavioral modeling, fast, dynamic decision in smart grids
Fuzzy and Neuro-Fuzzy	Fast and accurate decision making during uncertainty and invariability in the system
Artificial Immune Systems	Immunizes against transients that results from disturbances and fault in smart grids, thus provides fault-tolerance
Swarm Intelligence and Evolutionary	Allows offline, large scale optimization of

Computation	smart grid operation
Swarm Intelligence and Evolutionary Computation	Allows design of robust, adaptive and optimal controllers in a dynamic, uncertain and variable smart grid environment, dynamic optimization and scheduling
Computational Intelligence (CI)	Self-healing characteristics in power grids

Some of key features of Smart Grid control and monitoring have been discussed as follows:

Self healing:

To ensure grid stability and improve the supply quality, avoid or mitigate power outages, power quality problem, and service disruption using real-time information from embedded sensor and automated control to anticipate, detect and respond to system problem, is conferred to be a self-healing power network. Such systems are independent of user interaction, where decisions making are based on the knowledge from the pre-estimated and pre-monitored results. In general, the self-healing is distinguished in two levels: self healing in the physical (monitored hardware) layer and the logical (monitored application/system) layer, according to situation of concerns.

Wide Area Monitoring and Control (WAMC)

Wide Area Monitoring and Control (WAMC) and Wide-area monitoring, protection, and control(WAMPAC) encompasses the use of system-wide information and the communication of specific local information to a remote location to counteract the propagation of large disturbances in a system. With the invasion of adaptive system of smart power grid; a dynamic, stochastic, computational and scalable

(DSCS) with innovative control technologies can be a promising trait for a reliable, secure and efficient functioning of WAMPAC. Synchrophasor Measurement Technology (SMT) is an important element of WAMPAC which includes both short-term objectives such as enhanced visualization of the power system, post disturbance analysis, and model validations, and long-term objectives such as the development of a WAMPAC system. Such type of conceptual architecture has been employed in Eastern Interconnect Phasor Project (EIPP) in United States.

With the increased international research and development, several monitoring and control application are based on Synchrophasor-based Wide-Area Monitoring, Protection and Control System (WAMPAC).

Though with small scale adoption, it has played a major role in some large transmission system operators.

The WAMPAC system consist of a measurement device, the Phase Measurement Units (PMUs), their supporting infrastructure which is formed by communication networks and computer systems capable of handling PMU data and other information, usually called the Phase Data Concentrators (PDCs). The set

PMUs and their aiding ICT infrastructure are termed as Synchrophasor Measurement Technology (SMT).

The basic components of a WAMC system are the following: PMUs, PDCs, a PMU-based application system, and a communication network to connect the interfaces. Similar to traditional SCADA systems, there are three layers in a WAMC system. Fig. illustrates a typical schematic of different layers and components of a basic WAMC system.

In Layer 1, the WAMC system interfaces with the power system on substation bars and power lines where the PMUs are placed, this is called the Data Acquisition layer.

Layer 2 is known as the Data Management layer, in this layer the Synchrophasor measurements are collected and sorted into a single time synchronized dataset.

Finally, Layer 3 is the Application Layer; it represents the real-time PMU data-based application functions that process the time-synchronized PMU measurements provided by Layer 2.

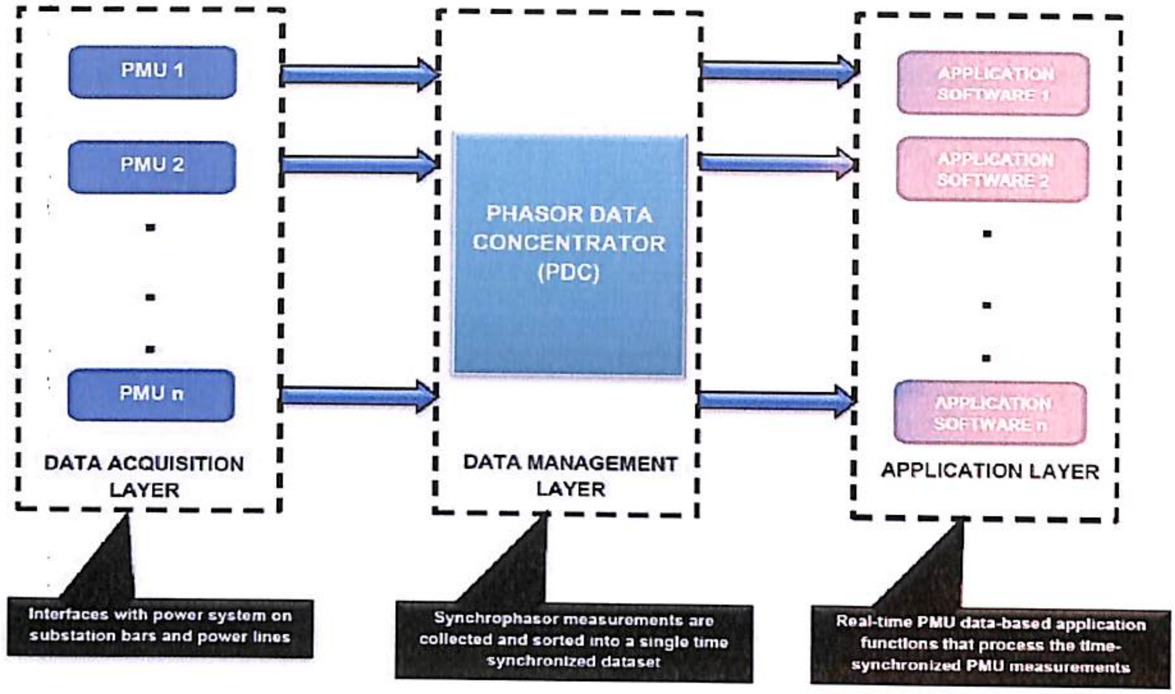


Fig 6: Components of wide area monitoring and control

The architecture depends on specific system needs, its topology, generation profile, and the quality of the communication infrastructure. Accordingly, several applications are being design as per requirements and system understanding using the desired WAM architecture and components as discussed. The application of the WAM system and control, are based on mainly two aspects viz. online application and offline application. As per the name goes, an online application entitles continuous up-gradation of data over a data link from client to server and vice-versa, measured at every pre-specified intervals. Whereas, an offline data application is archived and stored, and the process incorporated quarrying as per batches or sets defined as per data volume. The WAMPAC demonstrates some applications namely, dynamic recording, real-time system state determination, tuning of system parameters, congestion management, phase angle and disturbance propagation monitoring, estimation of load model parameters, as well as protection and control related applications.

These applications that route real-time sub-second incoming continuous streams of measurement data have a greater number of challenges and constraints. If the data was inaccurate or distorted this could lead to an application failure or worst, producing misleading results which could deceive the operators. Another aspect is the overwhelming volume of incoming data that a client system has to process, which could inhibit performance. As a foremost concern, future works are being focused on implementing more algorithms and evaluating such ICT challenges and constraints.

3.6 Information Technology

The head-end system is the apex node of the network; it consists of the telecommunication system and field devices. The role and function of the head-end system vary depending on the system's application (for example, metering for billing, SCADA, automatic generation control with economic dispatch, metering for load research, demand-side and load management, load shedding, disconnection and reconnection as part of billing, energy accounting, and SAIDI, SAIFI, and CAIDI indices).

The size of the head-end system is usually in proportion to its position within the utility hierarchy, with systems at the apex usually being the largest. System size (number of file servers, amount of storage, etc.) decreases for systems in the second and third tiers of the hierarchy.

This combination of growing technology in distribution management and operations is leading to an emerging need to support the integration of micro grids, open-access energy systems, and the use of network-controlled devices, and hence, a need for a converged security infrastructure for all. The first priority is securing these assets of electric power delivery systems, from the control center to the substation, to the feeders and even to the customer meters. This will require an end-to-end secure infrastructure that protects the web of communication assets (control center-based SCADA, RTUs, PLCs, power meters, digital relays and bay control) used to operate, monitor and control power flow and measurement.

Physical & Cyber security:

Smart grid communications will play a critical role in maintaining high levels of electric system reliability, performance and manageability. But at the same time, the grid is increasingly subject to attack, as many of the technologies being deployed to support smart grid projects (such as smart meters, sensors, and advanced communication networks) are interoperable and open.

Meeting the critical need for an integrated security infrastructure will require the establishment and implementation of a security framework for managing physical and cyber security, as well as an accompanying security policy. In addition to reducing the system's vulnerability to physical or cyber attacks, a comprehensive approach to security will help utilities better manage their systems, keep costs lower, and improve the system's resilience against security disruptions and data privacy invasions. This framework should cover:

- Physical safety and security
- Generation plant security
- Substation security
- Utility regulatory compliance
- Identity management
- Access control
- Threat defense
- Wide Area Network security
- Security management and monitoring.

Cyber security encompasses privacy. The Government in India has yet not demonstrated superior cyber security enforcement, and its standards for security are limited.

Business application & Services

The first priorities in smart grid development are addressing the transmission and distribution infrastructure, the telecommunications network, and data centers (computing platforms). Next, attention should turn to building the right operational systems for automated metering infrastructure, outage information, customer information, geographic information systems (GIS), meter data management, asset management and distribution management. Currently the R-APDRP does not adequately address these systems, which should be viewed from the perspective of overall business applications and workforce management so that India can evolve into transmission and distribution automation, smart meter communications, and business and home energy management applications.

As discussed above, several software companies are working to develop these infrastructures. However, in India infrastructure developments have been restricted to micro grids and pilots in which a zone is ring fenced and then preliminary analytics are done to make business cases for smart metering. Hopefully in R-APDRP, 100% distribution transformer and feeder metering will be completed, although interoperability issues may still need to be addressed. The Ministry of Power has appointed a task force on the adoption of smart grid technology, and has charged the Central Power Research Institute with helping to finalize standards; the Ministry is conducting capacity building and awareness programs for the adoption of standards.

Indian companies that are developing products for world markets have adopted a standards-based approach for software integration. Significant contributions towards integrated applications are also being made as a result of the focus on utility business applications in R-APDRP, such as enterprise resource planning systems, customer relations management, and meter data analysis solutions. This, in turn, will encourage standards-based provisions for backward compatibility so that it becomes easier to migrate from one technology to another and to make those technologies interoperable.

Software standardization in the distribution sector is being based on International Electro-technical Commission standards (IEC SG / IEEE SG P 2030), which will help ensure:

- Interoperability: The capability of "plug and play" devices and software is important for the field devices, telecommunication channels, and IT system of the head-end equipment.
- Open architecture: A service-oriented architecture produces savings in both capital and life cycle costs. Adopting a non-proprietary architecture will eliminate vendor lock-in, be easier to maintain than the architectures of disparate proprietary systems, and will help in

the development of uniform systems across enterprises because when vendors compete, innovations result.

- Based on industry- accepted standards: Architectures that conform to such standards protect the utility's investment, reduce the risk of obsolescence, and ensure a smooth migration to future technologies.

Unfortunately, India's utilities lack the basic hardware and software required to deploy a smart grid. India's utilities have not adopted large-scale basic enterprise systems or followed a broad IT strategy (the few exceptions are mainly found in private distribution utilities). Most deployments are limited to a few functionalities such as computerized billings and setting up control centers. Several pilot projects have been implemented and most deployments have delivered results, but an integrated approach and road map for taking these pilots to the utility scale are still needed to enable smart grid implementations.

A major hurdle to be overcome in India is that the asset and customer repositories are not being updated. A GIS-based approach is being adopted in R-APDRP, which will require validating and migrating current data to create an integrated customer asset profile. Several aspects of a comprehensive strategy and plan have been addressed in R-APDRP, but successful implementation and a utility-wide scaling plan are absent.

R-APDRP partially addresses customer relationship management, outage management, and work management. From a smart grid perspective, however, power resource management (trading and contracts, settlement and risk) needs to be addressed on a functional level, as do network management at the operations level and home area networks for communications.

At the infrastructure level, the smart home infrastructure (smart thermostats, load control devices, gateways, etc.) has also not been addressed. Government support for these technologies, through incentives and subsidies, will help build meaningful volumes and spur adoption. In summary, India is some distance away from the time when peak power demand loads can be assessed at the customer and cluster levels.

3.7 Customer relationship management

Customer management, particularly regarding increased availability and reduced commercial losses, is key driver for the smart grid. India has a long way to go in customer management because most of its distribution companies are in various stages of updating and organizing their customer information. Under R-APDRP they are investing in business applications that will help integrate the various pieces of customer information over various customer databases.

Utility customers are becoming more demanding and impatient. They expect utilities to produce such benefits as:

- Reduced outages
- Lower bills
- Increased awareness and control over energy consumption through better information on usage patterns (the telecom industry has achieved something akin to this)
- More choices for energy sources along with options to supply energy to the grid
- More green and renewable choices to increase environmental sustainability (this pressure is greater now that the price gap between peak power, solar and diesel generation alternatives is closing)

Integrating customer relations management (CRM) and advanced metering infrastructure (AMI) data will be a key enabler here, as it will help derive the benefits of optimized capacity utilization and system performance. Up-to-date load data at each feeder section are required along with customer load profiles in order to develop auto fault detection, location isolation, and service restoration. In addition such data will help evolve fault isolation and service restoration switching sequences for premium customers. This integration will also enable utilities to set up quick response teams that will improve demand response (DR) and lead to the integration of AMI/DR in systems planning and engineering. Coincident load data for optimized load balancing and the potential for using AMI for end voltage monitoring will help complete the load profile data for estimating and minimizing technical losses.

Currently meter vendors in many Indian states own the meter data. A holistic approach for meter data management will help bridge this gap and build the ability to conduct end voltage monitoring. Thus, knowledge of customers' profiles with their usage requirements and patterns is critical for utilities wishing to implement a smart grid.

Complete knowledge of customers and their needs will also allow utilities to influence consumers to shift peak demand consumption and protect customers from over-consumption. In addition, it will enable utilities to help customers comply with contract fulfillments, environmental and security regulations. This, in turn, will help utilities to manage their assets, improve customer service, and control costs.

An important aspect of CRM is customer awareness (education) and participation. Customers will be important stakeholders in the smart grid and they will need to be more aware of the risks involved. For example, unless availability-based tariff customers modify their usage patterns, they will see higher bills. Also, because smart meters will be more accurate than current electromechanical meters, customers' usage will be tracked more accurately and they may see higher bills. Last, the energy savings accrued through smart grids will need to be distributed and incentives to conserve energy will be needed. Customer participation will be important in all of these activities and will also help improve the smart grid's overall governance and utility-wide implementations.

Automated call centers

The infrastructure set up for automated call centers is being developed under the R-APDRP. These centers will allow utilities to integrate customer information, address customer queries and complaints, and provide basic information about office locations, billing information, bill payment centers, modes, connection status, service levels, planned outages, and information on efficiency programs, among others. These initiatives will help utilities measure and drive customer satisfaction, and make customers more aware of opportunities for energy efficiency. They will also help utilities track consumption patterns and payments. In addition, the databases maintained by the centers would enable quick-start smart grid implementations, through targeted programs for home area networks and smart appliances projects to increase availability and reduce commercial losses.

At present, the complaint handling process in India is weak, resulting in decreased customer satisfaction. However, these centers are helping build better processes and more accountability within the utilities.

Utility portals

Utility portals (interactive websites that are linked to the call center databases and help customers log directly into websites) are being enhanced under R- APDRP. Their objectives are similar to those of the automated call centers and give customers another medium for interacting with the utility. Again, private utilities are leading in this area in India. Government-owned utilities are also implementing portals, but a few of these have failed due to a lack of training staff and integration of IT into the workflow. Because of this lack of integration, many state-owned utilities find it necessary to maintain a paper-based system as well, resulting in a duplication of effort.

Informing customers before and during meter change out

The change-out of an existing meter is often a contentious issue for customers, especially when the new electronic meter registers a higher bill. The reasons why customers' bills can be higher after a meter change-out are well known and are not repeated here. In addition, the customer may have to bear some of the costs of the change-out. For example, the customer's electrical installation may not comply with electrical safety codes, and the installation may have be the rehabilitated at the customer's expense.

A customer relations program is needed to alert customers to the upcoming meter change-out. It should spell out what the customer's rights are, explain the long-run benefits of smart meters, and describe how the change-out will be conducted.

Resolving bill complaints

When a new, accurate meter replaces an old, inaccurate or tampered meter, the customer will receive a higher bill. The customer relations program of the utility needs to be ready to address this collateral effect of the re-metering program.

3.8 Some illustrative applications

This section presents some examples of the application of smart grid and smart metering, and the issues that will likely arise with their implementation in India. The extant literature provides numerous examples and offerings of the features and benefits of smart grids and smart metering.

Automatic meter reading

Automatic meter reading is often the most widely implemented smart system in a utility. Its contribution to making the grid smarter is that meter data are rapidly and accurately collected. Many countries have adopted this technology to save labor costs, but labor costs are not an important factor in India. However, in India, as in other countries, automatic meter reading facilitates the collection of data that are critical for utility planning and implementation. Such data also improve the inputs to the retail tariff structure, help with regulatory compliance, and help customers better understand their consumption and plan their usage accordingly.

Remote disconnect & reconnect

The remote disconnection and reconnection of customers who do not pay their bills is an extension of automated meter reading. The meter contains, or controls, a large contactor (relay) that disconnects or reconnects the customer from the head-end system, most often the billing system

Outage monitoring & evaluation

SAIDI, SAIFI, and CAIDI are common measures of the power system network's availability and reliability. The collection of the field data to perform these measurements is time consuming, tedious, prone to arithmetic errors, and open to manipulation by personnel who collect the data. Smart devices on the distribution system (meters, circuit breaker controllers, etc.) that are equipped with remote reading capability make the collection of field data automatic and accurate. This will help the utility improve its planning process and optimize the resources deployed in power restoration.

Mini-SCADA

In the past, the high cost and large size of RTUs for SCADA limited SCADA systems to the transmission network. As the size of RTUs increases and their costs decrease, SCADA is penetrating the distribution networks.

Demand-side management and load management

Like automated meter reading, demand-side management and load management have long been features of the utility system. As the cost of the field devices for demand-side and load management drops and their functionality increases, these devices will become increasingly integrated into customers' lives.

Renewable energy

Wind generation, small hydro, micro hydro, bio gas generation, bio gas fuel cells, solar and similar supply-side technologies need to be integrated into the power system network. Smart control devices are needed to connect these renewable energy sources to the power grid, and exchange information and commands with the energy dispatch center.

Distributed, standby, mini-grids, and off-grid generation

A large portion of India's energy comes from distributed, standby, mini-grid, and off-grid generation sources. However, as rural electrification extends farther into un-electrified areas, there is a concern that the arrival of relatively inexpensive national grid energy will lead to the abandonment of much off-grid generation. Since there may not be a corresponding increase in national generation, the sudden addition of off-grid load to the national grid will increase load shedding.

The smart grid offers a way to incorporate these sources of energy into the national grid in a rational and balanced way. For example, off-grid generation could be dispatched by the central control center and used only during peak times. Appropriate feed-in tariffs would compensate the off-grid generator for costs, and would shield the pool of customers from adverse pricing by blending the cost of off-grid generation with the average weighted price of electricity used in the tariff. The smart grid can convert this problem into an advantage for India, and changes in regulations and feed-in tariffs can manage the societal aspects.

Time-of-use rates

Time-of-use (TOU) tariffs involve a sharing of some risks between the utility and the customer. During those times of the day when energy is cheap for the utility (early morning hours and weekends), the savings are passed on to the customer. When energy is expensive for the utility (peak times) the customer experiences the high cost. The objective is for customers to shift their utilization in response to a price signal.

For over two decades electronic static meters have been available to handle TOU tariffs. In fact, they handle very complicated and very extensive tariffs (on peak, shoulder peak, and off peak; fixed and variable holidays; seasonal data capture; etc.). A difficulty that a smart grid can overcome is the effort needed to re-configure the meters on a regular basis, which will allow TOU tariffs to change as rapidly as desired by the utility and customer. The smart grid, with its telecommunication link between the customer information (billing) computer system and the meter in the field, overcomes this.

Islanding

When interconnected power system out-of-step occurs, it is authoritative to sense it rapidly, and islanding should be taken to prevent widespread blackout of the system. Due to system transient instability, which causes large separation of generator rotor angles, large swings of power flows, large fluctuations of voltages and currents, and eventually lead to a loss of synchronism between groups of generators or between neighboring utility systems, for certain severe disturbances, shall be intentionally split into two or more 'islands' to preserve as much of the generation and load as possible.

An islanding scheme has widespread application in micro grid, significantly in distribution grids that can operate in controllable, intentional islanding conditions, decoupled from the main grid. In addition, islanding detection is also employed in order to switch the control modes of distributed generators from power injection to voltage and frequency control during disconnection and opposite during reconnection to the main grid. In order to endure a seamless islanding scheme, some restraints are to be satisfied for splitting operation as such:

- ➢ Pre-planned splitting should be procured as well as system should be isolated at pre-determined splitting points during fault.
- ➢ Synchronism of the generators at each island and isolation of asynchronous groups of generators into different islands should be incorporated, and
- ➢ Balance of the power should be maintained in each island

Different adaption strategies and multi-functionality (voltage, frequency and power) algorithms are being deployed for the islanding of the power system for the proficient and steadfast control of the power grid resulting in smart operations. Few of such incorporative techniques are being described in.

As mentioned earlier the smart power grid becomes much more complex than the classical grid as time varying sources of energy and integration of new technologies. Apparently, numerous organizations and institutional aids are being associated for the design and development of optimized and reckless dynamic response control algorithms for the smart operation of the grid networks.

Capacitor control

Capacitor control in the distribution network has a direct and significant effect on customer satisfaction. It also improves utilities' financial performance by reducing a component of technical losses. If capacitor control is implemented poorly, there will be insufficient capacitor support during periods of high demand and low voltage (peak times), and over-compensation during periods of light load and high voltage (midnight to dawn, and weekends).

When integrated into a smart grid, advanced capacitor control by the utility (not the customer) allows the utility to provide the right amount of capacitor injection at the right time. This approach also removes a requirement on customers to install, operate, control, and maintain their own capacitors.

Demand response

Smart grid applications allow electricity producers and customers to communicate with one another and make decisions about how and when to produce and consume. This emerging technology will allow customers to shift from an event-based demand response where the utility requests the shedding of load, towards a more 24/7-based demand response where the customer sees incentives for controlling load at all times. Although this utility-customer dialogue increases the opportunities for demand response, customers are still largely influenced by behavioral as well as economic incentives and many have demonstrated reluctance to relinquish total control of their assets to utility companies.

One advantage of a smart grid application is time-based pricing. Customers who traditionally pay a fixed rate for kWh and kW/month can set their threshold and adjust their usage to take advantage of fluctuating prices. This may require the use of an energy management system to control appliances and equipment, and can involve economies of scale. Another advantage, mainly for large customers with generation, is being able to closely monitor, shift, and balance load in a way that allows the customer to save during times of peak load, not only kWh.

Smart grid applications increase the opportunities for demand response by providing real-time data to producers and consumers, but economic and environmental incentives remain the driving force behind this practice. The foundation for this would again be having accurate customer profiles with load, consumption pattern and asset data so as to be able to evolve customer segmentation and develop business cases for supporting each of those categories with different plans & incentives.

Phase measuring units

Phasor measurement units (PMUs) are the most accurate and advanced technology available for wide area monitoring, protection and control. A well-planned, system-wide PMU deployment over optimal system architecture provides several unique advantages, including the avoidance of outages as the result of a true early warning system, congestion mitigation through better system margin management and better "state estimation" for the location marginal pricing that will be increasingly required to enable transmission grids that optimize competitive markets.

Table 7: Technology contributions to the Smart Grid:

	Availability	Reliability	Reduce operating cost	Reduce commercial loss	Increase electricity supply	CRM applicable
Automated meter reading			☐	☐	☐	☐
Remote disconnection and reconnection			☐	☐		☐
Outage monitoring and control	☐	☐				
Mini-SCADA	☐	☐	☐		☐	
DSM and LM			☐		☐	☐
Renewable energy					☐	☐
Distributed, standby and off-grid generation					☐	☐
Time-off-use			☐		☐	☐

tariffs						
Islanding	☐	☐	☐		☐	
Capacitor control		☐	☐		☐	
Demand response			☐	☐		☐
Phasor measurement units	☐	☐	☐			

Chapter 4

ENGINEERING ECONOMICS AND FINANCING

Since the early 2000s, the Government of India's policy has been to balance the development of generation, transmission and distribution. This policy has served the touchstone for a number of financing innovations to deal with the power sector's large capital investment deficit: unbundling the vertically-integrated power companies to improve their performance and accountability, attracting increasing private sector participation, expanding all sources of capital market financing (bonds, listing and privatizations), and continuing public and multilateral investments in strengthening and expanding transmission and distribution, in particular. These new capital sources are expected to play a role in Smart grid roll-outs in India.

A number of problems, however, will continue to hamper smart grid deployments and must be factored in during project design, including the determination of the financial feasibility of investing in projects.

The poor balance sheets of many electric utilities, coupled with the lack of an efficient procurement and project management culture at most State Electricity Boards, has resulted in inadequate investments in state transmission and distribution systems. In addition, many of the utilities that are undertaking projects under the Restructured Accelerated Power Development and Reform Programme lack management experience with R-APDRP; this lack of experience spans the full project cycle, from formulation to appraisal, procurement, construction supervision and commissioning. As a result of the lack of automation (computerization and telecommunications) in their businesses, the discoms also have a serious skills deficit in information and communications technology (ICT). Many will also be hard pressed to attract qualified talent to join bureaucracies that are still dominated by work cultures and practices of the past.

The barriers to implementing smart grid concepts in India are much the same as the barriers that have slowed power sector reform since market liberalization was first announced almost 20 years ago. With the government already running severe losses on its current power subsidies, the additional cost of moving to a smart grid will be problematic. If there are only limited fiscal benefits from smart grid investments in the short term, it will be a challenge to get a commitment for significant additional funds from the government. Hence, innovative financing alternatives will have to be explored.

Some possible avenues for funding include a combination of grants, self-funding, and public-private partnerships. Ultimately, however, the widespread implementation of a broad interpretation of the smart grid vision may be held back by the sector's lack of commercial viability.

In India, smart grid projects will be subject to the same issues that face conventional utility capital projects. Cost-benefit methodologies have been established for energy efficiency and renewable energy projects, and these can serve as a starting point for determining the viability of smart grid projects.

4.1 Engineering Economic Issues

The smart grid is a system that enables two-way communication between consumers and electric power companies. In this system, electric power companies receive consumer's information in order to provide the most efficient electric network operations. At the same time, consumers get better access to data to help them make intelligent decisions about their consumption. Thus, project economics will need to reflect the benefits to both consumers and utilities.

A top-down review of "typical" smart grid projects reveals that a large capital outlay will usually be required to fund the various aspects of implementation. The primary costs will include automated metering infrastructure, customer systems such as in-home displays and digitally controlled appliances, and electric distribution and transmission system grid automation.

The primary benefits include lower operating and maintenance costs, lower peak demand, increased reliability and power quality, reductions in carbon emissions, expansion of access to electricity and lower energy costs from fuel switching and home automation.

4.2 Traditional cost benefit analysis

Although many countries have been discussing the concept of a smart grid for several years, projects are only now beginning to move forward. In the United States, where many projects are in various stages of preparation, most project sponsors are using traditional cost-benefit approaches to gauge their projects' viability,

The suggested cost-benefit analysis methodology described here has three main objectives

- Develop a common cost-benefit methodology that can be applied across all smart grid demonstrations (approved by financing sources and regulators)
- Publish an agreed upon methodology, including underlying rules and assumptions
- Ensure that the methodology can easily accommodate changes and expansion.

In order to work out the engineering economics of smart grid projects, one needs to consider various scenarios with selected elements being implemented in a phased manner .

This section presents a high-level framework for identifying the typical costs attached to the various elements of smart grid and the potential benefits associated with its projects. This framework must be customized for each project.

While still new enough to lack a universally agreed upon definition, some typical project components of a smart grid include:

➢ Smart power meters records consumption of electrical energy and communicates that information back to a central server for monitoring and billing purpose. Such remote reporting of data and advanced metering infrastructure enables a two way communication with the meter. With a maturing status of metering in the country and growing government interest and growing government interest and support, adoption of smart metering technologies is also growing.

➢ Reduction in commercial losses is one of the principal advantages of using smart meters and is particularly of relevance to India which at about 8% has the highest AT&C losses in the world.

➢ Smart metering plays a very important role in effectively monitoring the energy efficiency in smart grid. Smart metering system helps utilities to maintain the grid stability and reliability by continuous monitoring and controlling the load at each consumer point to minimize the demand supply gap in the electrical network.

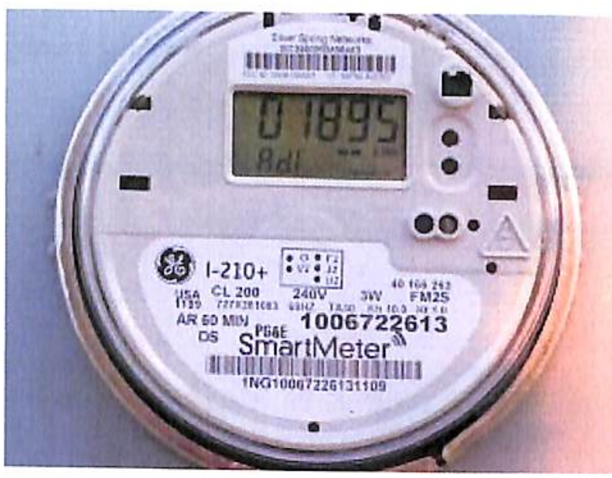


Fig 7: Smart meter

➢ Substations automation include the monitoring and control of critical and non-critical operational data such as power factor performance, security, and breaker, transformer and battery status .

- Smart distribution is self-healing, self-balancing and self-optimizing, including superconducting cables for long-distance transmission, and automated monitoring and analysis tools capable of detecting or even predicting cable and other failures based on real-time data on weather, outage history, etc.

- Smart generation capable of "learning" the unique behavior of power generation resources to optimize energy production, and to automatically maintain voltage, frequency and power factor standards based on feedback form.

- Universal access to affordable, low-carbon electrical power generation (e.g., wind turbines, concentrating solar power systems, photovoltaic panels) and storage (e.g., in batteries, flywheels or super-capacitors or in plug-in hybrid electric vehicles).

- Intelligent appliances capable of deciding when to use power based on pre-set customer preferences. This can go a long way toward reducing peak loads, which has a major impact on electricity generation costs by alleviating the need for new power plants and cutting down on damaging greenhouse gas emissions. Early tests with smart grids show that consumers can save up to 25% on their energy usage by simply providing them with information on that usage and the tools to manage it.

Cost analysis

The typical costs associated with the smart grid are categorized according to the elements and functions they provide. The major cost items are:

- Cost of project design and feasibility studies

- Cost of program management

- Cost of setting up infrastructure to enable two-way communications between the consumer and the utility; this will include the costs of the communications medium (e.g., fiber optic, PLC), installing sensors, monitoring equipment, and software, and an online tracking mechanism

- Cost of purchasing and installing the smart meters
- Costs for in-home devices and customer information systems
- Training and development of key staff.

Some key variables that can have a major impact on costs are also worth noting:

- Size of the project, which is determined by the number of transmission and distribution lines in the grid, and number of buildings to be covered
- Strength and compatibility of the existing infrastructure, if the project is not a green field project
- Ability to forecast the schedule of generation for that area

Benefit analysis

The move to a smarter grid promises to change the power industry's entire business model and its relationship with all stakeholders, involving and affecting utilities, regulators, energy service providers, technology and automation vendors, and all consumers of electric power.

The smart grid envisages providing choices to every customer and enabling them to control the timing and amount of power they consume based upon the price of the power at a particular moment of time. Some basic benefits of a smart grid are:

- Peak load reduction. Smart grids can use time-of-day price signals to reduce peak load – this benefit has particular importance for Indian utilities coping with urban loads.
- AT& C loss reduction. For Indian utilities, this is a major driver from a commercial and regulatory point of view. For distribution operations with high losses that are upgrading meters and other equipment, companies may consider smart grid components as a way to build in additional communication technology and upgrades.

- Self-healing. A smart grid automatically detects and responds to routine problems and quickly recovers if they occur, minimizing downtime and financial loss.

- Consumer motivation. A smart grid gives all consumers – industrial, commercial, and residential – visibility into real-time pricing, and affords them the opportunity to choose the volume of consumption and price that best suits their needs.

- Attack resistance. A smart grid has security built-in from the ground up.

- Improved power quality. A smart grid provides power free of sags, spikes, disturbances and interruptions. It is suitable for use by the data center, computers, electronics and robotic manufacturing that power an economy.

- Accommodation of all generation and storage options. A smart grid enables "plug-and-play" interconnection to multiple and distributed sources of power and storage (e.g., wind, solar, battery storage).

- Enabled markets. By providing consistently dependable operation, a smart grid supports energy markets that encourage both investment and innovation.

- Optimized assets and operating efficiently. A smart grid enables the construction of less new infrastructure and the transmittal of more power through existing systems, thereby requiring less spending to operate and maintain the grid.

These benefits can be combined under three broad categories:

Economic benefits: Five types of benefits can be derived from the smart grid.

- Cost savings from peak load reduction. Smart grids bring about a reduction in per-unit production costs due to demand response / load management programs.

- Reductions in capacity costs. These can be attributed to residential customer reductions in demand during the 50 to 100 hours of highest system demand each year (critical peak periods) in response to some form of dynamic pricing, either peak time rebates or critical peak pricing.

- Deferred capital spending for generation, transmission, and distribution investments. By reducing peak demand, a smart grid can reduce the need for additional transmission lines and power plants that would otherwise be needed to meet that demand.

- Reduced operations and maintenance costs. Smart grid technologies allow for remote and automated disconnections and reconnections, which eliminate unneeded field trips, reduce consumer outage and high-bill calls, and ultimately reduce O&M costs. Reduced costs can also result from near real-time remote asset monitoring, enabling utilities to move from time-based maintenance practices to equipment condition-based maintenance.

- Reduced industrial consumer costs. Industrial and commercial consumers could benefit significantly from a smart grid. Electric motors account for about 65% of industrial electricity usage because they power virtually every moving process necessary for process industries, including power generation, oil and mining extraction, and pharmaceuticals, as well as for the compression and pumping needed for heating and cooling buildings. Motors are also essential to India's growing manufacturing sector for automobiles and other products. Small improvements in motor efficiency can generate significant savings in energy costs, but more sophisticated motors require higher-quality power.

Service benefits: The smart grid will bring benefits to residential, commercial, and industrial consumers alike:

- Improved reliability. A smart grid enables significant improvements in power quality and reliability. Smart meters will allow utilities to confirm more easily that meters are working properly. Two-way communications all across the grid will let utilities remotely identify, locate, isolate, and restore power outages more quickly without having to send field crews on trouble calls. A smart grid could eliminate up to 50% of trouble calls in a mature power sector.

- Increased efficiency of power delivery. Up to a 30% reduction in distribution losses is possible from optimal power factor performance and system balancing. Today, this problem is managed to some extent by controlled or automated capacitor banks on distribution circuits and in substations. But the control of these devices can be greatly improved with better real-time information through a smart grid.

- Consumption management. Smart grid technologies offer consumers the knowledge and ability to manage their own consumption habits through in-home or building automation. Advanced meters tell consumers how energy is used within their home or business, what that usage costs them, and what kind of impact that usage has on the environment. They can manage their usage interactively or set preferences that tell the utility to automatically make adjustments based on those choices.

- Improved system security. Utilities are increasingly employing digital devices in substations to improve protection, enable substation automation, and increase reliability and control.

- Enhanced business and residential consumer service. The smart grid will allow automatic monitoring and proactive maintenance of end-use equipment, which can be an avenue for energy savings and reduced carbon emissions. Equipment is sometimes not properly commissioned when it is first installed or replaced. With the two-way communications of a smart grid infrastructure in place, a utility could monitor the performance of major consumer equipment through advanced interval metering and on-premise energy management control systems. The utility would thus be able to advise the consumer on the condition of specific facilities.

Environmental benefits: According to recent studies, the smart grid can reduce emissions at a lower cost than many of the newest clean energy technologies. The smart grid will reduce emissions in four ways:

- Enabling the integration of clean, renewable generation sources
- Reducing electrical losses
- Increasing the penetration of distributed energy resources
- Increasing energy conservation through feedback to consumers

More specifically, emission reductions will come from:

- Expanded renewable resource integration, enabled by a smart grid through its "plug and play" capability.

- Reduced transmission and distribution electrical losses, as generation is placed closer to the load, load curves are flattened, flow patterns are optimized, and more efficient components are deployed, and as power quality (e.g., harmonics and phase balance) are improved. Reduced losses translate to a corresponding reduction in gross generation, and hence, less emissions.

- Improved central generation efficiency, as units face flatter load curves.

- Increased penetration of distributed energy resources, including combined heat and power, and plug-in hybrid electric vehicles. These resources could provide fine-tuned support for the grid and ancillary services to increase efficiency and reduce energy-consuming spinning reserves.

- Increased conservation, as software provides feedback information about emissions to the marketplace and customers. This will also encourage consumers to invest in energy efficiency and demand response options to save money.

- Reductions in other major pollutants (e.g., nitrous and sulfur oxides, particulate matter, ozone) due to conservation and the use of cleaner energy sources.

Calculating project costs and benefits

- Identify the assets/elements that are deployed for the smart grid's systems

- Assess the principal characteristics of the smart grid; each will have one or more metrics that are reflected in the project

- Identify, from a standardized set, the smart grid functions that each project element/asset could provide and what will be demonstrated
- Estimate benefits
- Map each function onto a standardized set of benefit categories
- Define the project baseline and how it is to be estimated
- Identify and obtain the baseline and project data needed to calculate each type of benefit
- Quantify the benefits
- Monetize the benefits
- Estimate the relevant, annualized costs
- Compare costs to benefits.

An insightful point noted in EPRI's Cost Methodology is that there is third dimension to cost-benefit analysis (CBA) in the form of the level of precision. Since the biggest risk with CBA relates to the accuracy of the assumptions made, it makes sense to attempt to measure the precision of estimates. For smart grid projects, an ongoing data base of projects and project studies could be maintained to enable users to hone their estimates on the basis of experience. The importance of accurate estimates may also warrant a focused study of early implementers and/or a review of earlier studies of the experience of other "first time" implementations.

4.3 Estimating Technology Costs for a "First Time" implementation

- Integrated communications include data acquisition, protection, and control, and enable users to interact with intelligent electronic devices in an integrated system.

- Sensing and measurement technologies support acquiring data to evaluate the health and integrity of the grid. They support automatic meter reading, eliminate billing estimates, and prevent energy theft.

- Advanced components are used to determine the electrical behavior of the grid and can be applied in either standalone applications or connected together to create complex systems such as micro grids. The success, availability, and affordability of these components will be based on fundamental research and development gains in power electronics, superconductivity, materials, chemistry, and microelectronics.

- Advanced control methods are the devices and algorithms that will analyze, diagnose, and predict grid conditions, and autonomously take appropriate corrective actions to eliminate, mitigate, and prevent outages and power quality disturbances.

- Improved interfaces and decision support convert complex power-system data into information that can be easily understood by grid operators.

Table 8: The categories of costs associated with technologies are listed below

Smart Grid Elements and Functionality	Prerequisites	Attached costs
Program design and appraisal		
Project design and feasibility	Need for project design team, feasibility studies, pilot projects and reporting requirements	Initial concept and pilot studies Feasibility studies Program management, measurement and verification
Demand side management an energy efficiency		
Smart metering	Smart meter capable of two-way communication with control facility	Cost of smart meter and installation
	Automated meter infrastructure, including software	Cost of actual software and installation

Smart Grid Elements and Functionality	Prerequisites	Attached costs
	Display at consumer premises	Cost of display elements
	Operational readiness	Cost of preparing the existing infrastructure compatible with the new metering
Load research	Meter having load survey capability for every category of consumers	Cost of smart meter or copy of upgrading a meter to provide this functionality
	Software capable of storing and processing data, and producing results in different scenarios	Software costs
	Facilitation through which load curve can be flattened including peak curtailment	Cost of man hours and training
Load control	Remote equipment control	Cost of equipment
	Adequate advance technological communication infrastructure	Cost of infrastructure including wiring, etc.
	Energy efficient appliances with remote control facility	Appliance costs
Integration of renewable energy sources		

Technically strong	Integration of renewable sources at any voltage	Cost of integrating the renewable sources to the new grid
	Promotion of energy storage devices	Cost of running workshops to build consumer awareness for purchasing energy storage devices
	Adequate and robust protection system	Cost of installing the protection system
Plug-in hybrid electrical vehicles	Market development of electrical vehicles	Cost of electrical vehicles and cost associated with bringing these to market
	Charging station	Cost of building, charging stations
	Advance information on charging price as per time-of-use pricing	Cost of monitoring equipment required to record time-of-use
Net metering	Regulatory insight and passage of tariff order	Regulatory intervention
	Promotion of solar roof tops and other models	Promotion costs
Energy costs	Energy storage devices	Cost of energy storage devices and installation costs

	Batteries	Cost of batteries
Smart Grid elements and Functionality	Prerequisites	Attached costs
Self-healing power quality		
Safety	Network sensors	Cost of network sensors
	Closed loop control system to detect and take appropriate preventive measures	Cost of loop control system
	Automatic adjustment and curtailment of load through smart grid software	Cost of installing smart grid software
Online monitoring of network health vis-à-vis improving reliability indices	Network sources	Cost of network sources
	Preventive maintenance	Cost of monitoring and maintaining the system
Loss minimization		
Available transfer capability	Online monitoring of energy	Cost of online systems

loss reduction	audit	
	Smart meter having control and bidirectional control facility	Cost of smart meter and installation
	Smart grid software integration with billing and other software	Software
Asset optimization		
Increase power throughput on transmission and distribution assets	Online monitoring and asset utilization	Cost of installing an online monitoring system
	Network reconfiguration as per informed decision	Cost of reconfiguring the network
Workforce management		
Workforce effectiveness	Advance visualization and control system to support and automate decision making	Cost of visualization and control system
	Usage of emerging field technologies to improve crew safety and efficiency	Cost of using new field technologies

Consumer web portal		
Consumer awareness and control	Repository of consumer information	Cost of designing and running a consumer web portal

4.4 Challenges for implementation of Smart Grid project in India

Several challenges present themselves for smart grid development, and may affect the results of a cost-benefit analysis.

Financial resources: The business case for a self-healing grid is good, particularly if it includes societal benefits. But regulators will require extensive proof before authorizing major investments based heavily on societal benefits.

Government support: The industry may not have the financial capacity to fund new technologies without the aid of government programs to provide incentives for investment. The utility industry is capital-intensive, but has been sustaining exorbitant losses due to thefts and subsidization

Compatible equipment: Some older equipment must be replaced as it cannot be retrofitted to be compatible with smart grid technologies. This may present a problem for utilities and regulators since keeping equipment beyond its depreciated life minimizes the capital cost to consumers. The early retirement of equipment may become an issue.

Speed of technology development: The solar shingle, the basement fuel cell, and the chimney wind generator were predicted 50 years ago as an integral part of the home of the future. This modest historical progress will need to accelerate.

Lack of policy and regulation: No defined standards and guidelines exist for the regulation of smart grid initiatives in India.

Capacity to absorb advanced technology: Most discoms have limited experience with even basic information and communications technology and, as a result, they have weak internal skills to manage this critical component of smart grids. R-APDRP aims to provide some redress, but it is relatively recent and has not yet had a major impact on the industry. The industry's reluctance to implement ICT appears to have been a by-product of a desire to avoid transparency, especially in meter-billing-collection processes. Now, the lack of automation and the heavy dependence on outsiders for ICT know-how is an unavoidable penalty for any effort to implement a smart grid vision. This suggests that 1) policy makers actively discourage the organizational culture that fostered a lack of transparency, 2) recruiting and capacity building in these areas should be accelerated, and 3) partnerships with leading Indian ICT organizations should be considered as a means to accelerate implementation of smart grid concepts.

Consumer education: "Customer response" is the phrase used to describe the reaction of customers to the new features and functionality enabled by the smart grid. If, for example, a company installs advanced metering and two-way communication along with time-of-use rates, the question is "Will customers use it?" If there aren't enough customers who use the features, the benefits of a smart grid will not be achieved. Thus, two critical and often overlooked components of a smart grid implementations are 1) sufficient marketing analysis and product design to optimize the likelihood that customers will use the new technology, and 2) an education, communication and public relations program aimed at creating an understanding of smart grids, the associated benefits and the potential implementation issues. The program should be aimed at customers but also policy makers, opinion leaders, regulators and financial institutions.

Cooperation: The challenge for diverse State utilities will be the cooperation needed to install critical circuit ties and freely exchange information to implement smart grid concepts.

Cost assessment: Costs could ultimately be higher than projected because the standards and protocols needed to design and operate an advanced metering infrastructure are still in a state of flux. Thus, investments made now, before the standards are settled, have a higher risk of obsolescence. Failure to include estimates of the costs for the control equipment customers will install to automate their response to time-differentiated pricing could put smart grid investments at risk. Other risks include 1) no demonstration that the proposed project is more cost-effective than alternative approaches that will achieve the same major energy cost reduction objectives at less cost and 2) exclusion of incremental costs of "stranded" existing meters (i.e., accelerated depreciation).

Rate design: Many utilities are proposing to recover these costs via a customer surcharge. This is not reasonable, based on the view of cost causation, and will have disproportionate adverse impacts on low-usage customers.

Consumer protection: Privacy concerns about customer usage data and other personal data are real, but it is not clear how such data will be protected. Also, the installation of smart meters will open the door to remote involuntary disconnection and the use of service limiters, all of which limit customer access to and control over electricity service. Even unfounded concerns about a "spy in the house" may affect consumer attitudes. Thus, issues related to consumer privacy will likely be submitted to regulators and consumer protection agencies as soon as new technologies are planned.

Lack of empirical evidence: Utilities have done a number of pilot projects to test AMI and dynamic pricing on a limited basis, but it is only recently that several US utilities received regulatory approval to deploy AMI and dynamic pricing tariffs on a wide scale. In fact, most of those utilities are still in the process of completing deployment. The absence of robust empirical evidence regarding the performance and economics of AMI and dynamic pricing on a system-wide basis over time is a source of uncertainty over both long-term technical performance and the magnitude of peak load reductions that will actually be sustained in the long term in response to dynamic pricing.

Funding issues for India

Historically, building the grid through transmission and distribution lines has been undertaken by Power Grid Corp. and various state-regulated distribution companies. Central programs such as APDRP and R-APDRP provided some support in modernizing and rationalizing the billing and metering systems, but there have been relatively few such programs.

While no one has estimated with any level of detail the costs required for India to upgrade to a smart grid, estimates range widely depending on the utilities involved and the timing.

Given the large investment required to build out the current set of plans, Indian utilities will need to experiment with how best to fund such projects. Based on a survey by the authors, most utilities are proposing to recover all of these costs via a fully reconcilable surcharge. Many are proposing to allocate these costs among rate classes according to the number of customers in each class. Some utilities are also proposing to recover these costs via a monthly customer surcharge.

With the introduction of smart grid technology at the distribution level, consumers will have more incentive to switch to a new tariff. The existing tariff structure will have to be rationalized and time-of-day tariffs must be introduced to provide incentives to consumers. Similarly, for new renewable generation, more system integration will be required to ensure system security.

Some possible alternatives for funding are presented below. However, these are only illustrative in nature. Detailed rounds of talks with government, banks and the private sector will need to be undertaken to rationalize and validate the plausibility of these alternatives.

For central sector lending, develop a new appraisal process for smart grid projects. Grant and loan funding for the smart grid can come through traditional sources (e.g., PFC), but a revised project appraisal process that incorporates operational benefits will be needed to evaluate project submittals.

Reach self-funding. Following the lead of on-going loss reduction projects, many smart grid projects will become self-funded by exceeding the stipulated payback periods.

Attract new players and bring in vendor financing. Information and communication technology companies such as IBM, Infosys, and Wipro have started smart grid programs and are developing commercial models. Some examples of pilot projects include those with real estate developers to implement small-scale smart grid projects for residential and commercial complexes.

Expand bank understanding of the smart grid. Banks that are already lending to the power sector will see the business case for the smart grid quickly and can act to increase funding directly to projects, or indirectly to companies and utilities.

The most prudent route is however, a combination of these sources through public-private partnerships. State utilities can take the lead on developing the business case for pilot implementations of smart grids and then invite private players to participate by providing both technical know-how and funding. Private players can further approach the banks to fund their investment.

Regulatory Issues

India's electric power delivery system is much like the telecommunications network of the past – dated and increasingly costly for consumers. Like the telecommunications revolution, which created new technologies, choices and improved service levels, there is a need for a similar revolution in the power sector.

Being a highly regulated sector, regulatory intervention is imperative for successful smart grid implementation across the following key areas:

Funding

- Consumer awareness
- Establishing common standards
- Playing the role of a "watchdog"
- Cyber-security
- Interoperability.

The Government of India is keen to prepare the power sector for the introduction of the smart grid. Indian utilities are showing initial interest and starting to explore the subject. The private sector, especially companies with global experience in smart grid technology, is helping the Indian market understand the concept of the smart grid.

Based on technical presentations and discussions held during a recent seminar on the subject of "Smart Power Grid," the following recommendations are being considered by the Government of India.

- India's Ministry of Power may appoint a task force consisting of various stakeholder representatives to study the status of smart grid implementations in other countries. It will consider various issues relevant to India in examining the introduction of smart grid technology and make suitable recommendations for introducing smart grids in the country at different levels.
- The Central Power Research Institute (CPRI), Bangalore, could be appointed as a nodal agency for the collection of data / information from other countries and assist the task force in its study and finalization of recommendations. CPRI could even coordinate with other agencies on the development of smart grid technologies.
- Institutions such as CPRI, IITs, technological universities like JNTU, IT industries etc., may be identified to conduct further research on the "smart grid" technology for implementation suitable for the Indian environment.
- Since the IT sector in distribution companies is being developed under R-APDRP, the scope of funding could be increased to introduce smart grid technology in distribution wherever distribution control centers are already in operation. One distribution company in each region may be selected to implement pilot projects, as recommended by the task force.
- A small region in a central location like Bangalore or Hyderabad could be selected to implement the concepts of the smart grid as a pilot project in order to update the status of the smart grid's design and implementation in a phased manner.

Other considerations

The potential benefits of the smart grid vision extend well beyond the power sector value chain. Thus, a utility-centric approach is too narrow and too parochial, and it probably won't produce the best results for customers and society. The only reason a state-owned utility deserves to exist is to benefit customers and the commonweal. Shaping a smart grid vision should begin with customers and customer solutions. The utility will play an important role in achieving these benefits – at least, it could play an important role – but the beneficiaries are the customers and commonweal of India.

It is difficult to monetize some of the gains or benefits of a smart grid. An improvement in the health of citizens due to a reduction in carbon emissions is one such benefit. Given the wide impact of smart grids, an innovative methodology for guiding CBA and project appraisals will be needed. In the United States, EPRI and DOE have recognized this need. They organized a high-level group for this purpose, but even with the very substantial work accomplished to date, their efforts are ongoing.

Certain of the benefits of smart grids can be monetized, but for others, the current regulatory framework or accounting rules may not be supportive. For example, utilities benefit from the increased sale of electricity, so there is no incentive to reduce sales by implementing DSM (Decoupling or, more specifically, revenue decoupling, has been proposed as an alternative. A decoupling mechanism seeks to provide an opportunity for a regulated power company to earn a fair return but in a way that"decouples" its earnings ability from sales volume.) – even though that would help reduce the supply-demand gap and benefit customers and society. Another example is the incentive utilities have to increase the absolute value of their earnings by expanding their asset base. (The phenomenon known as the Averch-Johnson Theorem is that utilities that are regulated under a "rate base, rate-of-return" approach demonstrate an observable tendency to over-invest in assets that can be included in rate base)Perversely, there is no incentive to deliver a high volume of electricity with existing assets. These issues suggest that some modifications to India's regulatory framework or accounting rules may be warranted.

Communications infrastructure is costly, yet is at the heart of the smart grid vision. As we move deeper into a smart grid world, communication will play an ever-larger role in the power sector. Often, utilities will argue that they should build their own communication infrastructure owing to reliability and security concerns. This could result in the duplication of infrastructure, and as noted earlier, the electricity sector may not have the bandwidth in term of ICT skills to engineer, procure and implement this technology. This suggests that it might be advantageous to encourage close coordination between the telecommunication and power sectors, with the participation of policy makers and regulators.

CHAPTER 5

CONCLUSIONS

5.1 Recommendations

India's energy generation and consumption are on high growth rate. Climatic change concerns due to emission combined with resource and infrastructure constraints are dampers. With nearly 40 % of its 1.22 billion population deprived of grid electricity, present 186 GW installed power capacity may have to be doubled by the end of this decade to meet energy need of its growing population and expectations of a high GDP growth economy. A serious energy shortage and growing pressure on imports have been seen in the Indian energy sector. In the middle of 2012, India's power shortage led to massive rolling power cuts across the nation. Industries and businesses shut down and public protests followed, demanding better power supply. The current power crisis is not a temporary hiccup in the power system, but rather a symptom of the entire energy sector reaching the tipping point, is worrying. An overview of Indian Power Market along with brief analysis about the power system units is described. Power market in India is generally characterized by the poor demand side management and response for lack of proper infrastructure and awareness.

Smart Grid Technology can intuitively overcome these issues. In addition to that, it can acknowledge reduction in line losses to overcome prevailing power shortages, improve the reliability of supply, power quality improvement and its management, safeguarding revenues, preventing theft etc.. Integration of RES is expected to play significant influence on the operation of the power system for sustainable energy in future. Grid codes are set up to specify the relevant requirements for efficient and secure operation of power system for all network users and these specifications have to be met in order to integrate wind turbine into the grid. Several technical and operational issues with increased power penetration has discussed for emerging Indian power system.

In addition, Micro grid is creating new smart grid technology requirements in the areas of automation, management and control of alternative energy sources with energy storage devices.

With this, the report may guide future policies which to lead Indian power system to take several steps to implement Smart grid with RES integration.

The thesis presents a discussion on Indian Power Strategy along with its pitfalls in various technical and non-technical themes, with an organized approach to evolve the conceptualization of Smart Grid. Model architecture as well as India's Smart Grid initiatives taken by the government and many private bodies, are presented in the thesis. Further, various prospects of sustainable energy and off-grid solutions, evolution of Micro Grid along with various policies and regulatory affairs of India is also presented at this point in short. Currently, the nation ranks to be 4th largest in installed power generation capacity using RES and 3rd largest in investment and implementation of smart grids, which will be a trend setter for emerging economies to pursue "green" and sustainable energy. In this connection, the thesis should act as advocate to bring forth the significance and fortification of Smart Grid philosophy and implanting it on the basis of proposed ideology in Indian subcontinent.

5.2 Scope for future works

Upon the finalizing of the entire study, the further research perspective would deliberately act as an advocate to discover the rank and strategy of nation's development in power and energy with respect to current and future energy demand.

BIBLIOGRAPHY

1. Central Electricity Authority. Technical standard for connectivity to the grid, Regulations 2000

2. Eyring, V., Köhler, H., Lauer, A., Lemper, B. (2005): Emissions from International Shipping: impact of Future Technologies on Scenarios until 2050, Journal of Geophysical Research, 110, D17305

3. Pradeep, Y.; Thomas, J.; Sabari, C.L.; Balijepalli, V.S.K.M.; Narasimhan, S.R.; Khaparde, S.A.; ,
"Towards usage of CIM in Indian Power Sector," IEEE Power and Energy Society General Meeting, 2011, vol., no., pp.1-7, 24-29 July 2011.

4. "The Green Grid: Energy Savings and Carbon Emission Reductions Enabled by a Smart Grid," EPRI Palo Alto, CA: 2008

5. Hashmi, M.; Hanninen, S.; Maki, K.; , "Survey of smart grid concepts, architectures, and Technological demonstrations worldwide," *Innovative Smart Grid Technologies (ISGT Latin America), 2011 IEEE PES Conference on*

6. Taqqali, W.M.; Abdulaziz, N.; , "Smart Grid and demand response technology," *Energy Conference*
and Exhibition (EnergyCon), 2010 IEEE International

7. Sooriyabandara, M.; Ekanayake, J.; , "Smart Grid - Technologies for its realization," *Sustainable*
Energy Technologies (ICSET), 2010 "IEEE International Conference on, vol., no., pp.1-4, 2010

8. [Online] "A Report on Transmission and Distribution in India" , Power Grid India Corporation
Limited, 2011, Available: http://powergridindia.com

9. Gungor, V.C.; Sahin, D.; Kocak, T.; Ergut, S.; Buccella, C.; Cecati, C.; Hancke, G.P.; , "Smart Grid

Technologies: Communication Technologies and Standards"

10. V.Teja, et all; , "Wide-Area Monitoring, Protection, and Control of Future Electric Power Network,"
11. [Online] Indian Smart Grid forum, Available : http://www.indiiasmartgrid.org
12. World Economic Forum, in connection with Accenture, "Accelerating Smart Grid Investments," 2009.
13. Technology Roadmap, Smart Grid, International Energy Agency (IEA), http://www.iea.org/papers/2011/smartgrids_roadmap.pdf, pp. 6, 2011
14. Ministry of Power, Government of India Website. [Online] Available: http://powermin.nic.in, Nov. 2009

Table 9: Smart Grid definitions of functions

Function	Definition
Fault Current Limiting	Fault current limiting can be achieved through sensors, communications, information processing, and actuators that allow the utility to use a higher degree of network coordination to reconfigure the system to prevent fault currents from exceeding damaging levels. Fault current limiting can also be achieved through the implementation of special stand alone devices known as Fault Current Limiters (FCLs) which act to automatically limit high through currents that occur during faults.
Wide Area Monitoring, Visualization, & Control	Wide area monitoring and visualization requires time synchronized sensors, communications, and information processing that makes it possible for the condition of the bulk power system to be observed and understood in real-time so that protective, preventative, or corrective action can be taken.
Dynamic Capability Rating	Dynamic capability rating can be achieved through real-time determination of an element's (e.g., line, transformer etc.) ability to carry load based on electrical and environmental conditions
Power Flow Control	Flow control requires techniques that are applied at transmission and distribution levels to influence the path that power (real & reactive) travels. This functionality is enabled by tools such as flexible AC transmission systems (FACTS), phase angle regulating transformers (PARs), series capacitors, and very low impedance superconductors
Adaptive Protection	Adaptive protection uses adjustable protective relay settings (e.g., current, voltage, feeders, and equipment) that can change in real time based on signals from local sensors or a central control system. This is particularly useful for feeder transfers and two-way power flow issues associated with high DER penetration.
Automated Feeder and Line Switching	Automated feeder and line switching is realized through automatic isolation and reconfiguration of faulted segments of distribution feeders or transmission lines via sensors, controls, switches, and communications systems. These devices can operate autonomously in response to local events or in response to signals from a central control system
Automated Islanding and Reconnection	Automated islanding and reconnection is achieved by automated separation and subsequent reconnection (autonomous synchronization) of an independently operated portion of the T&D system (i.e., micro grid) from the interconnected electric grid. A micro grid is an integrated energy system consisting of interconnected loads and distributed energy resources which, as an integrated

	system, can operate in parallel with the grid or as an island.
Automated Voltage and VAR Control	Automated voltage and VAR control requires coordinated operation of reactive power resources such as capacitor banks, voltage regulators, transformer load-tap changers, and distributed generation (DG) with sensors, controls, and communications systems. These devices could operate autonomously in response to local events or in response to signals from a central control system.
Diagnosis & Notification of Equipment Condition	Diagnosis and notification of equipment condition is defined as on-line monitoring and analysis of equipment, its performance, and operating environment in order to detect abnormal conditions (e.g., high number of equipment operations, temperature, or vibration). Asset managers and operations personnel can then be automatically notified to respond to conditions that increase the probability of equipment failure.
Enhanced Fault Protection	Enhanced fault protection requires higher precision and greater discrimination of fault location and type with coordinated measurement among multiple devices. For distribution applications, these systems will detect and isolate faults without full-power re-closing, reducing the frequency of through-fault currents. Using high resolution sensors and fault signatures, these systems can better detect high impedance faults. For transmission applications, these systems will employ high speed communications between multiple elements (e.g., stations) to protect entire regions, rather than just single elements. They will also use the latest digital techniques to advance beyond conventional impedance relaying of transmission lines
Real-time Load Measurement and Management	This function provides real-time measurement of customer consumption and management of load through Advanced Metering Infrastructure (AMI) systems (smart meters, two-way communications) and embedded appliance controllers that help customers make informed energy use decisions via real-time price signals, time-of-use (TOU) rates, and service options
Real-time Load Transfer	Real-time load transfer is achieved through real-time feeder reconfiguration and optimization to relieve load on equipment, improve asset utilization, improve distribution system efficiency, and enhance system performance.
Customer Electricity Use Optimization	Customer electricity use optimization is possible if customers are provided with information to make educated decisions about their electricity use. Customers could be able to optimize toward multiple goals such as cost, reliability, convenience, and environmental impact.

Table 10: Smart Grid description of benefits

Benefit	Description
Energy Revenue	Revenue generated through the competitive energy market by buying power at low prices and selling at high prices.
Capacity Revenue	Revenue generated through the competitive capacity market for a capacity credit.
Ancillary Services Revenue	Revenue generated through the competitive ancillary services market for spinning reserves or frequency regulation
Optimized Generator Operation	Better forecasting and monitoring of load and grid performance would enable grid operators to dispatch a more efficient mix of generation that could be optimized to reduce cost. The coordinated operation of energy storage, distributed generation, or plug-in electric vehicle assets could also result in completely avoiding central generation dispatch.
Deferred Generation Capacity Investments	Utilities and grid operators ensure that generation capacity can serve the maximum amount of load that planning and operations forecasts indicate. The trouble is, this capacity is only required for very short periods each year, when demand peaks. Reducing peak demand and flattening the load curve should reduce the generation capacity required to service load and lead to cheaper electricity for customers.
Reduced Ancillary Service Cost	Ancillary services are necessary to ensure the reliable and efficient operation of the grid. The level of ancillary services required at any point in time is determined by the grid operator and/or energy market rules. Ancillary services, including spinning reserve and frequency regulation, could be reduced if generators could more closely follow load; peak load on the system was reduced; power factor, voltage, and VAR control were improved; or information available to grid operators were improved.
Reduced Congestion Cost	Transmission congestion is a phenomenon that occurs in electric power markets. It happens when scheduled market transactions (generation and load) result in power flow over a transmission element that exceeds the available capacity for that element. Since grid operators must ensure that physical overloads do not occur,

	they will dispatch generation so as to prevent them. The functions that provide this benefit provide lower cost energy, decrease loading on system elements, shift load to off-peak, or allow the grid operator to manage the flow of electricity around constrained interfaces (i.e. dynamic line capability or power flow control).
Deferred Transmission Capacity Investments	Reducing the load and stress on transmission elements increases asset utilization and reduces the potential need for upgrades. Closer monitoring, rerouting power flow, and reducing fault current could enable utilities to defer upgrades on lines and transformers.
Deferred Distribution Capacity Investments	As with the transmission system, reducing the load and stress on distribution elements increases asset utilization and reduces the potential need for upgrades. Closer monitoring and load management on distribution feeders could potentially extend the time before upgrades or capacity additions are required
Reduced Equipment Failures	Reducing mechanical stresses on equipment increases service life and reduces the probability of premature failure. This can be accomplished though enhanced monitoring and detection, reduction of fault currents, enhanced fault protection, or loading limits based on real-time equipment or environmental factors.
Reduced T&D Equipment Maintenance Cost	The cost of sending technicians into the field to check equipment condition is high. Moreover, to ensure that they maintain equipment sufficiently, and identify failure precursors, some utilities may conduct equipment testing and maintenance more often than is necessary. Online diagnosis and reporting of equipment condition would reduce or eliminate the need to send people out to check equipment resulting in a cost savings.
Reduced T&D Operations Cost	Automated or remote controlled operation of capacitor banks and feeder and line switches eliminates the need to send a line worker or crew to the switch location in order to operate it. This reduces the cost associated with the field service worker(s) and service vehicle.
Reduced Meter Reading Cost	Advanced metering infrastructure (AMI) equipment eliminates the need to send someone to each location to read the meter manually, leading to reduced meter operations costs. AMI technology can also reduce costs associated with other meter operations such as connection/disconnects, outage investigations, and maintenance
Reduced Electricity Theft	Smart meters can typically detect tampering. Moreover, a meter data management system can analyze customer usage to identify patterns that could indicate diversion. These new capabilities can lead to a reduction in electricity theft through earlier identification and

	prevention of theft.
Reduced Electricity Losses	Functions that provide this benefit could help manage peak feeder loads, reduced electricity throughput, locate electricity production closer to the load and ensure that voltages remain within service tolerances, while minimizing the amount of reactive power provided. These actions can reduce electricity losses by making the system more efficient for a given load served or by actually reducing the overall load on the system.
Reduced Electricity Cost	Functions that provide this benefit could help alter customer usage patterns (demand response with price signals or direct load control), or help reduce the cost of electricity during peak times through either production (DG) or storage.
Reduced Sustained Outages	A sustained outage is one lasting > 5 minutes, excluding major outages and wide-scale outages. The monetary benefit of reducing sustained outages is based on the value of service (VOS) of each customer class. The VOS parameter represents the total cost of a power outage per MWh. This cost includes the value of unserved energy, lost productivity, collateral damage, administrative costs, the value of penalties and performance-based rates. Functions that lead to this benefit can reduce the likelihood that there will be an outage, allow the system to be reconfigured on the fly to help restore service to as many customers as possible, enable a quicker response in the restoration effort, or mitigate the impact of an outage through islanding or alternative power supply.
Reduced Major Outages	A major outage is defined using the beta method, per IEEE Std 1366-2003 (IEEE Power Engineering Society 2004). The monetary benefit of reducing major outages is based on the VOS of each customer class. The VOS parameter represents the total cost of a power outage per MWh. This cost includes the value of unsaved energy, lost productivity, collateral damage, the value of penalties and performance-based rates. Functions that lead to this benefit can mitigate major outages by allowing the system to be reconfigured on the fly to help restore service to as many customers as possible, enable a quicker response in the restoration effort, or mitigate the impact of an outage through islanding or alternative power supply.
Reduced Restoration	The functions that provide this benefit lead to fewer outages and/or help restore power quicker or with less manual labor hours, which

Cost	results in lower restoration costs. These costs can include line crew labor/material/equipment, support services such as logistics, call centers, media relations, and other professional staff time and material associated with service restoration
Reduced Momentary Outages	By locating faults more accurately or adding electricity storage, momentary outages could be reduced or eliminated. Moreover, fewer customers on the same or adjacent distribution feeders would experience the momentary interruptions associated with reclosing. Momentary outages last <5 min in duration. The benefit to consumers is based on the value of service.
Reduced Sags and Swells	Locating high impedance faults more quickly and precisely and adding electricity storage will reduce the frequency and severity of the voltage fluctuations that they can cause. Installing advanced recloses that only allow a limited amount of current to flow through them upon reclosing can also reduce voltage fluctuations. Moreover, fewer customers on the same or adjacent distribution feeders would experience the voltage fluctuation caused by the fault. The benefit to consumers is based on the value of service
Reduced CO2 Emissions	Functions that provide this benefit can lead to avoided vehicle miles, decrease the amount of central generation needed to their serve load (through reduced electricity consumption, reduced electricity losses, more optimal generation dispatch), and or reduce peak generation. These impacts translate into a reduction in CO2 emissions produced by fossil-based electricity generators and vehicles
Reduced SOx, NOx, and PM-2.5 Emissions	Functions that provide this benefit can lead to avoided vehicle miles, decrease the amount of central generation needed to their serve load (through reduced electricity consumption, reduced electricity losses, more optimal generation dispatch), and or reduce peak generation. These impacts translate into a reduction in pollutant emissions produced by fossil-based electricity generators and vehicles
Reduced Oil Usage (not monetized	The functions that provide this benefit eliminate the need to send a line worker or crew to the switch or capacitor locations to operate them eliminate the need for truck rolls to perform diagnosis of equipment condition, and reduce truck rolls for meter reading and measurement purposes. This reduces the fuel consumed by a service vehicle or line truck. The use of plug-in electric vehicles can also lead to this benefit since the electrical energy used by plug-in electric vehicles displaces the equivalent amount of oil.

Reduced Wide-Scale Blackouts	The functions that lead to this benefit will give grid operators a better picture of the bulk power system and allow them to better coordinate resources and operations between regions. This will reduce the probability of wide-scale regional blackouts.