Integrating Wind And Solar Energy In India

For A Smart Grid Platform



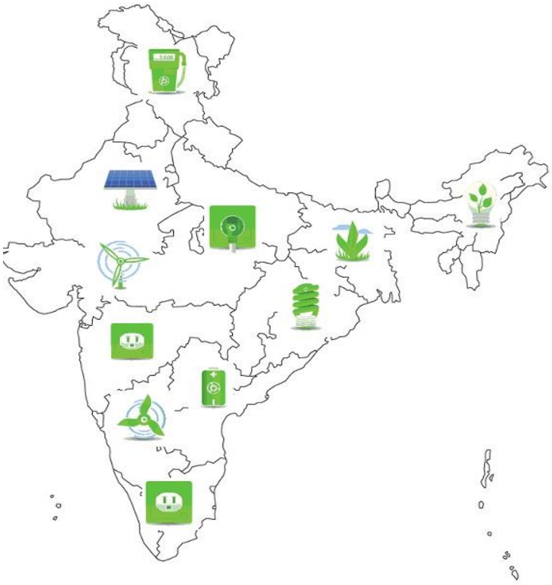

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Table of Contents

List of Tables & Figures

List of Abbreviations

1. IEA: International Energy Association
2. CEA: Central Electricity Authority
3. CERC: Central Electricity Regulatory Commission
4. CTU: Central Transmission Utility
5. IEGC: International Electricity Grid Code
6. RoW: Right of Way
7. PLF: Plant Load Factor
8. Discom: Distribution Companies
9. T&D: Transmission and Distribution
10. TERI: Tata Energy & Research Institute
11. EPRI: Electrical Power Research Institute
12. DER: Distributed Energy Resources
13. DG: Distributed Generation
14. AMI: Advanced Metering Infrastructure
15. RES: Renewable Energy Sources
16. JNNSM: Jawaharlal Nehru National Solar Mission
17. ICT: Information & Communications Technology
18. SGTF: Smart Grid Task Force
19. ESP: Ethernet Service Provider
20. EV: Electric Vehicles
21. BU: Billion Units
22. GPRS: General Packet Radio Service
23. HAN: House Area Network
24. SCADA: Supervisory Control And Data Acquisition
25. OFC: Optical Fibre Communication
26. FSAS: Frequency Support and Ancillary Services
27. DG: Distributed Generation
28. MNRE: Ministry of New and Renewable Energy
29. GDP: Gross Domestic Product
30. PLC: Programmable Logic Controller
31. PLCC: Power Line Carrier Communication
32. NTPC: National Thermal Power Corporation

Abstract

With an ever increasing population coupled with aconstant depletion of fossil fuel resources and many sites reaching their ultimate capacity, India is in dire need of a Midas touch or of an Aladdin's Lamp. A much smarter approach towards the electrical grid is needed. This smarter approach, technically referred to as the *smart grid*,promises affordable electrical environment which seems to be the need of the hour.

India has large untapped resources of wind and solar energy, which if utilized properly, can fulfill the energy requirements of the country to a large extent. This paper presents the journey of the Indian power sector through time, analyses various demand and supply scenarios, which are mutually exclusive,and also assesses various issues facing the Indian Power System.

This paper proposes that integration of enhanced electrical capacity realized through a large-scale integration of renewable energy resources, such as wind and solar energy, in the Indian electrical grid can lead to a smarter grid platform. This platform will ensure increased efficiency, reliability, and security, as well as reducing the environmental impact of supplying the electrical power needs of the modern society. The result is an enhanced electricity management environment and a dynamic programable renewable source mobilization in India leading to energy independence and an electrical grid that is much more reliable, secure, efficient, and greener.

Keywords: Smart grid, Wind and Solar energy, Micro sources, Electricity management.

1. Introduction

Electricity is a crucial facet of any country's prosperity. India had an installed power generation capacity of 210 GW as of November 30, 2012, which is about 154 times the installed capacity in 1947 (1362 MW).[1] Electricity generation growth has been steadily increasing year after year, and in the year 2011-12 the generation was about 876.8 billion KwH with a growth of 8% over the previous year. During the 11th Five Year Plan, the power sector made considerable progress with a capacity addition of 58 GW, which was significantly more than the capacity commissioned in the previous plans.[2]

However, the demand has been consistently outstripping the supply even as power availability has increased due to significant investments on the supply side. India faces the challenge of poor reliability and a poor quality of electricity, leading to frequent load shedding situations in one part of the country or the other.India has witnessed substantial energy and peak shortages of 8.5% and 11% respectively in the year 2011-12[3].

The Indian power sector has been undergoing an evolution, from vertically involved public utilities to unbundled entities, especially with more private assets joining in on the generation side. The changes have led to steady improvements in efficiency and competition and offer contingency management with better price signals to encourage the market participants across the value chain.

Banking on the inspiration from these changes, India targets to set up substantially high 88 GW[4] additional capacity during the 12thFive Year Plan period, which may to a large extent match the ever growing demand. To better understand the state of the Indian power sector, a deeper analysis of all the three components, generation, transmission and distribution is required.

[1]CEA, General Review 2012
[2]Ministry of Power, India Energy Statistics, 2011
[3]IEA International Energy Association, 2012
[4]All India Energy Statistics, 2012

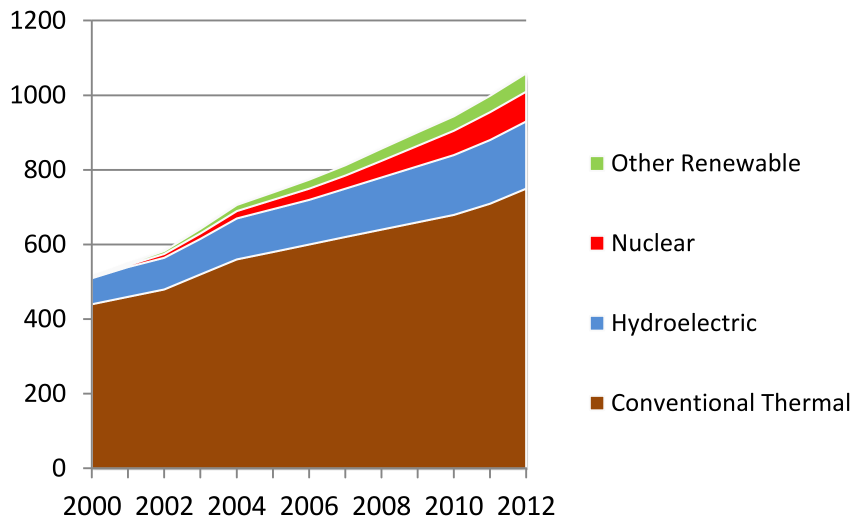

Figure 1: Indian Electricity Generation by Type, 2000-2012
Source: Author, Data obtained from *CEA Annual Report* 2012

The Indian power generation industry is going through rough times. The sector is battling several issues, largely related to fuel shortages, which could slow down the industrious pace of capacity addition witnessed during the 11thFive Year Pan period. In 2011-2012, a record capacity addition of over 20,500 MW in a single year was registered in the sector, raising the total capacity to about 55,000 MW.[5] A significant contribution was reported from the private sector with a share of over 58% during 2011 – 2012 and 42% during the entire five year plan period. As on July 31 2012, India's installed capacity (excluding captive plants) stood at 206,456 MW.[6]

Thermal sources continued to account for two thirds of the capacity at 137,386 MW, followed by hydropower (19% or 39,291 MW),renewable energy (12.1% or 24,998 MW) and nuclear power (2.3% or 4780 MW)[7] of installed generating capacity.

At present the traditional power generation industry is at a juncture where issues like capacity additions, enhanced reliability of power supply and quality, need to be addressed quickly. These issues are paving the way for more investments and easier regulatory norms for absorption of more renewable energy in the Indian National Grid. India's power generation sector consists mainly of coal-based thermal plants.

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[5]Ibid
[6]Indianpowersector.com, Central Electricity Authority, 2012
[7] Central Electricity Regulatory Commission, India, 2013

It is ironic that India, with the fourth largest coal reserves in the world,is perpetually struggling to meet its coal demand due to deficient coal production because of various policy and infrastructural bottlenecks. The issues faced by the generation sectorare:

- **Coal and gas shortages**: Thermal power generation suffered a shortfall of 20 BUs during 2011 – 2012, 9 BUs and 11 BUs due to a shortage of coal and gas respectively.[4]

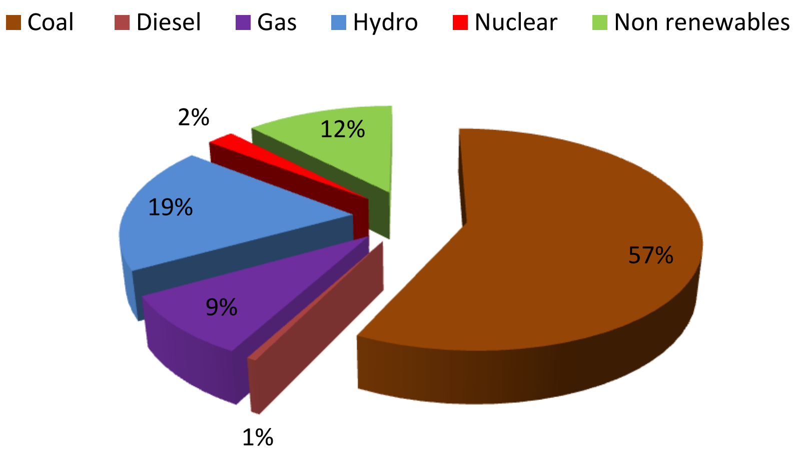

Figure 2:All India Installed Capacity (as of November 30, 2012)
Source: Author, with data from *Monthly Reports CEA* December 2012

- **Slowdown in hydropower capacity addition**: Capacity addition from hydropower sources slowed in the past couple of years. The year on year growth rates declined to 3.8% 2011-12 from 7.2% in 2006 – 2007.[8] This is due to geological changes; to some extent on local issues; deficiencies in survey and investigation; lack of transparency in the process of award contracts and inadequacies in project execution.
- **Brake on nuclear power**: In the post- Fukushima scenario, the opposition to nuclear power in the country has gained ground. Although India has decided to proceed with its nuclear agenda with greater safety measures, local opposition against the upcoming nuclear projects could adversely impact its nuclear power ambition.

[8]www.nldc.in,National Load Dispatch Centre

1.2 Transmission

In India, the power transmission business is a monopoly where the Central Transmission Utility and the State Transmission Utility have the key responsibility for network planning, development and execution. The private players have a negligible presence.[9] It was only during the 11th Plan Period that the Inter- State transmission sector was opened for private sector participation through the establishment of joint ventures with power grid or through the selection of Transmission System Provider involving competitive bidding.

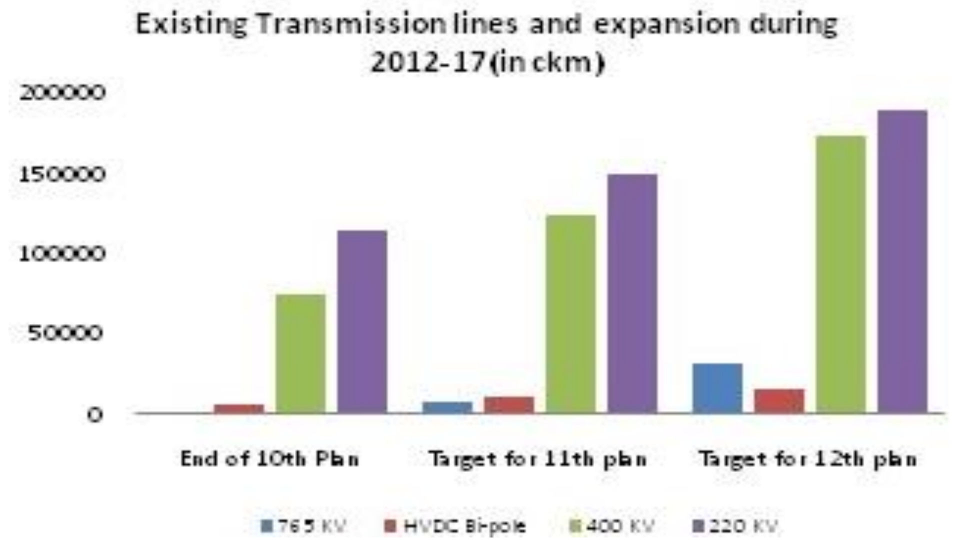

Figure 3: Existing Transmission Lines and Expansion
Source: Metris Business Solutions, *Transmission Lines Expansion in India*, 2013

During the 11th Plan Period (years 2007- 2012), open access in transmission was introduced to promote competition among the generating companies that can now sell to different distribution licensees across the country as well as consumers with a power demand greater than 1 MW.[10] The growth of transmission system is summarized in Figure 4.

[9] Ministry of Power, Government of India, 2013
[10] ibid

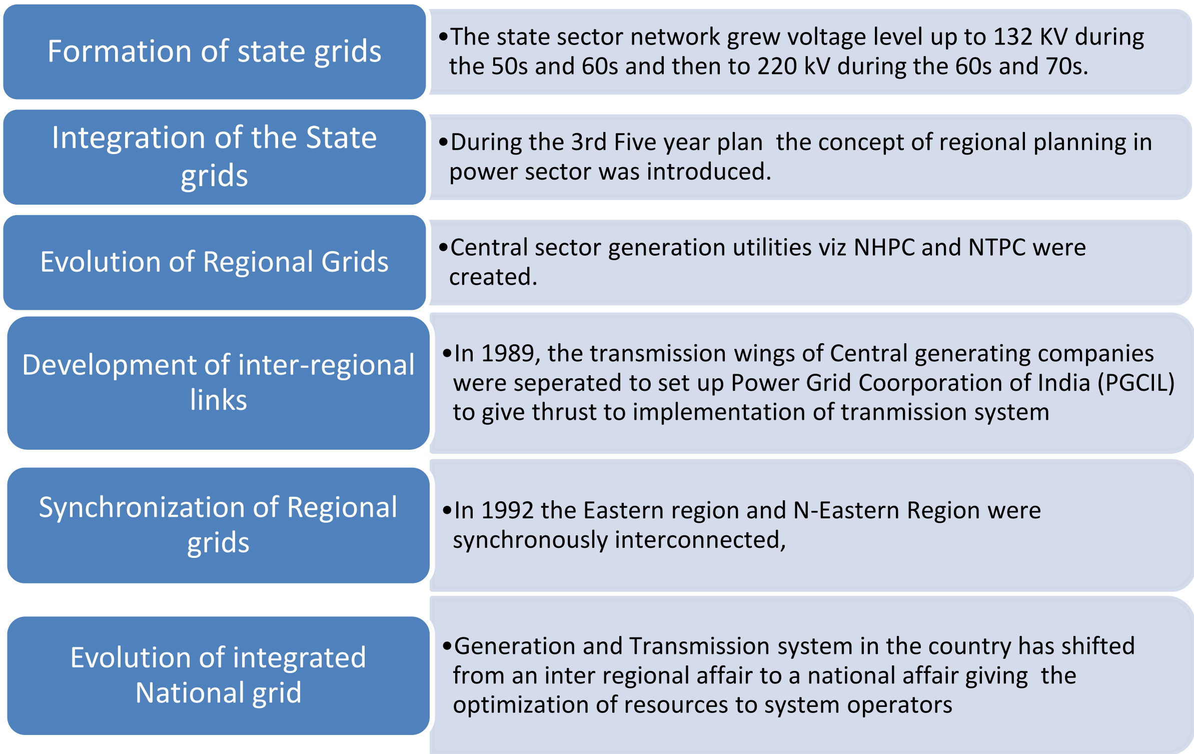

Figure 4: Growth of transmission system in India
Source: Author, with data from *FICCI* and Power *Plus Magazine*, January 2013

Power transmission is regulated though elaborate and multi-faceted legislations, such as the Electricity Act 2003 and India Electricity Grid Code (IEGC), and the effective implementation of these legislations are essential. Greater executing powers need to be given to the central and the state regulators as well as the system operators. The issues that need to be addressed at present for both public and private transmission project developers are procedural delays in land acquisition; obtaining rights of way; environmental and related statutory clearances; and equipment deployment, particularly in hostile terrain.

1.3. Distribution

Distribution systems provide the critical last mile connectivity in the electricity sector. The revenue collection, as the subsector of the electrical industry characteristic of this link, makes it an important segment. Moreover, unlike the other two sectors- generation and transmission, the distribution consumers (residential, commercial and industrial and often have conflicting needs:

- From2007 to 2011, the overall unit cost increased by 21%; but, the increase has not been comparable or even proportionate with the increase in the cost of supply. As a result, the gap between the cost of supply and the average tariff has been widening over the years. The financial position of the electricity distribution sector has been a concern for over a decade now. The financial and commercial viability of the state owned distribution utilities is a major issue and is putting at risk the significant investments being pumped into the electricity sector by private and public players.An investment to the tune of $300,000 Million is the financial exposure of the Indian banking industry.[11]

- The estimated loss of all the State distribution utilities has been estimated at Rs 2.4 lakh crore as of March 31, 2012.[12]
- Distribution companies, mostly state-owned, are mired with about $35 billion in debt.[13]
- Tariffs have not been revised in the last ten years, leading to calls for higher subsidies to be implemented in the sub-sector to cover costs of inefficiencies; indifference of consumers towards the efficiency of the appliances they use; augmentation of distribution network to the ever changing profile of consumers in terms of consumption levels, and distribution in time and space. In addition electricity theft has not been checked to the extent that feasible. The electricity distribution losses are huge and may be as high as 40% in some states, while the country-wide average is 27%.[14]
- The current AT&C losses vary across state utilities, in the range of 12.22%(Himachal Pradesh) to 72.86% (Jammu &Kashmir),to some extent owing to the fact that the some areas are thinly populated; while the national average was about 26% in the year 2010-11.[15]

[11]Power Grid Corporation of India Limited, *T&D report 2012*
[12]Ibid
[13]Index Mundi, *India Public Debt, 2012*
[14]IndiaWorldEnergy.com, *Transmission and Distribution in India*, 2013
[15]M.S. Bhalla, *Transmission and Distribution Loss,* Energy and resources Institute (TERIIN), 2012

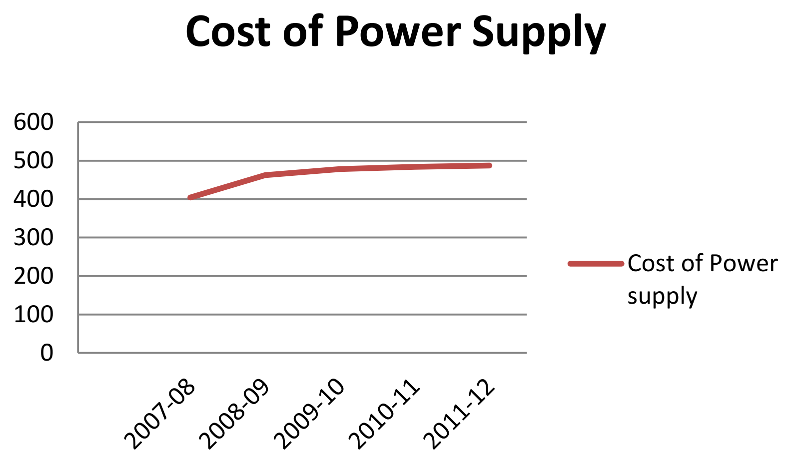

Figure 5: Cost of Power Supply (Paisa/kWh Sold)
Source: *Annual Report on Working of State Power Utilities and Electricity Departments 2011-12,* Power & electricity Division, Planning Commission, Government of India

2. India's Aging Electrical Grid

On July 31 2012,India experienced the largest electrical blackout in history affecting nearly 670 million people or 10% of the world's population. The Northern Power Grid that connects three of the country's grids discontinued operating as blackouts extended almost 2,000 miles, from India's eastern border with Myanmar to its western border with Pakistan[16].

Such an enormous power failure paves the way for more stringent regulations throughout the electricity chain delivery system in the power sector. Indian authorities are leavingno stone unturned to augment the supply chain of electricity delivery system so as the fragile and weary electrical power delivery system of India is mended to the extent that such blackouts do not occur in the near future.

The primary issue is that of adaptability if blackouts occur in India is compared with that of some other country where electrical supply is far more reliable. The Indian electrical system is rated as a fragile and an unreliable system. It lacks considerable self-healing and progressive capabilities that tend to have a cascading effect on the overall health of the electrical system. Issues facing India's electrical system have been discussed rather generously because they are pivotal to the growth of India's power sector and the economy.

2.1. Power Generation and Infrastructure

India's booming economy has put acute pressure on the Indian power supply chain, which is largely dependent on coal and gas for nearly 80% of its generation. The acute shortage of coal at the generation sites is hampering the generation of electricity with many of the power stations running at very low plant load factors (PLFs). While importing of gas from gas-rich countries is considered uneconomical and not a feasible option, production and refining of coal in the country is not keeping pace needed to match the demand at the stations. At times the coal stock may touch the critical level leaving no options for the power stations but to run at low PLFs.

Such a situation is critical to grid security and its uninterrupted and a continuous operation. This state of the power generation may be attributed to the presence of a monopolistic model of coal mining in the country. Coal India Limited has the sole authority over most of the mines in the country and is not able to keep pace with the demand. This can be attributed to reasons such as stringent policy regulations, non-availability of advanced

[16]Jim Yeardley and Gardiner Harris, "Over Half a Billion Without Power in India as Grids Fail," *The New York Times*, July 31, 2012

technology at the mines, difficulties in obtaining clearances, such as environmental, and lack of an internal organizational structure.

Most of the gas based power stations in the western part of the country are fuel starved and there is an immense need to either increase the production of gas in the country or import gas from other countries.

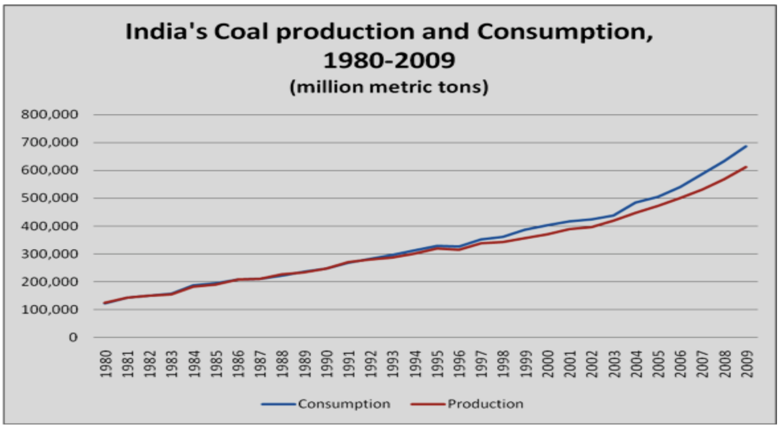

Figure 6: India's Coal Production and Consumption
Source: Gregor.us *India's Coal Scenario, An Analysis*, April 2010

2.2. Supply, Demand and Unofficial Connections

Power infrastructure in India cannot be considered capable of providing a dependable and a reliable power supply that is taken for grantedlike those in the western countries. An absence of connectivity results in some 300 million people having no access to electricity because the grid does not connect to their regions.Although India ranks sixth in the world in terms of overall electricity production and consumption, the huge population of 1.2 billion means that per capita levels of electricity consumption remains low at just over 500 kWh per person per year,as compared to more than 2,600 kWh inChina and nearly 12,000 kWh in the United States[17].

To efficiently manage the power supply and thereby provide quality power to the consumers is an uphill task considering the steady increase in the demand that offsets the supply and demand equation. According to Indian government regulations, each consumer has to declare the type of connections they require. Often this is not observed due to the lack of knowledge and non-committal attitude of consumers to the requirements of the distribution company. In addition, some consumers operating industrial loads may declare their connections for residential purposes. This practice has a cascading effect that escalates to the distribution companies that bear the losses.

[17]Raul and Mueller, "India Power Bloackout: THe Shape of Things to Come? *Market* Oracle, August 20, 2012

Even when India boasts of a highly industrialized economy and emerging urban lifestyles, the availability of an electrical connection still seems to be out of reach of many, most particularly the residents of slums. This definitely does not mean that slums are looming under dark; but that unofficial power tappings are common in such areas.

Figure 7: Indian Distribution system, Crying out for help.
Source: blogs.worldwatch.org

2.3. Blackouts - Planned and Unplanned

The blackout of July, 2012 had its roots in Agra in the state of Uttar Pradesh where transmission lines were carrying twice the capacity load. The tripping of Agra Gwalior line resulted in a cascading effect with lines tripping one after the other. The result of the blackout was a catastrophe and affected nearly 100 million people. Most of the populace of Northern India had to face the scorching and sweating heat of July. Massive traffic jams of massive formed in New Delhi as traffic lights stopped working. Hundreds of miners were trapped underground. Water supply was heavily impacted. Some hospitals faced major difficulties in the days following the blackout.

What makes India different from the western countries is the way blackouts are treated. In India, the main issue is not whether or not there will be a blackout. People know that there will be, often for several hours every day. They *prepare for outages* and take them head on.

The difference is between planned and unplanned blackouts. Planned outages are often referred to as rolling blackouts and are common in many places across the country. A rolling blackout also called load shedding and is an engineering technique employing an intentional electrical shutdown where electricity delivery is stopped for non-overlapping periods of time.

Rolling blackouts are a normal daily event in many developing countries where electricity generation capacity is underfunded or infrastructure is poorly managed. Where outages are scheduled, people adjust their activities accordingly. However, unscheduled disruption is tolerated, and has developed an entire industry of back-up power supply services

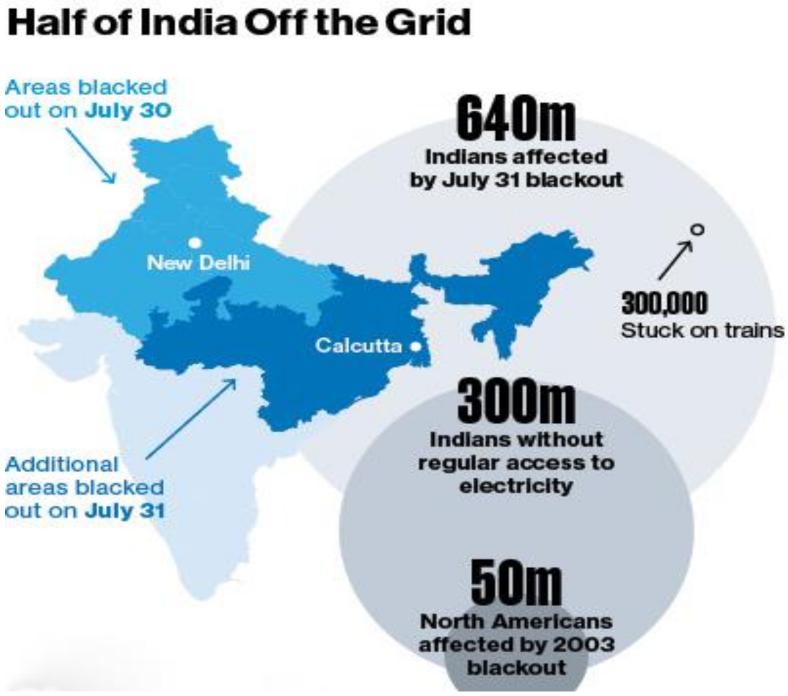

Figure 8: August 2012 Power Blackout in India
Source: Bruce Einhirn, et. al., "Modern India By Candlelight," *Bloomberg Businessweek* July 31, 2012

2.4. Transmission and Distribution losses:

In India, a large portion (23%) of the electricity generated is lost while transferring power to the consumers. This is known as T&D (Transmission and Distribution losses). Studies carried out by various independent agencies including TERI estimate the losses to be as high as 50 % in some states. Accurate estimation of losses is very important as it directly affects the sales and the power purchase requirements and hence determines the electricity tariff of a utility by the Regulatory Authority.

Electrical energy losses mainly occur in the process of transferring power to consumers as technical as well as commercial losses. The officially declared transmission and distribution losses in India have risen steadily from about 15% in 1966 – 1967 to about 23% in 1998 – 1999.[18] The continued rising trend in the losses is a matter of serious concern and dedicated efforts are required to curtail them. According to a study by the *Electric Power Research Institute* (EPRI) of the USA, the losses in various elements of the T&D system usually are on the order as shown below.

[18]*India Electricity Statistics* 2011,Minstry of Power

System Element	Power losses Minimum (%)	Power losses Maximum (%)
Step up Transformers and EHV transmission system	**05**	**1.0**
Step down to sub transmission voltage level	**1.5**	**3.0**
Step down to distribution voltage level	**2.0**	**4.5**
Distribution lines and Service connections	**3.0**	**7.0**
Total losses	**7.0**	**15.5**

Figure 9: T&D Losses in the System
Source: Author, with data from *T&D losses, An Independent Study*, The Energy and Resource Institute

2.5. Environmental Ramifications of the Power Sector

In India, power shortages are not the only issue. Traditionally, resources for electricity generation would be utilized by the simple theory of *cheap is good*. Although important, there are certain other parameters that need to be taken into consideration, such as social, environmental and technological benefits and consequences of the energy sources selection[19]. A figure showing the comparison of different energy sources for life cycle of carbon emissions is shown below.

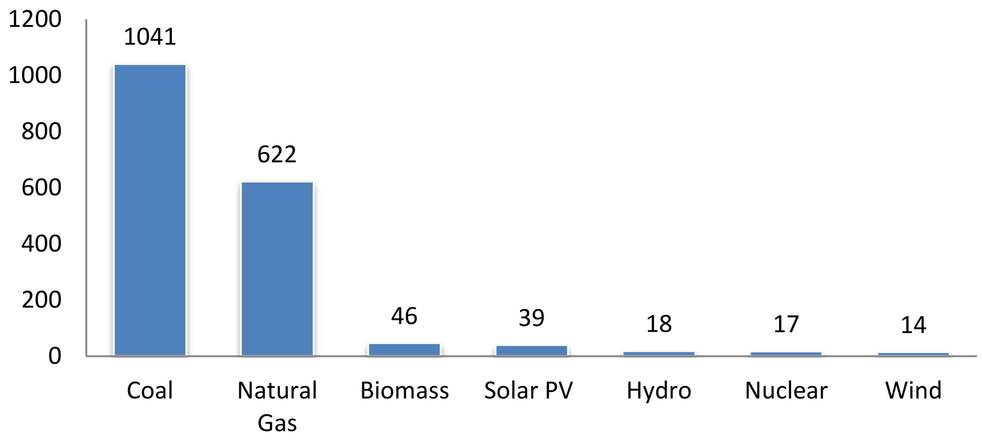

Figure 7: Comparison of Life- Cycle Emissions (Tons of Carbon Dioxide Equiv. Per Gig watt Hour)
Source::Paul, J. Meier, *Life Cycle Assessment of Electricity Generation Systems and Applications for Climate Change Policy Analysis*, Fusion Technology Institute, University of Wisconsin 2002

It can be easily seen that generating electricity using Coal has the maximum global warming potential followed by natural gas. In a developing country like India the economics of producing electricity is of paramount concern while planning for the type of plant to be installed and more so with the presumption that coal for electricity generation is available at a regulated price. However, if the consequences of prolonged use of coal for producing electricity on human health and environment cost as well as efforts required to improve or alter the path of degradation, it seems the initial low cost of using coal seems a strategically bad idea when compared to renewable resources for producing electricity.

[19] Meier PJ, life cycle assessment of electricity generation systems and applications for climate change policy analysis(2002)

Taking into account the growing economy of India compared to other countries in the west, switching to cleaner sources of energy is more of a multi-step mechanism rather than a single step. There is an urgent need for transfer of technology and development of other financial instruments from the developed world. India is 145th in the world in the release of 1.25t CO_2 per annum[20].

[20] World Energy Council (2010) , 2010 Survey of Energy Resources, London4

3. Prognosis and Smart Grid Introduction

India's electric power framework, known as *the grid*, has served the country for a long time is finally reaching it total capacity. Grids capabilities in the present developing socio-economic scenario are not to be taken for granted. The current electric power grid was developed over 100 years ago, when the sole purpose of the power system was to transfer electricity from the generating stations to the consumer for lighting purposes. Primarily coal was used to generate power and production plants were built for local communities.

With the advancement of technology and industry, the needs of the people grew, requiring the generation plants to grow to expand and supply the increasing demand for electricity. But, with the increasing reach of the electrical grid, optimization and control could not be satisfied by merely increasing the number of generating sites.[21]

Today, the electrical power system delivers energy to agriculture, industry, commercial and residential consumers, utilities struggle to keep up with the ever increasing demand for electricity. Systematically, the hazards associated with relying on an overburdened grid grow in size, scope and complexity with every passing day. The limited one-way interaction makes it difficult for the grid to respond to the changing and increasing energy demands of the 21st century. To its credit, the Ministry of Power's *Vision 2027* program focuses on transforming and upgrading the Indian power infrastructure into a secure, adaptive, sustainable and digitally enabled ecosystem that will provide reliable energy with the active participation of all stakeholders.[22] The following graphic illustrates the difference between traditional power grid and a smart grid.

[21] Rahul Tongia, "What the smart Grid Means and Doesn't Mean for India," *IEEE Smart Grid*, July, 2011
[22] *Virendra Kumar Sharmara, Electricity India, Vision 2027, 2004*

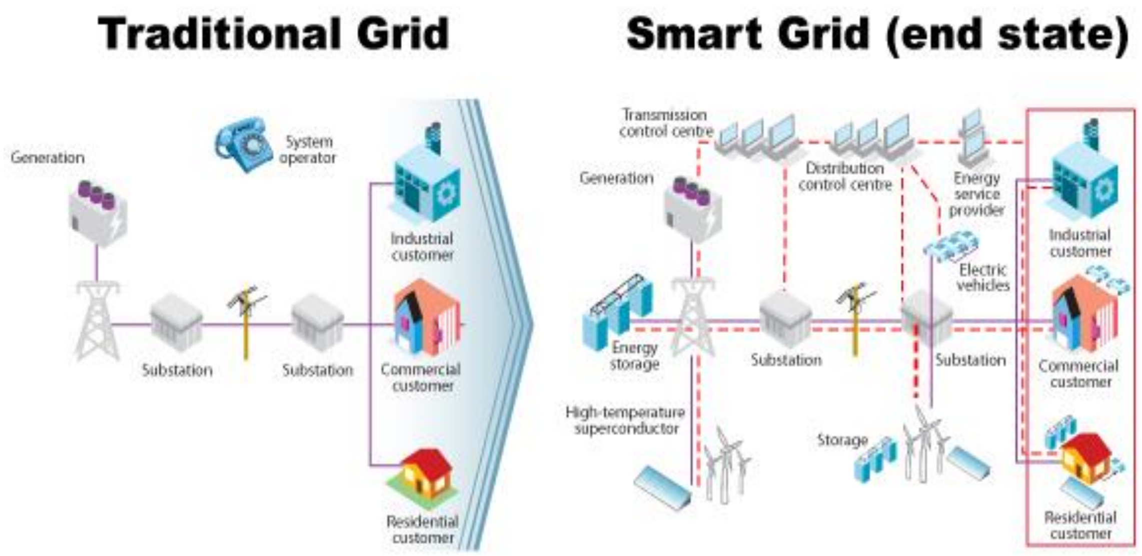

Figure 8: Evolution of Traditional Grid to Smart Grid
Source: International Energy Agency, 2013

A smart grid makes the transformation from a traditional one way (generation to consumer) grid to a highly connected and 2 way grid possible by applying the technologies and various associated operating principles to the grid. More importantly, it enables the industry's best ideas for grid modernization to achieve their full potential.[23]

The smart grid provides two way flow by which electricity and information can be exchanged between a utility and its customers. It is new network for communications, its control, computers, automation and introduction of new technologies and tools to work harmoniously, thus making the grid more efficient, more reliable, more secure and greener. The smart grid enables newer generation technologies to be integrated, such as wind and solar energy production. It will soon upgrade and replace the aging electrical infrastructure and ensure optimized and green electricityproduction.

India's power system needs are not necessarily the same as those in the advanced and industrialized countries. The same also goes for the most important power system constraints. Generally, not all smart grid technologies are equally relevant worldwide. In India, themost useful technologies would be those that help constrain peak demand and peak load growth at reasonable cost while cutting losses. As yet,there is not any internationally unified definition of a smart grid.[24]

[23]U.S. Department of Energy, *The Smart Grid: An Introduction*, 2008
[24] European Regulators Group for Electricity and Gas, *Position Paper on Smart Grids: An EREG Conclusions*, December 10, 2009

4. Key Drivers of India's Smart Grid

India is at a preleminary stage of its smart grid deployments with many technologies, such as advanced metering and remote sensing of renewable generation, still at a very crucial juncture. Its deployment is being reviewed andtested at certain pilots sites around the country. Such technologies are undergoing various trials and advanced testing before they could be deployed around the country. The coherence of many factors would drive India's adoption of smart grids,such as reducing all technical and commercial losses to resolve the ongoing supply/demand gap. India is upgrading its infrastructure to a more advanced electricity supply solution that has sustainable, low carbon, high growth economic development goals.Certain factors will drive the adoption of India's smart grid. These are described in the following pages.

4.1. Supply Shortfalls and Continuing Increases in Demand

Demand, especially the daytime peak demand of electricity, is continuously outpacing the India's power supply. With the rapid growth of the economy and a prosperous industrial sector with more households buying more electrical appliances, there is a continuing increase in the demand of electricity. Industries also require a consistently increasing power supply to match the needs of their growth. Officially, India is falling short by around 12% for energy demand with a peak energy demand shortfall of 16%.

Addressing the needs of the growing economy and satisfying the needs of a developing society are the primary drivers for the adoption of smart grid technologies in India. With the country's high growth economy, the demand for electricity is forecasted to grow by about 10% per year as long as the gap between supply and demand is not closed.

Region	Energy				Peak			
	Requirement	Availability	Surplus/Deficit		Requirement	Availability	Surplus/Deficit	
	MU	MU	MU	%	MW	MW	MW	%
Northern	276,121	258,382	-17,739	-6.4	40248	37117	-3131	-7.8
Western	290,421	257,403	-33,018	-11.4	42,352	36,509	-5,843	-13.8
Southern	260,302	237,480	-22,822	8.8	37,599	32,188	-5,411	-14.4
Eastern	99,344	94,657	-4,687	-4.7	14707	13,999	-7,08	-4.8
N. Eastern	11011	9,964	-1,047	-9.5	1,920	1,782	-138	-7.2

Figure 9: Supply and Demand by Region – 2012
Source: Author, with data from Central energy Alliance,*CEA AnnualReports*,2012

4.2. Distributed Energy Resources (DERs) and Loss Reduction

A smart grid can make a substantial contribution towards the reduction of losses by allowing integration of DERs that enables localized generation, thus reducing transmission and equipment losses. A smart grid allows system operators to integrate local renewable energy sources, which can supply energy needs to the local community, and supply power to the grid. This offers a launch pad for the utilization of local natural resources for the benefit of the power supply leading to cost reduction. Both distributed generation and distributed energy storage are encompassed in distributed resources. A distributed utility uses both distributed resources, as well as load management, to accomplish its goal. In addition, several compact DG technologies are fast becoming economically feasible.

Integration of DG into an existing structure results in several benefits. These benefits include

- Reduced line losses
- Reduced environmental impact
- Increased energy efficiency; transmission and distribution congestion management
- Improved harmonic voltage support
- Increased investment fluidity to upgrade existing generation, transmission, and distribution systems
- Increased savings to the utility and the consumer.

The various benefits are not only limited to the utility. Consumers also benefit from distributed generation in terms of obtaining a better quality of supply at reduced costs.[25]

4.3. Managing the Human Element in System Operations

Prediction of system reliability is based entirely on equipment failures and neglects the human component of the man-machine interface. Such tools do not consider the various human errors that can creep into the system. Human characteristics and other dynamic interactive factors affect the reliability and safety of industrial and commercial power systems. The consequences of human errors are diverse and can range from damaging

[25] P. Chiradeja, *Benefits of Distributed Generation: A One Loss Reduction Analysis,* Transmission and Distribution Conference, 2005

equipment or property; causing injuries, sometimes fatal to workers; or disrupting scheduled system operations, all of which have a significant cost to society.[26]

Indian contracts for outsourcing are relatively inexpensive; so, labor saving is not a prime driver for the smart grids in India. Advanced metering infrastructure would definitely be pivotal in reducing recording and other errors such as *shade tree* readings or even deliberate errors that lead to significant losses. AMI can also bring about a better User Interface, where the user can participate in an interactive way. This involvement may lead to a better monitoring of energy usage, which can reduce costs and better monitor the peak time usage.

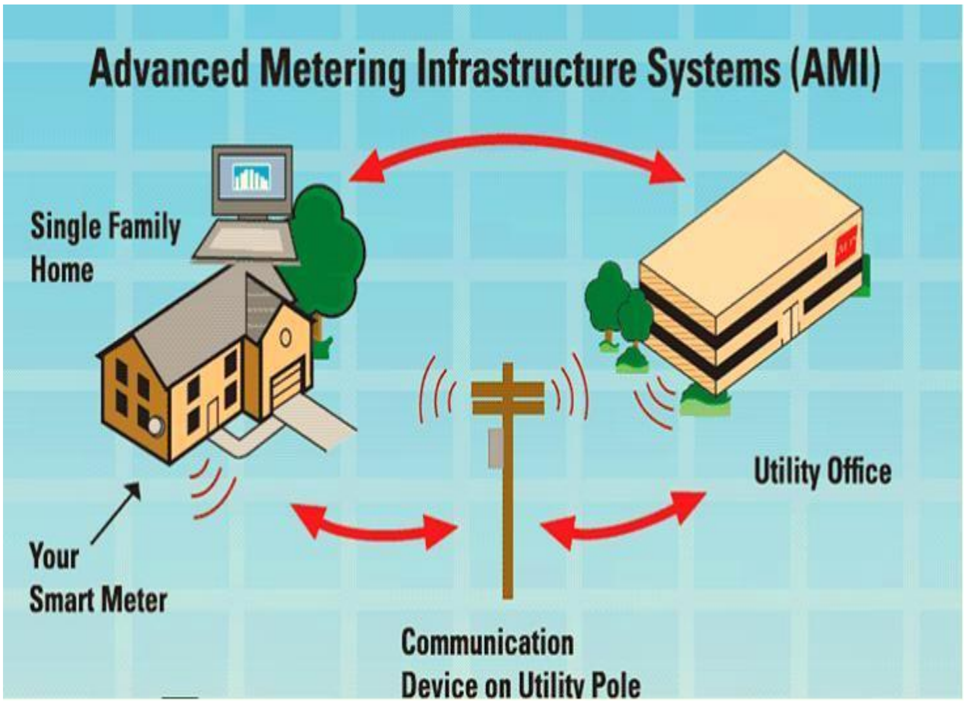

Figure 10: Advanced Metering Infrastructure
Source:Public Service Company of Oklahoma, *How Advanced Digital Meters Work*, 2012

[26] D.O. Koval, "Human Element Factors Affecting Reliability and Safety," *IEEE Transactions on Industry Applications*, 1998

4.4 Peak Load Management

The smart grid is driven by need and has a different priority for each country, In western countries; it is driven by labor cost, renewable energy and electric vehicles to reduce the carbon dioxide footprint. For India, managing peak load is the key driver for smart grid deployment. Energy cannot be stored in large scale and has to be increased to take care of increased peak demand or the demand reduced significantly by load shedding.

In the west, supply is increased through *peaker* plants, which operate during time of high electricity demand. These plants operate at a high cost, and are used a few hours each day and usually the most expensive power option. If India follows the western model, the price of electricity will rise by 35%, a very expensive proposition for a developing country like India[27].

India's supply and demand gap is wide enough to persist for many years. A smart grid would allow more "perceptive" load control, directly or indirectly by controlling the household demand, switching off the non-critical appliances to reduce the power usage to prevent peak time deficit, thus preventing the outages and load shedding. This can be done by either communicating to the consumer about the economic pricing incentives in a dynamic manner or by having a real time protocol to allow utilities have a direct control over the devices and setting less important tasks for a time when electricity is cheap and hence acting as a buffer for fluctuations in the peak energy supply.

By providing incentives related to the operation of appliances, the consumer can control the amount of electricity they are using in a better way. Such measures can, to an important extent, mitigate the supply and demand gap. For example, by introducing the right price signals and smart appliances/devices, a smarter grid can reduce the need for infrastructure while keeping electricity affordable and reliable. During peak demand periods, the intense stress on the power system threatens its feasibility and reliability and raises the possibility of brownouts and blackouts.[28]

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[27]Smart Grid for India, *Tackling Smart GridChallenges under India Context*, July 28, 2011
[28]The U.S. Department of Energy, *The Smart Grid: An Introduction*, 2008

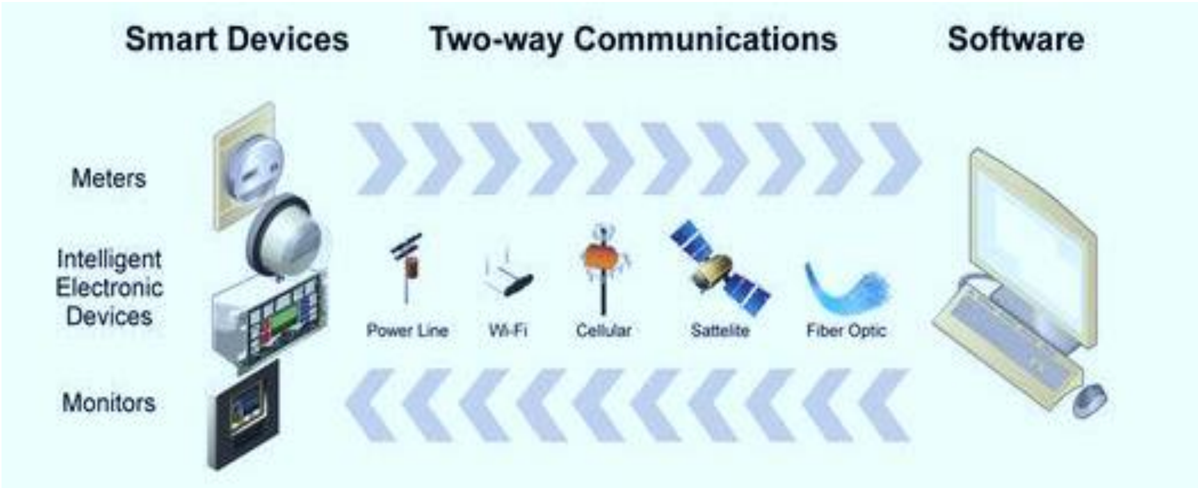

Figure 11:Smart Grids Provide Two-way Communication
Source: Smart Grid News, *Communication Protocols of Smart Grids*, 2012

4.5. Renewable Energy

Indian renewable energy industry growth has been increasing at a steep rate in the last two decades. Even though a significant portion of the contribution of RES to the power generated is from the hydro power, with almost 20 % still being obtained from this sector, it has not progressed much on utilizing other renewable sources of energy. Recently, the Indian power sector has broadened into other renewable energy sources. Wind power is the most prominent type of renewable energy so far.

Since 2010, significant activities in a few other renewable energy sectors, such as solar, have also been observed. With the inception of the National Solar Mission in 2010 and the successful operation of the initial stages of this project, the Indian government has shown its eagerness to harness the significant potential that solar energy presents for the country. India can also utilize other renewable energy sources, such as small hydro and biomass plants and there is a huge potential for it.

Some alternative energies have shown that show little activity recently, like wave, tidal and geothermal energy, yet have the potential for significant growth in future. As many of the renewable energy sectors are in the early stages of development, there is significant need and eagerness from Indian businesses for technology transfer from companies and countries on the cutting edge of clean technology.

To successfully integrate clean power from renewable sources, such as wind and solar energy, utilities will need a smart grid to manage problems caused by intermittency (the sun and wind only produce during certain times of the day) and the power distribution system. Driven by the need to protect the environment and the desire to tap in all the possible sources of power, this move would also be a primary driver for the smart grid.[29]

[29] Energy Alternative India, *Indian Renewable Energy Guide: Highlights of Indian Renewable Energy Industry for Foreign Investors*, November 30,2001

4.6. Technological Leapfrogging

A chance to leapfrog into a new future of electricity is perhaps the most intriguing driver for India to address it regulations and policies for making the power grid *smart*. The *smart* in a smart grid is information and communication technology, -an area of unique capability in India. Smart grid deployment involves not only addressing domestic energy challenges; but, also executing its policy to become a superpower as it involves technology standardization. India has dedicated research centres and a Smart Grid Task Force working on the deployment of smart grids in some pilot cities, and then upgrading to a pan-national scale. Technological standardization is also seen as a critical step in moving up the value chain and is playing a major role in global technology markets.[30]

[30]Hans de Keulenere,"Smart Grid an Introduction*," Scribd.com*, 2008

5. Smart Grid Philosophy

We are at the crossroads of a great transformation in the way electricity was perceived traditionally. A revolutionary makeover from a central, utility controlled network to a grid that is less central and more interactive with the consumers is coming. The upgrade to a smart grid promises to widely affect the industry's entire business model that consisted of vertically integrated entities and its relationship with all stakeholders in the service chain affecting and involving utilities: Energy service providers regulators, technology and control dealers, and users will all be impacted.

A smart grid makes this upgrade possible by bringing together the various concepts, information technology and other technologies in a common spectrum enabling an interconnection between the utility and the electric grid. Simply put, a smart grid is the integration of information and communication technology into the electric transmission and distribution networks delivering electricity to consumers using a two way digital technology to enable a more efficient management of consumers' use of electricity. The technology makes more efficient use of the grid to identify and correct supply and demand imbalances instantaneously and detect faults in a *self-healing* process that improves service quality, enhances reliability, and reduces costs.[31]

[31]U.S. AID, *Smart Grid Vision for India's Power Sector*, 2010

5. Smart Grid Technology

With the restructuring and broadening of power sector infrastructure;introduction of new regulations; open sourcing; and increasing the share of renewable energy in energy transactions, it is very important to design and operate the Indian grid as a centralized national smart grid. The combined total capacity of the centralized grid is estimated to be in the range of 300 GW, consisting of about 40 –50 GW of renewable energy in the next few years. Integrating renewable energy, with wind as the main energy source would lead to an increase in the complexity of monitoring and control of such a large grid, because wind is intermittent rather than constant. Application of advanced synchrophasor measurement technology, rather than the traditional electric meter, may to some extent provide the needed interface for the wide area monitoring of such a widespread grid.

The information and communication technology in the Smart Grids enables it to make envisioned benefits a reality. These technologies encompass a wide range of operations, such as detecting and identifying faults and a quick response to power outages; providing consumers with near real-time information on the amount and cost of the power they use; improving the security of the system; and linking all elements of the grid to enable better decision making on resource use. With continual up-gradation and modifications these technologies will produce more and better quality data that will give the utilities more flexibility and new opportunities to improve their analysis in areas, such as customer load patterns and tariffs, and thus offer better services to their customers.

Several of the initiatives that have already been introduced into the system include Supervisory Control and Data Acquisition (SCADA), Distribution Management System (DMS), Distribution Automation System (DA), Energy management System (EMS), Automated Meter Reading (AMR), Outage Management System (OMS), Enterprise Resource Planning (ERP) and Geographical Information System (GIS). Installing the latest technology and systems in the power system promises a decrease in loss levels and a subsequent increase in the reliability of the network.

Successful implementation of the smart grid would also require introduction of a Wide Area Measurement System (WAMS) based technology for achieving grid performance. Installation of Phasor Measurement Units (PMU’s) at the utilities is a prerequisite for WAMS.

The existing interface involving SCADA/EMS based grid operation has the potential to provide the steady state view of the power grid.[32] Dynamic real time measurements and visualization of the power infrastructure, which are useful for an optimal working of the grid as well as introducing corrective measure, can be realized only with the introduction of PMU based technology.

Smart grid deployment is a journey rather than a onetime event. Taking a cue from this universally accepted paradigm, India has to observe grass roots revolutionary changes in its power infrastructure relating to this requirement. What a smart grid can deliver is marginally driven by specific need. The western countries care more about labor costs, renewable and electric vehicles (EV). In India, however, load management, especially peak load, is a major and primary driver. Therefore, more investments are being made related to superior load management.[33]

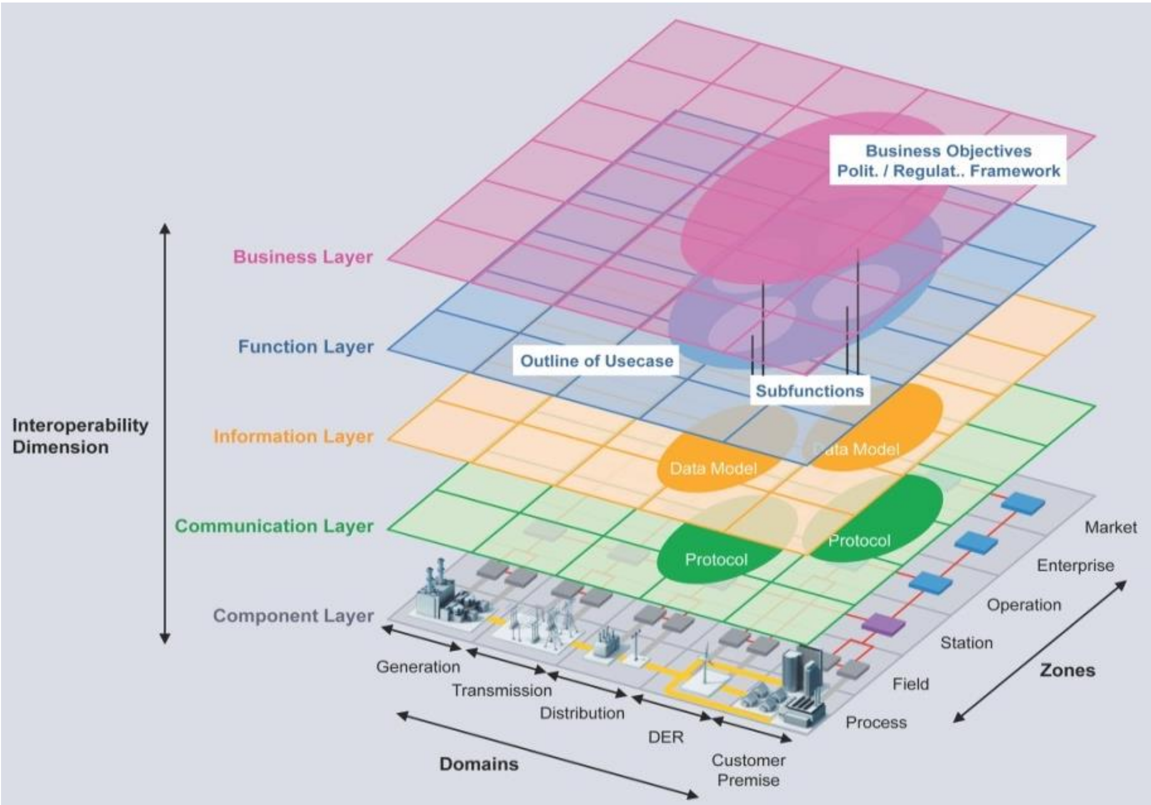

Figure 12: Various Layers of Smart Grid Infra-Structure
Source: Data Center Dynamics**,** *Multilayer Infrastructure of Smart Grids*

[32] Central Electricity Authority, *National Electricity Plan Volume III, Transmission*, 2007
[33] Business Standard, *Rahul Tongia: A Smart Solution to Power Shortage*, July 5, 2011

6.1 Network Operations

The main difference between the traditional power infrastructure and the smart grid is in the distribution area at the customer/network interfaces. However, in the areas of generation and transmission, the role the system operators play becomes quite complicated and critical as it must ensure an efficient, reliable system, as well as the integration of other sources of energy. An ancillary support system will be required with sophisticated and technologically advanced energy management systems to oversee and manage all available energy resources and transmission parameters in every part of the system under a broad variety of operating conditions and possible future scenarios.

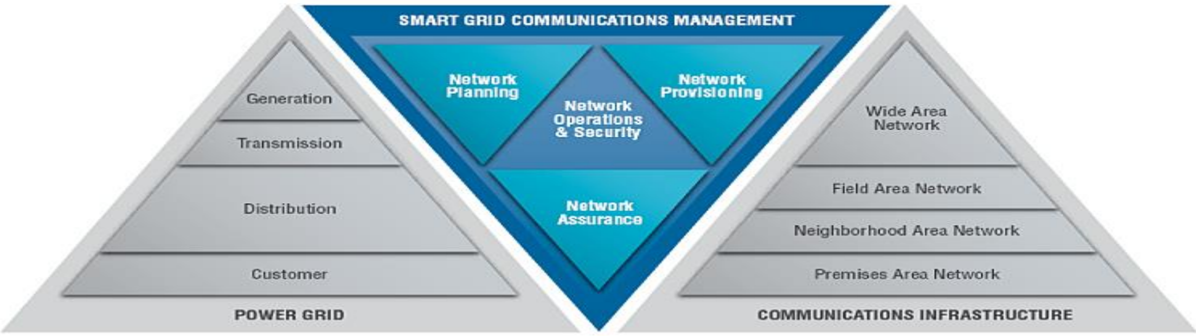

Figure 13: **Smart Grid Management**
Source: Jason Taylor, "Bulk System Reliability Assessment and the Smart Grid," *Electric Energy T&D Magazine*, January/February. 2013

6.2 Automated Metering Infra-structure Through Smart Meters

Smart metering will be a very important focus area for distibuting utilties. The main demand driver for this upgrade is the energy accounting backbone created under the Restructured Accelerated Power Development and Reforms Program (RAPDRP) By introducing a smart grid infra-structure, the industry can expect a rise in the demand for metering technologies, such as Automated Meter Reading (AMR) and prepaid metering. Smart meters will be installed at the customers' premises to enable a bi-directional communication between the meters and the uility meter data management system. This two-way communication will enable the utility company to measurethe demand profile of the customers in near real time. The real time data also allows the customers to monitor and control their consumption. Implementation of the tariff of day (TOD) metering encourages customers to use energy wisely.Smart metering also enables the remote connect and/or disconnect of unauthorized customers, thus introducing a transparent mechanism and ultimate control.

A Meter Data Management System (MDMS) is required to interface the SAP-ISU billing system. This system obtains the meter data from the smart meters and is used for various purposes like billing, planning and load forecasting.Implementation of AMI in India presents a few challenges :

- Smart meters are a relatively new concept in the Indian infrastructure and there are a few technical challenges with respect to their customization for local conditions, like security protocals and, at the same time, there are no standards yet formulated for smart meters.
- Suppliers are not yet prepared to bring smart meters in the Indian market as the technical regulations are not yet coordinated with the utilities and the suppliers and also because of a lack of skilled personnel.
- Worldwide, such projects have been implemented using GPRS and PLC. The PLC implementation requires a very high quality of power cable framework, which is a relatively new concept for the Indian conditions. GPRS requires enhanced provisioning and a superior service quality from the service providers.

AMI facilitates the collection of data that is 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.[34].

6.3 Home Area Network

Even though the home area network (HAN) is not a primary driver for implementing the smart grid in India, it provides a definite edge to the idea of complete overhaul of the traditional power system to a grid of the future. A home area network provides the platform for smart devices in a home to communicate directly with the grid and enables the consumers to manage their electricity usage by measuring a home's electricity consumption more frequently through a smart meter. With home area networks, utilities can provide their customers with much better information to manage their electricity bills. The HAN connects thermostats, refrigerators and other electrical devices to an energy management system. Smart appliances and devices will adjust their run schedule to reduce electricity demand on the grid at critical times and lower consumer's energy bills.[35]

[34] USAID, *The Smart Gird Vision for India's Power Structure,* March, 2010
[35] Navigant Research, *Home Area Networks*, 2013

6.3.1. Wiring

The basic standard for wiring is the Ethernet. Most of the homes in India lack Ethernet running in their structures. The cost and effort of retrofitting a home or a building with new wires is appalling. Speed, reliability and security are often the reasons cited for installing new wires. The demands for most HAN smart grid applications are between 10kbps and 500 kbps, thus speed is not seen as a working driver for installing new wires; but, reliability and security are plausible reasons.

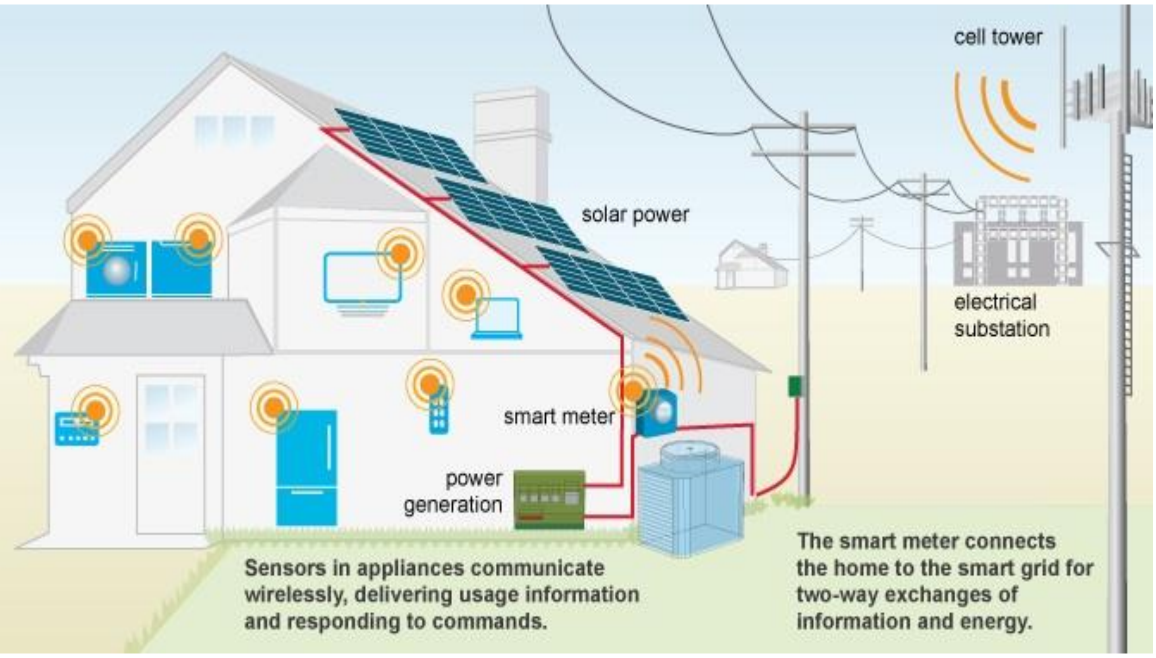

Figure 14: Home Area Network Visualization

Source:Don Brown, "Tech View: Laying the Groundwork for the Coming Smart Grid,"*AT&T Home Area Networks*, February 16, 2010

6.3.2. IEEE 802.3 Ethernet

IEEE 802.3, or Ethernet as it is more commonly known, is used widely for establishing local networks in offices and homes. Systems communicating over Ethernet divide a stream of data into shorter pieces called frames. Each frame contains source and destination address and error checking data so that damaged data can be detected and re-transmitted. Ethernet provides service up to and including the data link layer, which handles data transmission and error correction.[36]

[36]Robert Metcalfe, The History of Ethernet, *NetEvents.tv*, 2006.

6.3.3. Power Line Communication (HomePlug)

HomePlug GREEN PHY (GP) is a low power, robust data communications technology that provides data rates of 4-10 Mbps over a building's existing electrical wiring. To define the media access control (MAC) and physical layer (PHY) for power line communications in Home Area Networks (HAN) the GP specification is used and has been recently adopted as a profile of the IEEE standard 1901 for broadband over power line networks.

6.4. Fibre Optic-based Communication

Reliable voice and data communication is a critical aspect of smart grid deployment. The need for a capable communication system has been substantiated with the introduction of dedicated protection schemes, wide area measurement technology, SCADA system and remote operation. Obtaining real time data of various utilities is a prerequisite for the successful installation and operation of a smart grid. At present, three basic modes of communication are used in power system operation:

- PLCC
- Microwave
- Fibre optic

PLCC is an integral part of power systems and is used for protection of the power system and providing speech communication in some instances. All of the requirements needed for a capable communication system are met by Optical Fibre Communication (OFC).

6.5. FSAS for Integration of Renewable Generation

Integration of renewable energy in the grid is one of the most important areas for infrastructure upgrades. The installed generation capacity of renewable generators is expected to grow rapidly in the near future. India has set ambitious plans to achieve high generation targets in the next ten years. Considering the high variability and unpredictability of generation from renewable energy sources, the power generated can be safely absorbed in the grid if the frequency in the grid is maintained in an appropriate range.

Frequency Support Ancillary Service (FSAS) can be used to complement the daily changes in the renewable generation. In the future, based on the renewable forecast for the next day, a dispatch schedule for FSAS can be prepared such that the variation in the renewable energy generation can be absorbed easily. Thus, FSAS can be used as mechanism to facilitate renewable energy integration by reducing the impact of variable generation.

Taking into account the restrained distress of global warming, the importance of distributed generation (DG) from cleaner sources, such as wind and solar, is critical. The Ministry of New and Renewable Energy Sources has proposed that to integrate these renewable energy sources at grid operator level will require a superior energy management system and is to be converged at the grid operator level. The smart grids superior capability of introducing new sources of energy to the grid clearly signifies that more DG can be integrated into the network. Solar and wind energy are crucial and primary factors of a cleaner and greener energy future.[37].

[37]Stanford University, Renewable energy and Smart Grids: A Case Study, 2008

7. India's Renewable Energy Scenario

7.1. Integration of Renewable Energy as a Primary Driver

Every aspect of India's energy resource capacity is being tested by the significant and sustained economic growth as well as by the country's ambitions to of becoming a super power. However, the ubiquitous supply and demand gap requires the country's policy makers to increase energy supplies.[38] Various energy equations have been analysed in the study, after which the need for integration of renewable energy into available energy sources became evident. Existing energy resources include:

- **Oil:** Total oil imports from the Gulf and the Pacific account to nearly 80% of the total oil transactions in the country.[39].Serious issues with energy security are anticipated with the threat of further increase in the cost per barrel of oil. Moreover, political instability poses a constant shadow on the future of oil imports to the country.
- **Coal:** National coal companies are failing to meet the coal demanded by the robust Indian economy. Imported coal, which is of better quality and low soot and ash content and hence better efficiency, is preferred over the local extract. While dependence on imported coal is on the rise, supply from the local quarries is slowing decreasing due to production and analytical constraints.[40]
- **Gas:** Domestic gas resources are limited. Moreover, regassified-liquid natural gas is costly and not a feasible option for power generation. A significant augmentation of gas reserves and production in the recent years has played a part in mitigating the power needs of the country to a small extent.
- **Hydel** (Hydro-power Electricity)**:**
  India is rich in hydel potential; but, harnessing its hydel potential to meet the requirements is a challenging task. Hydel power projects play a huge part in altering river ecosystems and disturbing the environment and are being challenged by the environmentalists and local populations. Moreover, land acquisition and obtaining clearances from the authorities are other issues impeding the immediate commissioning of new hydel power projects.[41]

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[38]Ernst & Young,*Renewable Energy Country Attractiveness Indices*, August 2012, Issue 34
[39]Ministry of Petroleum Government of India, *Annual Report on Petroleum Transactions*, 2011
[40]Ministry of Coal, Government of India 2012
[41]*Hydel Power Projects in India, A Report*, 2013

Robust economic growth, urbanization, prospering industrial areas, and the rise in per capita consumption are the key factors resulting in a substantial increase in the demand for electricity in India. Anticipated energy and peaking shortages in the country are estimated to be 10.3% and 12.9% respectively in 2011 and 2012.[42] Energy access is going to remain the biggest challenge in the foreseeable future.

The following figure shows illustratively the variation of different renewable energies based on the attractive index and the potential of their deployment in India.

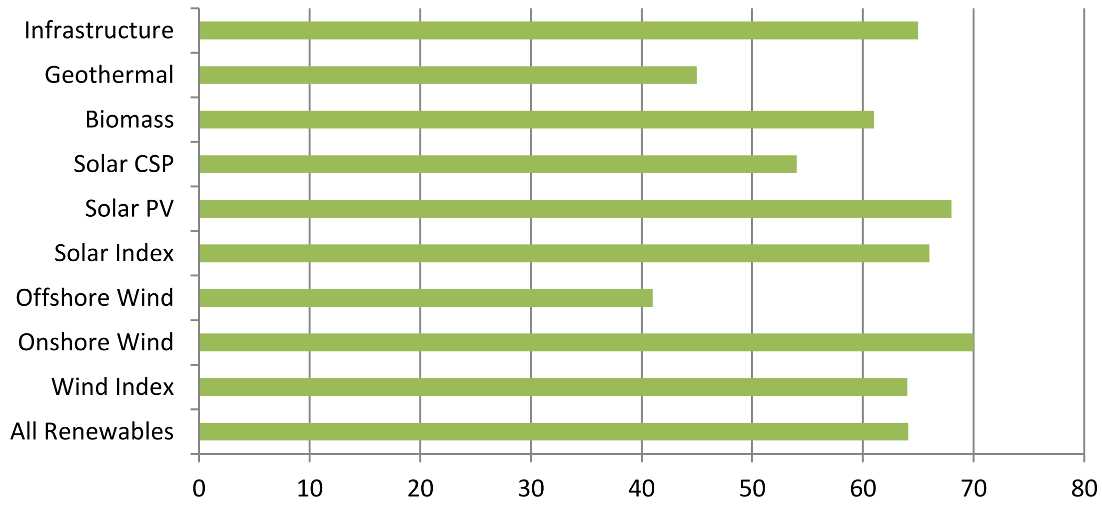

Figure 15: India Renewable Index in August 2012
Source: Author, with from*Renewable Energy Country Attractiveness Indices*, August 2012 Issue 34

7.2. Role of Renewable Energy

The notion of renewable energy as an *alternate* form of energy is no longer a valid argument. Renewable energy is increasingly becoming a solution, to some extent, for the nation's large energy demands. In all renewable energy fronts, India is currently ranked 5th in the world. With a total capacity from renewable sources being about 30 GW, mostly obtained through wind (18.3GW), small hydro (3.4GW), biomass (1.2GW) and solar (1GW).

According to the Ernst and Young's renewable energy attractiveness index, India is among the top five countries worldwide for solar energy development.[43] The main renewable energy sources in India are wind energy, solar energy, biomass and waste energy and small plant hydro energy. Since this paper is dedicated to the study of integration of wind and solar energy systems in to the grid that are the major players of India's renewable energy endeavours only these two have been studied deeply.

[42]Government of India, Ministry of Power, *Load Generation Balance Report*, 2012 – 2013
[43]Ernst & Young: Renewable energy country attractiveness indices August 2012 Issue 34

7.3 Wind Energy in India

The wind power programin India was initiated in 1983-84 with the goal of speeding up the commercialization of wind power in the country and it has progressed rapidly in the last few years. The relatively short period required for the installation of wind turbines and the constant advancements made in the wind turbine technology leading to higher reliability and performance of the turbines has made wind power the preferred choice for energy capacity additions in the country. The latest estimates indicate the total potential of wind energy in the country to be at 45,000 MW.[44] The wind sector of the country has observed significant investments, catalysed by the highly indicative wind potential;the availability of wind farm equipment at subsidized rates; and supportive government policies. Presently, India, with 15,700 MW of wind energy, is at the fifth position with China (44,733 MW), the US (40,180 MW), Germany (27,215 MW) and Spain (20,676 MW) leading in development.[45] Wind power accounts for about 8% of India's total installed power capacity.

Historically, wind energy has always met and many times exceeded the targets such as those set in the 10th (2002-2007) and the 11thFive Year Plan (2007-2012) periods. During the 10th plan period, the target set was at 1,500 MW and actual installations were 5,427 MW. Similarly, in the 11th plan, the revised target was for 9,000 MW and the actual installations reached 10,260 MW.[46]

In 2011, the Centre for Wind Energy Technology, a state run organization, assessed India's wind power potential as 102,778 MW at 80 meter height at 2% land availability. This estimate was significantly higher than earlier estimates of approximate 49,130 MW at 50 metres height, also at 2% land availability. Different research organizations use different models for mapping wind resources. The Lawrence Berkeley National Laboratory, in a study assuming a turbine density of 9 MW/square kilometers, concluded the total wind potential in India, with a minimum capacity factor of 20%, ranges from 2,006 GW at 8 meter hub height to 3121 GW at 120 meter hub height.[47]

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[44] S. P. Sukhatme, "Meeting India's Future Needs of Electricity Through Renewable Energy Sources, *Current Science*, September, 2011.

[45] Ministry of New and Renewable Energy*, India's Renewable Energy Sector -Potential and Investment Opportunities*, Government of India, 2010

[46] Ministry of New and Renewable Energy, *A Report on the Wind Potential in India,* Government of India, May, 2012.

[47] Julie Chao, *Berkeley Lab Shows Significantly Higher Potential for Wind Energy in India Than Previously Estimated*, Lawrence Berkeley National Laboratory, March, 2012

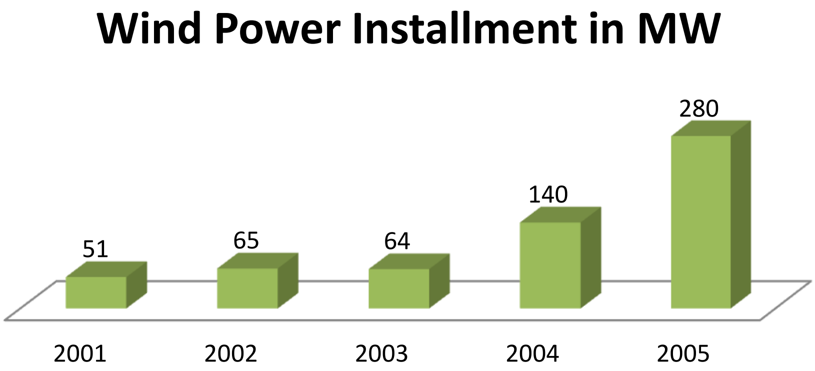

Figure 16: **Wind Power Installment World Ranking (est. August 2012(**
Source: Author, with from *Renewable Energy Country Attractiveness Indices,* August 2012 Issue 34

7.4 State wide Wind Energy Installations

The states of Karnataka, Tamil Nadu, Maharashtra and Gujarat have always taken the lead in terms of total wind installations. Meanwhile the states of Rajasthan, Madhya Pradesh and Kerala are rapidly catching up. By the end of the 11thPlan Period in March, 2012, the total installed capacity had reached a total of 17,351 MW.[48]More than 95% of the nation's wind energy is concentrated in just five states in southern and western states of India – Tamil Nadu, Andhra Pradesh, Karnataka, Maharashtra and Gujarat.[49]Rajasthan is another emerging state with strong prospects in wind energy development.

7.5 Solar Energy in India

The Indian subcontinent is blessed with a rich potential of solar energy resource. The average intensity of solar radiation in India is on the order of 20 MW/square kilometre. India has a geographical area of 3.287 million square km, and the total solar energy potential may be as high as 657.4 million MW[50] though only 12.5 % of the land area which is about 0.413 million square kilometers can be installed with solar energy platforms because of logistical and theoretical reasons. Even if 10% of the area is used, the available solar energy can amount to nearly 8 million MW per year, which is purely for the basis of analysis because the conversion efficiency of solar energy is low and the energy actually available will be lower than the estimated values.

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[48]International Energy Agency, *India Wind Energy Report*, November, 2012
[49]Ishan Purohit and Pallav Purohit, "Wind energy in India: Status and future prospects," *Journal of Renewable and Sustainable Energy*, 2009
[50]India Emergy Portal, *Solar Thermal*, The Energy and Resources Institute (TERI), 2012

Until recently, solar energy has remained dormant in the Indian energy scenario. The total on-grid capacity has reached 941.48 MW while as the total potential of solar power is 50,000 MW.[51]India's solar energy development is increasing based on the growing supply and demand- gap; the continual increase in non-renewable fuel prices; the *National Solar Mission*; various local initiatives; renewable energy allocations including the solar energy allocation, as well as advancements in cheap and highly practical technologies. India is on track to become a solar energy hub based on its vast solar potential.

The Indian gross domestic product is increasing at the rate of 8% and, with this, the country's supply and demand gap is only widening, Solar energy, which has not yet been tapped anywhere near its optimal potential in the country, actually leads the list of possible renewable sources in the country followed by wind energy and can definitely contribute to and assist the growing Indian economy by reducing the supply demand gap.

The status of India' solar energy industry may be summarized so follows:

- Most parts of the country, consisting of the central and the western regions, have 300 – 330 sunny days in a year. This has the potential to generation 5000 trillion kWh per year, which is higher than India's total energy consumption in a year.
- The average extent of solar radiation stands at a prosperous 4-7 kWh per square meter per day.
- Nearly 66 MW of average capacity is already installed in various capacities and applications consisting of nearly a million industrial photovoltaic systems of which solar lanterns, home lighting, street lighting systems and solar energy-based water pumps lead the list.
- The Indian Ministry overseeing the solar program has estimated a potential of nearly 20 MW/sq km.
- An additional 500 MWs have been proposed by the ministry during the first phase of the proposed *Jawaharlal Nehru Solar Mission* due to the solar thermal potential of the country.
- Establishment of research and development centres to come up with cost effective and efficient conversion technologies has already been initiated in the form of the *Solar Energy Centre,* which is dedicated to bringing India's solar mission up to the level of the European and the United States Solar Mission.

[51]Gyan Research and Analytics, *The Potential for Renewable Energy in India*, 2012

7.6. Solar Technologies

At the end of June 2010, India had an installed solar power capacity of 15.2 MW, which was based entirely on solar technologies. Off grid applications consisted of nearly 20% of the total capacity being used.[52]India had set a target of achieving 500 MW of grid connected solar power in the Phase 1 of JNNSM. With Phase 1 in the final stage, large scale PV projects have been targeted in Phase 2.[53] Many projects are being commissioned under state programs such as in Gujarat, Punjab, West Bengal, Rajasthan and Karnataka, many of these are running under the aegis of the JNNSM. The domestic manufacturing industry is observing a growing trend driven by financial incentives and the creation of special economic zones. India's solar market holds a net value of nearly INR 3,500 billion (USD 70 billion). As of June 2010, India's grid connected solar power stood at a marginal 12.28 MW or 0.7% of the total renewable capacity.[54]

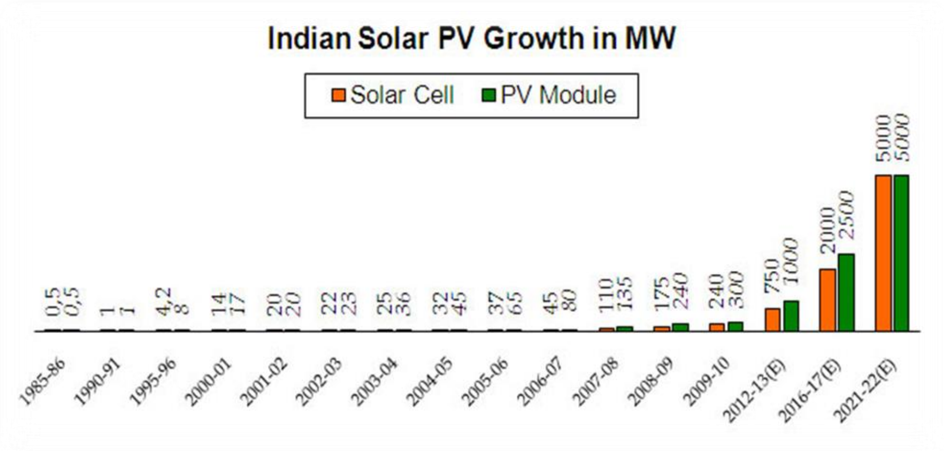

Figure 17: Indian Solar PV Growth in MW
Source:Jaideep Malaviya, "India on a Roll to Become a Solar Energy Super Power," *Energy Portal*, December, 2012

52 Ministry of New and Renewable Energy, *Strategic Plan for New and Renewable Energy* Sector, November, 2011

53 Ministry of New and Renewable Energy, *Jawaharlal Nehru National Solar Mission, Towards Building a Solar India*

54 Manoj K.Solanki, et. al., "Current Indian Perspective for Unconventional Energy Resources and its Exploration," *International Journal of Engineering Research & Technology*, August, 2012

The National Plan for climate change (June 2008) identified the development of solar technological area in India as a *national mission* and consequently the JNNSM was launched in January 2010. JNNSM is one of the many missions currently underway in India. The main aim of this mission is to facilitate the installation of 22,000 MW of on- and off-grid solar power, using both photovoltaic and concentrated solar power technologies by 2022.Vidyut Vyapar Nigam Ltd (NVVN), a power trading arm of the National Thermal Power Corporation (NTPC), has been designated to bring about a smooth execution of the first phase of this mission.[55]

Addressing the shortcomings of the prior schemes through revised and attractive feed-in-tariff and a single window application process for the quick commissioning of new plants and RPOs are the main aims of the JNNSM. The CERC is responsible for introducing tariff revisions every year. Under JNNSM, the NVVN purchases expensive solar power from developers, bundles it with much cheaper power generated from coal and then sells the product to various utilities at a marketable tariff.

7.7. Solar Thermal

Solar thermal power systems, also known as concentrating solar power systems use concentrated solar radiation as a very high temperature energy source to produce electricity using the conventional heat route. Solar thermal technology is appropriate for applications with direct, high intensity solar radiation. Much advanced research is already underway in India to upgrade and develop several types of solar water heating technologies. Forced circulation flat plate collectors and thermo-siphons are very popular. Even though they have already been installed in large commercial establishments, they are now being used in the domestic sector as well. Selectively coated and black paint absorbers on flat plate collectors are being manufactured and marketed in the country.

The complete blueprint for the flat plate collectors consisting of the black chrome selective coating for the absorber has been developed in India. Solar thermal power can occupy a unique position in the India’s energy arsenal. It’s potential to absorb hybrid technologies and, coupled with storage, could pave way for unlocking the base load power,[56] thereby introducing a platform for large scale integration of renewable energy.

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[55] Ministry of New and Renewable Energy, *Jawaharlal Nehru National Solar Mission, Towards Building a Solar India*

[56] Council on Energy, Environment and Water Natural Resources Defense Council, *Concentrated Solar Power Heating up India’s Solar Thermal Market under the National Solar Mission*, September 2012

To make solar thermal sustainable and feasible for the Indian conditions, much needs to be done on the ground level. Solar thermal is much more expensive than photovoltaic technology because it has a long development period. In addition, the solar thermal plants need more water per unit of electricity produced. These factors present some challenges to solar thermal engineers; but, are not enough for the technicians to abandon the idea of solar thermal power generation on the whole; especially when innovation and research can address some of the barriers.

To produce heat from solar radiation, solar collectors are used. There are three basic types of solar collectors used in the systems:

- Parabolic Trough Systems can reach temperatures as high as 400 degree Celsius heating water to steam, which powers turbines to produce electricity.
- Power Trough Systems use a receiver that is placed in such a way so that the reflected and converged rays of the sun are always aimed at it. This system can reach a temperature of nearly a 1000 degree Celsius.
- Parabolic Dish Systems can reach a temperature of 1000 degree Celsius at the receiver and thereby achieve very high efficiency of energy conversion from solar to electrical.

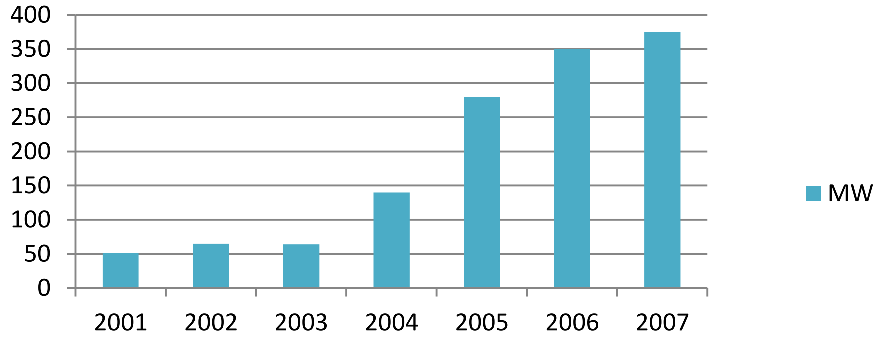

Figure 18: Annually Installed Solar Thermal Capacity
Source: Author, with data obtained from report of the working group on New and Renewable Energy for the 11th five year plan (2007 – 2012)

8. Large-scale Integration of Wind and Solar Energy in the Grid

Integrating wind and solar energy into the grid will allow the grid to be far more reliable, independent, and efficient and self-remedial in case of power system breakdowns and blackouts; allowing clusters of local communities to receive power from the local renewable generation and lead to a grid transition from a non-self-healing infrastructure to a detection and control infrastructure. To a large extent, this integration is directed towards managing peak loads; offering new services to meet user needs at an individual level; and improving asset use. It involves a systems approach to develop and demonstrate the technical, regulatory, economic and other barriers in the use of renewable energy and distributed generation.

The major focus for the integration of renewable energy is on wind and solar in India and while some development is already underway, wind and solar energy both suffer from a technical issue of intermittency; a variability that cannot be controlled; unpredictability to some extent; and location dependency. Grid operators and generation owners face three distinct issues in integrating wind and solar energy into the grid:

- **Variability of resources:** Power plant operators cannot control the wind and solar output because wind speeds and solar intensity vary dramatically, affecting power output. To balance the supply and demand on an instantaneous basis, there needs to be additional energy input as well as peripheral ancillary services, such as voltage and frequency regulation.
- **Unpredictability:** Availability of wind and solar energy is unpredictable to some extent. Electricity is only produced when the wind is blowing and the presence of sunlight is crucial for the working of the PV systems. Systems that use advanced forecasting technologies can manage unpredictability. Availability of reserves that stand ready to supply any power when the renewable sources provide less power than predicted and the presence of dispatchable load to soak up excess power in the case of renewable generation producing more power than had been predicted are parts of technological systems.

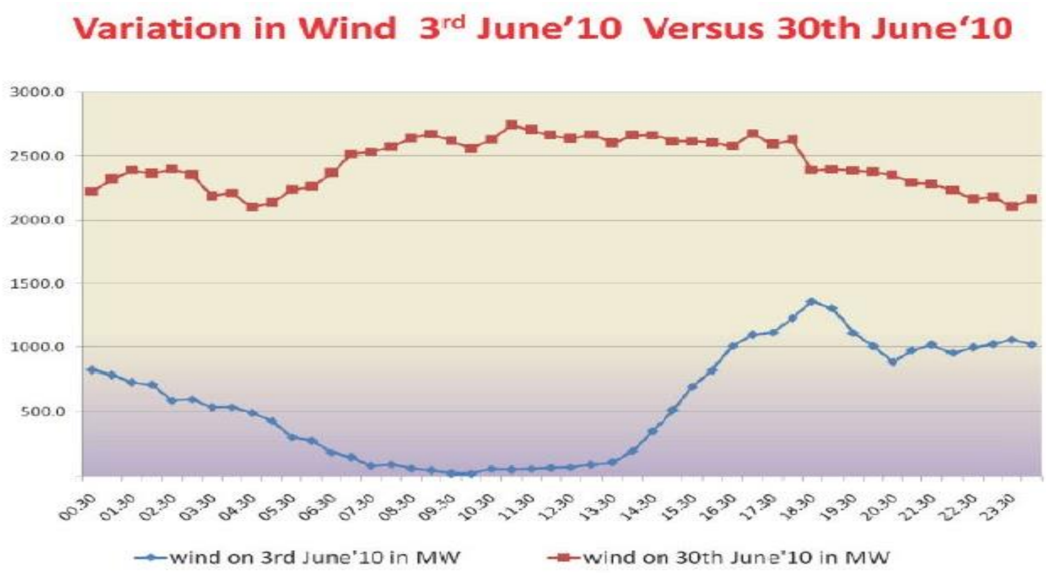

Figure 19: Variability of Wind Pictograph.
Source: *Variability of Wind*, Exit Opinion Polls India Blog

- **Location Dependence:** Quality wind and solar resources that are most feasible for renewable energy generation are unfortunately based only in specific locations and unlike various fossil fuels, such as coal, oil, gas or uranium, transporting them to a generation plant that is grid optimal cannot be done. Generation is co-located with the resource and often the places where the power is ultimately used is far from these locations. Connecting wind and solar energy resources to the grid involves the use of new transmission capacity. Moreover transmission costs are especially high for offshore wind resources, often utilizing technology not used in land based transmission lines.

Since wind and sunlight are a universal phenomenon, spatially and temporally outside the control of human beings, integration of wind and solar energy into the grid consists of managing certain other controllable features affecting other parts of the grid including the generation by conventional fuels. Theoretically, these operations occur along a wide range of time scales, from seconds to years, and may include:

- New power evacuation strategies for additive generation resources,
- Typical management of load, frequency and voltage control using ancillary services,
- Continuous ramping up of the transmission capacity,
- Use of energy storage technologies and processes that bring grid operator dispatch planning in a common sphere with weather monitoring and forecasting.

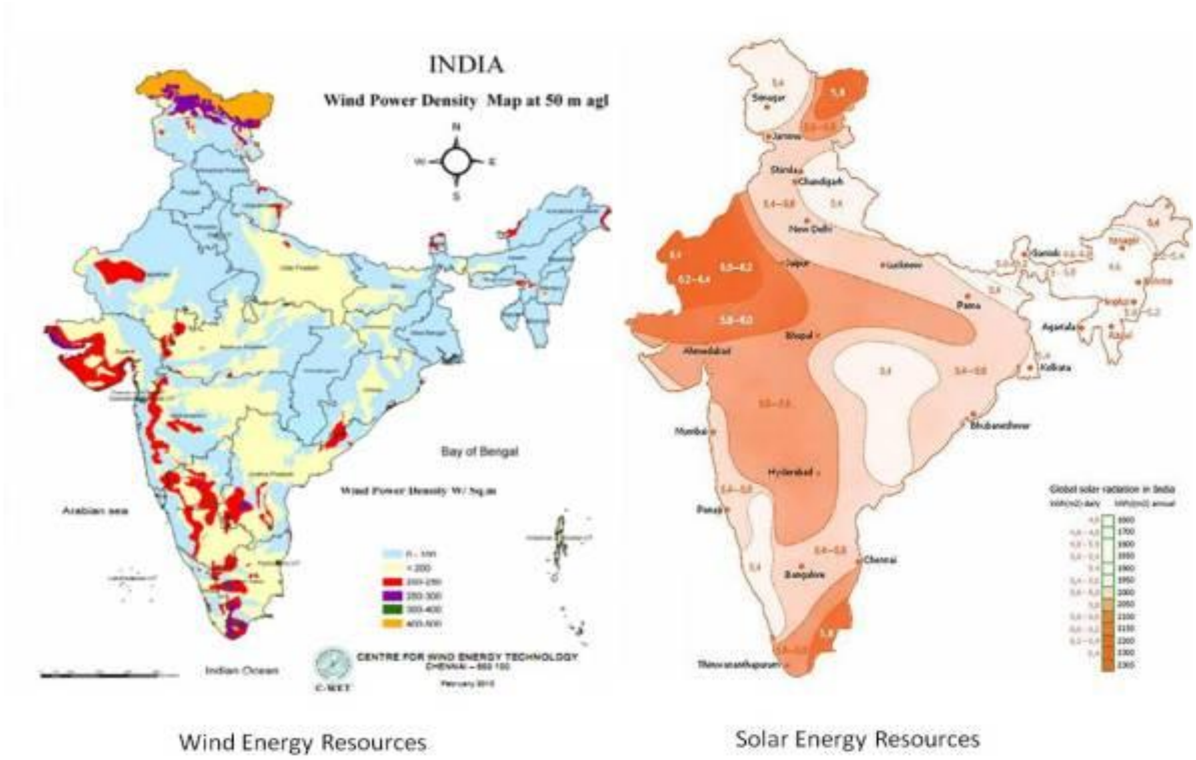

Figure 20: Wind and Solar Resources in India
Source: Agneya Carbon Ventures, *Renewable Energy in India: Past, Present and Future*, November, 2004

8.1. Non Controllable Variability:

In the context of renewable energy resources, variability refers to a non-steady output. It is different from unpredictability, in the sense that even if operators are able to predict wind and solar output perfectly, the output will still tend to be variable and pose challenges to the operator. Grid operators need to deal with fluctuations in voltage and frequency on a second to minute scale that, if left unchecked, can do significant damage to the system, including the equipment attached with it. A possible method of doing that may be to inject power (active or reactive) into the grid having a technical characteristic of balancing the actual to the forecasted power generation which is pivotal to maintaining a steady voltage as well as frequency on the grid. There may be a number of names and descriptions of such ancillary services. An overview of the various services observed consists of:

- **Frequency regulation**: Mainly done by automatic generation control (AGC) signals to renewable generation and occurs on a seconds-to-minutes basis.
- **Spinning reserves**: When a generator goes down or deactivates abruptly in the system, the spinning reserves come into action providing power within 10 minutes.
- **Non-spinning reserves**: Even though observing the same function as the spinning reserves, the non-spinning reserves have a much slower response time.

- **Voltage support**: These generators are used for reactive voltage in order to increase the voltage whenever needed.
- **Black-start capacity**: In case of a cascading black-out, these generators are available to re-start the power system.

In addition, grid operators also need to track the load deviations over the course of the dayand ensure that supply always matches the demand. The load following function becomes more important at peak load times of the day when electricity demand increases significantly.

On the flip-side, grid operators have always maintained the voltage and the frequency, following load shifts and maintaining reserves since the installation of the electrical grid. This is attributed to the varying nature of loads. Moreover, conventional generation also faces problems time and again and the scheduled performance is not obtained. Consume demands, while predictable, have some degree of variability.

Wind and solar generation does not introduce problems that generation operators have never faced. While as at low penetrations, integrating the renewable energy introduces local grid specific and primarily device problems, such as harmonics and sub synchronous resonance; but, at relatively high penetrations, wind and solar generation adds more non-uniformity to the energy system that grid operators may not have faced before, thus introducing the need of ancillary services and energy balance over-all.

8.2. Extensive Unpredictability

Unpredictability or uncertainty differs from variability in that variability of solar and wind generation is present always, as a result of reliance on the ever changing sunlight or wind speed affecting the system on a moment to moment time scale. Unpredictability on the other hand, relates to our innate inability to predict whether the wind and sun will be available for energy generation an hour or a day later. Unit commitment is used by the grid operators to manage majority of energy on the grid and hence the hour to day uncertainty is not as significant. Unit commitment refers to the process of scheduling generation beforehand, generally around a day ahead, with the purpose of meeting the expected load. Consequently when production does not meet the demand, the grid operator employs ancillary services to meet the difference.

Renewable energy generation leads to an increase in the spread between supplied and predicted energy and hence leads to an increased cost, borne ultimately by the consumers. At present, unit commitment is largely deterministic implying that once a generator is run-scheduled, it is expected to run at full capacity. This practice shows in the relative predictability and controllability of traditional generation. Availability of resources is ensured by the operators, generators that hold the supply of energy in order to be ready to balance the supply and demand and hence protect against possible generator and transmission line outages.

A complex problem arises when the process of unit commitment and reserve calculation in order to ensure reliability is calculated based on hypothetical or random data and hence carries uncertainty. Weather predictions by forecasting technologies predicts the wind and solar resources at various time frames more accurately and consequently communicates the predictions to grid operators allowing the operators to schedule and dispatch resources more effectively. Anticipating solar and wind output levels properly allow the operators to modify the generator schedules more dynamically and result in optimal use of all the assets by the grid operator. Advanced unit commitment methods assist the operator in the processes that prepare the system for potentially uncertain outcomes not predicted by forecasting technologies.

8.3. Dependency on Locations:

Long term planning, such as the utilization of new transmission lines, is not addressed to in the day-to-day management of the grid. Even though renewable energy generation plays a very important role in this scenario, it introduces new challenges. Wind and solar energy resources are often present in remote areas far from the areas of actual usage. Being far from load centers, development of sufficient transmission infrastructure is crucial for the integration of renewable energy into the grid.

Transmission planning policies are highly varied and tend to be affected by regional politics. Capacity for energy production may be found in one state, pass through another and finally be utilized in another state. Such disparities in generation capacity, location of transmission capacity and variations in load size between various locations makes the development of renewable energy transmission complex, and more so with respect to cost allocation.

Since new transmission infrastructure that will be established will primarily carry renewable energy generation, variable electricity, certain technical needs come up regarding the technology used for transmission. Distributed energy resources provide for an alternative flexible version of the future grid where energy generation and use is local on a micro-grid thus preventing the transmission losses and capital costs of transmission lines. The electric grid can be conceptualized as a collection of cluster grids spread all over the country and working together in order to significantly reduce drastically the energy transmission needs.

Conclusion

India is a vast country and home to a plethora of cultures, ideas, religions and a conscientious economic sphere. Banking on its aspirations to become a superpower in the near future, India is on track to increasing its economic pace. The huge growth in the economy is putting an acute stress on the energy sector. Even with vast resources of certain conventional fuels, such as coal, the abrupt shift from a producer controlled to a vertical utility controlled infrastructure to bridge the supply and demand gap has put a tremendous amount of pressure on the producers. Many times, the producers succumb to this frenzy which results in an unreliable electrical infra-structure in the country. Besides that, the traditional electrical grid of the country is deemed inefficient and not at the level necessary to provide services to the growing economy of the country, which is showing in various reliability reports about India.

Indian policymakers have finally accepted the growing need of reforms in the basic working of the country's electric grid. A shift from conventional approach to a modern smart grid approach is progressing taking inspiration from the advanced western countries. While as the earlier five year plans would focus on achieving goals by increasing production of fuels, the 12th Five Year Plan, shows a slight shift in the mechanism. The plan consists of an approach to achieve various goals by tapping into more readily available resources, rather than putting a pressure on the mining industry of the country. Various Missions have been introduced such as the JNNSM and the National Mission for Wind Energy, that is helping shed the conventional ideas and to embrace a modern approach.

To achieve the 'electricity for all' by 2027 goal, there is but a need to tap into all the possible renewable energy sources, and optimizing energy use. This can be done by the introduction of a smart grid in the country, which has already been deployed in certain cities and Pradesh's. A smart grid approach will upgrade the electrical infrastructure of the country to a modern, well connected, efficient and reliable system that provides a platform for the economic and overall development of the country.

Even though India still in the early stages with regards to the smart grid, it will have to increase the number of smart grid deployments and take lessons from each initiative so as to achieve a centralized national smart grid. Technology transfer, security protocols and investor regulations are core areas on which the policy makers must focus to make the smart grid deployment a reality for India.

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