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Smart Grid Implementation in India with HVDC Transmission and MicroGrids

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***Abstract*— Increasing demand with the growing economy has called the need for innovations in the field of energy transmission and distribution. India is a country with immense potential in development of the grid system which can be improved by implementation of Smart Grid consisting of HVDC transmission and renewable energy integration. The localized renewable energy tapped can be transmitted over long distances with minimal losses using the help of HVDC transmission and distributed locally using micro grid initiative.**

Keywords*— HVDC; Smart Grid; AMI (Advanced Metering Infrastructure); AT & C (Aggregated Technical and Commercial) Loss; MicroGrid ; Renewable Energy

I. INTRODUCTION

The Electric Power Industry over the globe suffers from some common problems like increasing demand, deficit in generating capacity, power theft etc. The challenges vary from an underdeveloped to developing and developed country. An under developed country aims to provide a stable power economically and faces problems from basic infrastructure to tariff, while a developing country needs to improve the lack of transmission infrastructure, adoption of newer technology and power sources. A developed and industrialized country will have to ensure a blackout free power system, to move ahead with better innovations and being able to handle the varying regional demands effectively [1].

These problems call for the use of smarter technology, a smarter grid which can communicate between the utility grid and the consumers so as to adjust and accommodate the variations in load demand, adjust the distribution process over time to different regions and to have a better control in power sharing between the generating stations of different power sources. The various sensing along the transmission path and the two-way communication between the utility grid and consumers makes the grid smart, the digital technology work with the electrical grid to respond to varying demands and for an intelligent control over the entire power system.

Extensive research has been done on the implementation of smart grid. This paper discusses the potential of implementing a smart grid using HVDC transmission which has considerable advantages over the conventional high voltage AC transmission.

II. SMART GRID INITIATIVES

A. US Department of Energy -ARRA Smart Grid Project

One of the largest implemented programs till date, the project comprises of Advanced Metering Infrastructure, including over 65 million Advanced "Smart" Meters, Customer Interface Systems, Distribution & Substation Automation, Volt/VAR Optimization Systems, over 1,000 Synchro phasors, Dynamic Line Rating, Cyber Security Projects, Advanced Distribution Management Systems, Energy Storage Systems, and Renewable Energy Integration Projects. Austin (Texas) manages 500,000 devices real-time including smart meters, smart thermostats, sensors across its service area and servicing over 1 million consumers and 43,000 businesses as of 2009 [2].

B. DESERTEC

DESERTEC was developed by the Trans-Mediterranean Renewable Energy Cooperation (TREC). Studies showed that the power from sun could meet power demand in the MENA region while also helping to power Europe. By importing desert power, Europe could save around €30/MWh. The Medgrid together with DESERTEC would serve as the backbone of the European super grid and the benefits of investing in HVDC technology are being assessed to reach the final goal – the super smart grid [3].

III. INDIAN SCENARIO

Fast paced growth of Indian economy has led to a surge in the energy demand and is expected to increase by many folds in the future. India is world's 6th largest energy consumer and has the 5th largest power generation capacity in the world. India's installed capacity stood at 272.5 Giga Watts (GW), as of FY15. Thermal power, the largest component, was 189.3 GW, followed by hydro 41.6 GW, renewable energy 35.8 GW and nuclear 5.8 GW. Renewable energy is fast emerging as a major source of power in India. Wind energy is the largest source of renewable energy in India. It accounts for an estimated 60 per cent of total installed capacity (21.1GW) [4].

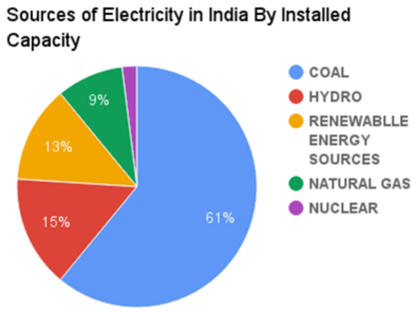


Fig. 1: Pie chart showing of distribution of power sources

The Government of India has been supportive for the growth of Power Sector.

- It has de-licensed the electrical machinery industry and also allowed 100 per cent Foreign Direct Investment (FDI) in the sector.
- De licensed the generation sector
- Allowed open access for the benefit of bulk consumers
- A clean energy trading platforms for the states are under development by the Ministry of New and Renewable Energy (MNRE) and Power Trading Corporation of India (PTC)
- Initiatives for electrifying non-electrified villages (e.g. Deen Dayal Upadhyaya Gram Jyoti Yojna)
- Increasing the total generating capacity by starting new projects mainly comprising of solar, biomass and wind power projects.

A. The Problem

India has historically failed to meet its power sector targets by a significant margin, the power sector continues to be affected by the shortfall both on generation as well as transmission side.15-20% of power transmitted is lost in transmission and distribution network. Distribution sector in the Indian power system suffers from operational inefficiencies (high AT&C losses, frequent and long outages etc.). The average AT&C loss for utilities selling directly to consumers is 27% in 2012-13. Other aspects like reliability in supply, power quality etc. are causes of concern. Other hurdles include:

- Fuel and Resource Shortage
- Equipment Shortage
- Right of Way Issues
- Land Acquisition and Environment Clearance
- Manpower Shortage

The basic yet general problem lies with the mode of transmission which was adopted decades back which needs improvisation. As of 2016, India has a single wide area synchronous grid that covers the country. Long distance transmission is achieved using High Voltage AC. The HV transmission lines (≥132 kV) installed in the country is nearly 700,000 km. The length of transmission lines (400 V and above and excluding 220 V lines) is 10,558,177 km as on 31 March 2015 in the country. The spread of total transmission lines (≥400 V) is such that it can form a square matrix of area 36.8 km2. A high proportion of non-technical losses are caused by illegal tapping of lines, and faulty electric meters that may read reduced consumption and hence decreases the payment revenue. A case study in Kerala estimated that replacing faulty meters could reduce distribution losses from 34% to 29%. It is estimated that the country has enough power generating capability to meet the full demand temporarily and spatially. But due to the inefficient last-mile link-up with all electricity consumers which remains as a major problem [5].

IV. SMART GRID

The situation demands a smarter technology that monitors, protects and automatically optimizes the operation of its interconnected elements – from the central and distributed generator through the high-voltage network and distribution system, to industrial users and building automation systems, to energy storage installations and to end-use consumers and their thermostats, electric vehicles, appliances and other household devices. The Smart Grid in large, sits at the intersection of Energy, IT and Telecommunication Technologies [6].

Smart grid initiatives focus on:

- Reducing the Aggregated Technical & Commercial (AT&C) Loss
- Interconnecting various energy sources through a common grid
- Integrating the localized renewable energy sources like wind and solar energy
- Creating awareness among the consumers and encouraging their involvement in the system [7].

V. PROPOSED LAYOUT

The designed layout consists of a central HVDC backbone, encompassing the Indian power network which acts as the central power transmission grid. The energy generated from conventional energy sources in India can be transmitted through this central network. Power from the renewable energy sources after utilization in the respective microgrid is fed into this central grid.

Every strategical node consists of an inverter station and a receiving substation which converts the High Voltage DC to flexible AC which powers the distribution network of the respective node. Further distribution can be achieved by the respective node's DISCOMs. The 33KV AC from receiving substation forms the secondary transmission which will be stepped down to 11KV at the regional sub stations and powers the primary distribution over the entire region. Further power will be stepped down to 440V at distribution sub stations and reaches the consumer. The distribution network incorporates cloud control of protective and switching devices along the grid and smart metering technologies at the consumer end. These technologies are realized using a two-way communication between the power distribution control station and consumers thus enhancing real-time monitoring of the energy consumption. This benefits the DISCOMs and the consumers and hence provide a reliable, efficient and effective power system network.

All the existing HVDC projects can be integrated within the proposed smart grid to strengthen the HVDC backbone with minimal change in the present infrastructure.

Table 1: Implemented HVDC Projects in India [8]

HVDC Transmission links	• ±500kV,1500 MW Rihand – Dadri HVDC Project • ±500kV ,2500 MW, HVDC Talchar – Kolar Transmission Link • ±500kV,2500 MW HVDC Ballia –Bhiwadi Transmission Link • ±500kV,1500MW Chandrapur – Padghe • ±200kV,100MW Sileru – Barsoor • ±500kV,2500MW Mundra–Haryana • ±800kV,2x3000MW Champra – Kurukshetra
HVDC Back to Back Links	• 2 x250 MW HVDC Vindhyachal Back to Back Station • 2x500 MW HVDC Chandrapur Back to Back Station • 1x500 MW HVDC Sasaram Back to Back Station • 2x500 MW HVDC Gazuwaka Back to Back Station • 1x500 MW HVDC Visakhapatnam Back to Back Station (Vizag 1) • 1x500 MW HVDC Visakhapatnam Gazuwaka (Vizag 2)

Geographically isolated regions such as deep forests, mountains, valleys, islands etc. are designed as isolated micrograms. These microgrids are powered by the locally available renewable energy sources such as solar, wind and hydel.

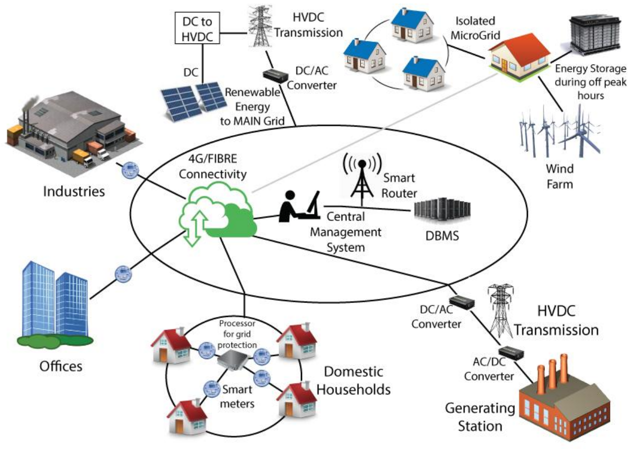


Fig. 2: Proposed layout for implementation of Smart Grid with HVDC

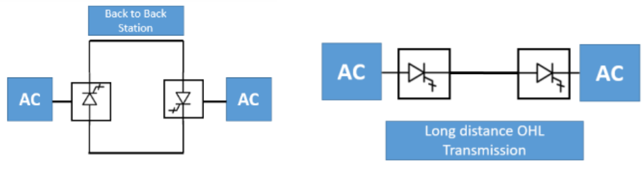
A. HVDC Transmission Grid

The end user requires AC power for various applications in general but transmitting AC over long distance incur transmission losses around 10-15%. This high voltage long span AC transmission can be replaced by a HVDC transmission grid which can reduce the effective line losses to around 2%. The practical deployment of such a grid is initially expensive but can yield profit in the long run. The developments in power electronic converters and harmonic filters add to our advantage. HVDC transmission is preferred when:

- Transmitting bulk power over long distance
- No or less intermediate tapping
- Sea crossing, through undersea cables
- Adding capacity through few wires
- Reducing corona loss
- Reducing line cost as HVDC transmission requires fewer lines.
-

Transmission ratings of 3 GW over large distances with only one bipolar DC line are state-of-the-art in many grids today. Now, there are ways of transmitting up to 6 GW and more over large distances with only one bipolar DC transmission system.

By means of these DC and AC Ultra High Power transmission technologies, the "Smart Grid", consisting of a number of highly flexible "Micro Grids" will turn into a "Super Grid" with Bulk Power Energy Highways, fully suitable for a secure and sustainable access to huge renewable energy resources such as hydro, solar and wind.



(a) (b)

Fig. 3: (a) HVDC Short Link (b) LDT Link

1. Bipolar HVDC-LDT Rectifier Station

The generated AC voltage can be converted to DC at the rectifier station and transmitted through the HVDC grid. At the receiving end, there are inverter stations which convert the HVDC back to the required AC voltage and further used for distribution to the load centers. Conversion is achieved by the use high-power, high-voltage electronic semiconductor valves. Broadly it consists of capacitor commutated converter (CCC), actively tuned AC filters, air insulated outdoor thyristor valves and active DC filters [9].

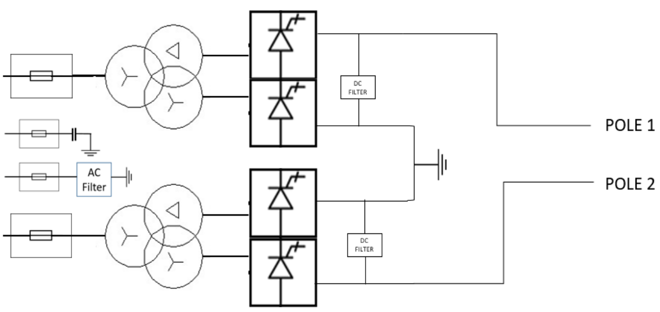


Fig. 4: Bipolar HVDC-LDT Rectifier Station

2. HVDC Back to Back Station

Back to Back link station is used for connecting two independent neighboring systems with different and incompatible electrical parameters (Frequency / Voltage Level / Short-Circuit Power Level) are connected via a DC link. Rectifier and Inverter are located at the same station. They are used:

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- to connect asynchronous high-voltage power systems or systems with different frequencies
- to stabilize weak AC links
- to supply more active power where the AC system already is at the limit of its short-circuit capability
- for grid power-flow control within synchronous AC systems

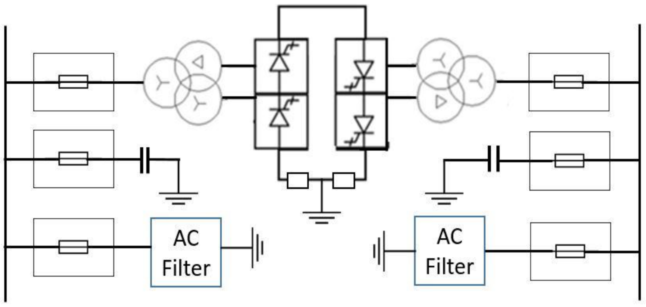

Fig. 5: HVDC Back to Back Station

B. Generating Power Plants

Conventional power generating units providing the majority of units demanded.

C. Small Scale Generating Plants

Comprises of both conventional and non-conventional power generating techniques

D. Digital Protective Relay

Computer-based system with software-based protection algorithms for the detection of electrical faults. They also facilitate cloud control of the relays from the control stations.

E. Isolated Microgrids

Microgrids can be almost entirely self-sustaining. When properly designed, they can almost meet the demand of the consumers under the microgrid. They can generate as much power as it consumes and hence are valued prospects. Certainly, the power grid backbone (HVDC) also needs to become increasingly efficient, integrating renewable resources that reduce society's need for fossil-based resources, among other approaches. The upgraded backbone, combined with microgrids, will help us meet our goals for an efficient and eco-friendly electric power system.

1. Solar Microgrid

The size of a solar microgrid depends upon the number of solar panels and wattage comprising the solar array. The requirement and size of a microgrid is calculated by adding the power needs of individual homes in the village that will be connected together.

Every solar PV panel connected in the array generates electricity by converting solar radiation into electrical energy. The electricity generated from the array of panels is transmitted to a central controller called the Power Conditioning Unit (PCU), which is, in simple terms, a large power inverter. The PCU is connected to the Distribution Box (DB) on one hand and the battery bank on the other. The PCU controls, regulates and directs the electrical energy transmitted from the array, and supplies electricity directly to consumers. During the day if the power generated is not used or surplus power is generated, the PCU directs this to the battery bank which stores power. This power can then be used at night. The microgrid and battery bank are connected to a computer for local power usage monitoring. With the addition of a modem, this information can be accessed from a remote location, eliminating the need for local manpower to monitor the system [10].

2. Wind Micro Grid

WECS (Wind energy conversion systems) convert wind energy into electrical energy. The principal component of WECS is the wind turbine. This is coupled to the generator through a multiple-ratio gearbox. Usually induction generators are used in WECS. Output voltage and frequency is maintained within specified range, by using supervisory metering, control and protection techniques. Wind turbines may have horizontal axis configuration or vertical axis configuration. The average commercial turbine size of WECS was 300 kW until the mid- 1990s, but recently machines of larger capacity, up to 5 MW, have been developed and installed. This electrical energy produced can be supplied to PCU controls that regulates and directs the electrical energy transmitted from the array, and supplies electricity directly to homes, shops, offices, street lights etc. During off peak hours if the power generation is surplus it is stored in battery banks which can be used at peak hours [11].

3. Tidal Microgrid

India has a long coastline spanning 7,157 km. The tides which are formed can be harnessed to obtain tidal power. Turbines placed in the path of the moving water spin as the water passes by. These spinning turbines are connected to generators that create electricity. Other forms of renewable energy, such as wind and solar energy, are dependent on random weather patterns. But tidal energy is based on the rise and fall of tides, which is more uniform and reliable. The tidal projects have been seen with less interest mainly because of the inconsistency in power generated as the generation occur for a short time. The initial cost is high so as to design the generating and blade units to be able to withstand the high intensity sea waves and the expense is covered over a relatively longer period.

Carnegie Wave Energy is about to trial the world's first wave-integrated renewable energy microgrid project to be connected to an electricity network in Fremantle, Western Australia. Similar projects can be designed in India so that tidal microgrids can be set up in coastal as well as island areas. Positioning of the turbines and the design and technology of the runners needs to be upgraded to ensure better performance, Deep sea turbine can be employed in regions where the sea transportation may cause trouble [12].

F. Integrating the Localized Renewable Energy Sources

India is rich in renewable resources, tapping them efficiently and integrating them with the utility grid proves to be effective. By April 2016 wind power was the leading source of renewable power in India with 26.9 GW installed capacity while solar power plants with 8 GW installed capacity as of 31 July 2016.Renewable-energy resources can be used for power generation as standalone or isolated system. But their benefits are significantly enhanced when they are integrated

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into bigger electric power grids. Each resource is different from the grid's perspective and some are easier to integrate than others. With greater use of smart grid technologies, higher degrees and rates of penetration can be accommodated. The localized resources should be used partly for the locality and the rest should be transmitted through the grid [13]. Smart grids facilitate the following operation:

- Supply side management such as distributed generation.
- Demand side management by the consumers.
- Storage options, such as EVs, batteries, and thermal storage [14].

As of March 31, 2016 the installed capacity of wind power in India was 26,769.05 MW mainly spread across Tamil Nadu (7,269.50 MW), Maharashtra (4,100.40 MW), Gujarat (3,454.30 MW), Rajasthan (2,784.90 MW), Karnataka (2,318.20 MW), Andhra Pradesh (746.20 MW) and Madhya Pradesh (423.40 MW). Wind power accounts for around 10% of India's total installed power capacity. After these resources are to be partly used for locality and then the rest is to be transmitted to the grid through HVDC network.

India is densely populated and has high solar installation, an ideal combination for using solar power in India. Neemuch-Madhya Pradesh, Phalodhi-Rajasthan, Mithapur-Gujarat, Charanka, and Gujarat are some of major power plants in India.

Distributed Generation

Distributed renewable generation, notably rooftop PV, is a particularly promising renewable technology. Smart grid technologies can do much to promote greater use of distributed renewable generation. They can provide system operators with continual, real-time information on how these systems are operating and allow full control over these systems. Normally Renewable resources are connected at the distribution level and as larger resources (wind farms, solar farms) are connected at the transmission level. It ensures future energy sustainability, empowering grid in peak hours, energy management, independent systems, upgrading electrical market.

This information and control can be used in several ways, including, for example:

● Reducing output of, or even disconnecting, distributed generation as needed to maintain reliability, match load, or protect workers.

● Providing real-time data on distributed generation electrical output.

● Supporting the distribution system through, for example, tighter control of voltage.

G. Integration of Smart Technology and Involving the Consumers

The development of more intelligent power systems, with detailed consumption data and more accurate forecasting of renewables, will help generation companies to make better use of existing generation capacity. Control systems within power plants can now help even large-scale generators to respond more rapidly to changes in demand and reduce the reliance of utilities on less efficient reserve capacity to meet peaks in demand.

1. Smart Metering

Accurate measurement and transmission of electricity using a two-way communication system between the meters and the suppliers as well as consumers. It also helps in raising awareness and empowering the consumer through delivery of actual consumption data. Better Customer Relationship Management (CRM) and services, like automated billing based on detailed metering data can be realized.

By Encouraging decentralized, micro-generation of energy, a normal consumer is transformed into a Prosumer (an energy producer)

The technology further enhances the power system by the following ways:

- By automatically detecting theft or any other attempted malpractices
- Managing energy networks/grids better by shifting or reducing energy consumption (E.g. DSM)
- Energy consumption by various household equipment can be easily monitored and hence any defects easily identified.

a. AMI (Advanced Metering Infrastructure)

Advanced metering infrastructure (AMI) is an integrated system of smart meters, communications networks, and data management systems that enables two-way communication between utilities and customers. Customer systems include in-home displays, home area networks, energy management systems, and other customer-side-of-the-meter [15].

b. MDMS (Meter Data Management System)

An MDM system performs long term data storage and management for the vast quantities of data delivered by smart metering systems. This system analyzes the data collected and sent by the Smart Meter to set electric power costs and to let consumers use energy efficiently. Collecting the metered data from consumers in real time makes it possible for electric power suppliers to understand how electricity is being used and it improves the efficiency of recovery work after natural disasters or accidents happen to the power grid itself.

VI. ADVANCEMENTS IN INDIA

Smart Grid Initiative in India-Restructured Accelerated Power Development and Reforms Programme(R-APDRP)

Ministry of Power, Government of India, has launched the Restructured Accelerated Power Development and Reforms Programme (R-APDRP) in July 2008 with focus on establishment of base line data, fixation of accountability, reduction of AT&C losses upto 15% level through strengthening & up-gradation of Sub Transmission and Distribution network and adoption of Information Technology during XI Plan. Projects under the scheme shall be taken up in two parts. Part-A shall include the projects for establishment of baseline data and IT applications for energy accounting/auditing & IT based consumer service centers. Part-B shall include regular distribution strengthening projects and will cover system improvement, strengthening and augmentation etc [16].

VII. CONCLUSION

This paper discusses about the smart grid implementation in India using HVDC transmission, its benefits, and the integration of renewable microgrids. This paper highlights the potential of HVDC transmission over the High Voltage AC transmission used presently for the central transmission grid. The burning problems faced by Indian power system and their solution using smart grid technology has been discussed. A practical layout of a HVDC SmartGrid has been discussed along with its applications. Further discussions on renewable microgrids are made and their implementation in isolated localities. The implementation of these technologies are set to bring efficiency, reliability and stability to the Indian power sector in the foreseeable future.

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