On the Progress of Renewable Energy Integration into Smart Grids in India

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Abstract**-- With more than 21,000 MW installed capacity of renewable energy sources as of now out of an estimated potential of about 189,000 MW, in the years to come it is really a challenge to integrate the same into the smart grids in a country like India. This is basically on account of unevenly distributed renewable resources. With 5 regional grids gradually getting connected, formation of national grid in totality is a reality. Of course with major sources of generation being thermal with availability up to certain distant future, entire thrust has been put in recent years on the development of renewable resources that would be the source of energy to run side by side to the conventional ones. At the same time vast assets created in transmission and distribution will also continue to be gainfully used, may be in conjunction other form of value addition to the same for proper functioning. Under this condition, keeping in mind the eventualities, regulations have been framed and so also the certification process has been made effective to handle the situation particularly on grid connectivity front. Expectations from smart grids by the consumers and suppliers as well of course may lead further refinement to the existing protocols in the process in the years to come as and when harnessing of renewable resources progresses to attain a very high level.**

Index Terms**— Automatic Power Factor Correction Device, Distributed Generation and Renewables, Dynamic Voltage Restorer, Green Energy, Grid Integration, Smart Grid, Spinning Reserve, Voltage Ride Through**

I. Nomenclature

AMI	Advanced Metering Infrastructure
APDRP	Accelerated Power Development and Reform Program
CEA	Central Electricity Authority
CHP	Combined Heat Power
DER	Distributed Energy Resources
DGR	Distributed Generation and Renewables
IEC	International Electrotechnical Commission
ISGTF	Indian Smart Grid Task Force
JNNSM	Jawaharlal Nehru National Solar Mission
MNRE	Ministry of New and Renewable Energy
REC	Renewable Energy Certificate
RPO	Renewable Purchase Obligation
VRT	Voltage Ride Through

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II. Introduction

INTEGRATION of Renewable Energy Sources to Smart Grids has already drawn due attention of the nation as evidenced from the formation of a specific Working Group on Distributed Generation and Renewables under Indian Smart Grid Task Force (ISGTF).

With installed capacity of 182.690 MW by October 2011 in India and having peak power shortage of about 10% and energy shortage of about 8%, side by side to adding conventional thermal, hydro, and nuclear generation, effort is on to promote development of Renewable Energy Resources, mainly Wind and Solar based ones that are dispersed geographically. All the sectors of renewable energy are being developed. However, the wind power program has been the fastest growing contributing to about two-third of the grid-connected renewable energy power installed capacity, as of now. Of course with the potential estimated on solar power, total of off-grid and on-grid of this form of Renewables would lead in the long run.

Initial development of Renewables concentrated following isolated systems. But with the advancement of technology with higher size and more number of units, particularly with wind power plants, being feasible at a place grid connectivity has improved. At the same time gradual evolution of intelligent or smart grid employing extensively communication and information technology is paving the way for connection to the grid even for the remotely located plants. Of course India is yet to use storage facility except pumped hydro storage, which are very few. But with roof-top solar plant at consumer premises a reality and steps envisaged for Advanced Metering System (AMI) with the possibility of bi-directional power and energy flow, optimum usage of energy could be possible. However, unlike developed countries, as India is still away from the use of Electric Vehicles, immediately on account of this use of battery storage is not possible. Of course in some areas battery storage is in use (particularly with computer and communication facilities), mainly due to overall shortage in peak power and to some extent on quality of supply.

III. Progress Of Power Development In India

A. Generation

Starting from a meager generation of 1,360 MW at the time of independence in 1947 [1], by October 2011 it has reached a value of 182,690 MW [2]. While initially unit size was limited to few MWs only, now it has reached size of 660 MW on thermal side, with super-critical boiler, on hydro size it has yet been limited to 250 MW size, mainly on account limitation of transportation. On the other hand after the power sector was unbundled in nineties, with private sector participation a number of private players are in the field along with public sector generating companies.

B. Transmission

While at the time of initial development of power sector in India in the post-independence era, centered around few urban agglomeration and on river-valley development, it called for limited transmission network at 132 kV level only. With demand rising manifold over the years, along with generation capacity addition depending upon geographical availability, higher and higher voltage transmission became a necessity for haulage of large amount of power to load centers. This saw over the successive five-year plans development of state-grids, five regional grids and then ultimately aiming towards national grid. Voltage level too increased from 132 to 220, then to 400 and now 765 kV with ac while with dc it is $\pm$ 500 kV. The day is not far when large corridors of power will be built at 1,200 kV ac and $\pm$ 800 kV dc. However, in transmission, private sector participation is gradually picking up and so is under the joint venture route.

C. Distribution

It is a fact that commensurate with generation while transmission too was not given adequate attention initially, distribution was most neglected to start with, leading to huge losses. Of late due focus is there through APDRP (Accelerated Power Development and Reform Program) that has already yielded very high availability of distribution system. In this segment of course in number of states private sector participation is quite encouraging.

D. Co-generation

Particularly in heavy industries, though it was not uncommon earlier due to their specific needs, due to change in regulation more and more participation is taking place. With adequate protection and advancement of technology, in fact renewable energy or green energy sources are finding path to penetrate power sector in a big way.

IV. Development of Renewable Resources

A. Predominant Types

Quoting IEEE 1547 Standard, Distributed Energy Resources (DER) is defined as Small-scale Electric Generator located next to and connected to the load being served either with or without an Electric Grid Interconnection sometimes referred to as a DG (Distributed Generator).

Under this category included are the following;

- Micro Turbines (only Hydro)
- Combustion turbines
- Reciprocating Engines
- Sterling Engines
- Solar PV Systems
- Solar thermal
- Wind Power Systems
- Fuel Cells
- Energy Storage devices
- Hybrid systems
- Combined Heat Power (CHP)
- Biomass and co-generation

`In India, though quite a lot of them are in application, Solar PV (Photo-Voltaic) Systems, and Wind Power Systems are the predominant ones under Renewables and Green Energy Resources with more and more being installed.

B. Progress Achieved

From Fig. 1 it may be seen that by August 2011 India had more than 21,000 MW [3] of various types of Renewables. Table I shows disposition along with the total estimated potential of 188,700 MW.

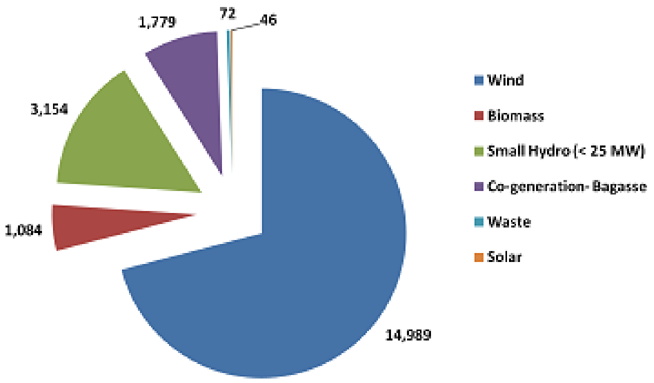

Fig. 1. Installed capacity of Renewably Energy (MW) as on Aug 31, 2011

Fig. 2 and 3 respectively show the Solar and Wind Energy maps of India. In fact major contribution under Renewables is coming from Solar and Wind. While harnessing of the latter is more as of now, gradual development of the former is envisaged in future.

TABLE I
SOURCE WISE POTENTIAL OF RENEWABLE ENERGY IN INDIA (MW)

Source	**Potential**	**Installed Capacity (MW)**
Wind	**49,000**	**14,989**
Biomass	**17,000**	**1,084**
Small Hydro <25 MW	**15,000**	**3,154**
Co-generation-Bagasse	**5,000**	**1,779**
Waste	**2,700**	**72**
Solar	**>100,000**	**46**
Total	**>188,700**	**21,124**

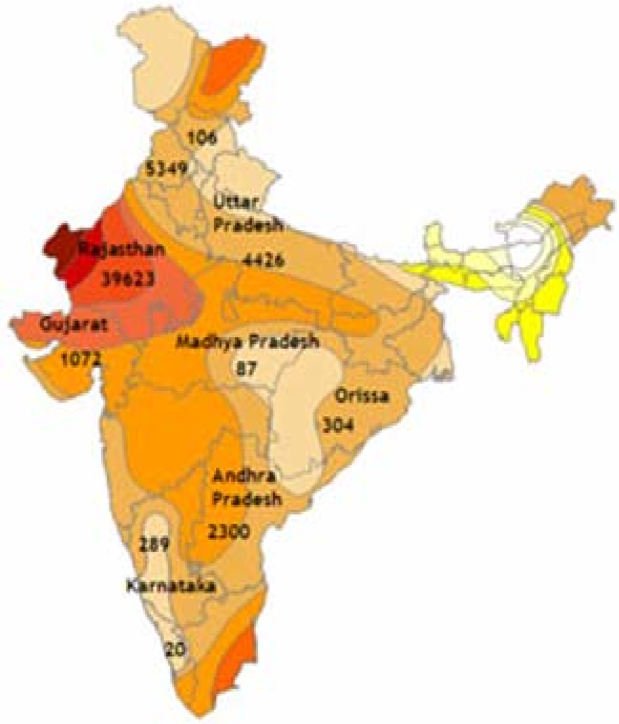

Fig. 2. Solar Energy map of India

As per Ministry of New and Renewable Energy (MNRE), Government of India sources [4], the country had targeted creation of 20,000 MW solar power grid capacity, including 20 million solar lights in the country by 2022. In addition, the Jawaharlal Nehru National Solar Mission (JNNSM) also aims at installation of 20 million square meters of solar thermal collector area by that time. The mission will be implemented in three phases.

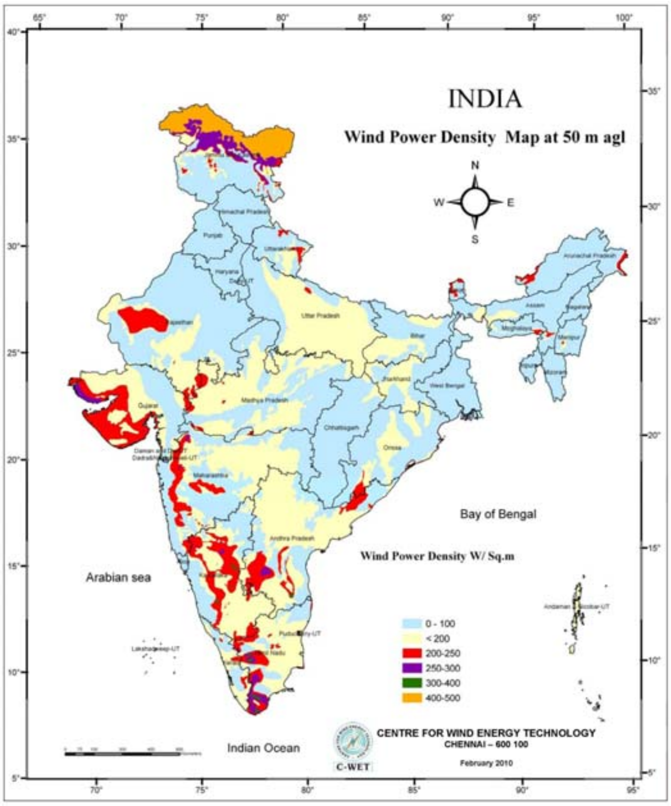

Fig. 3. Wind Energy map of India

The first phase of the mission, approved by the government, targets setting up of 1,100 MW grid connected solar plants, including 100 MW capacity plants as rooftop and small solar plants. In addition, 200 MW capacity equivalent off-grid solar applications and seven million square meter solar thermal collector area are also proposed in the first phase of the mission, till 2012-13. The National Solar Mission will also support research and capacity building activities in solar energy. An amount of Rs. 43.37 Billion has been approved for the first phase of the mission.

For a typical 1 MW generation, there is a central power plant consisting of several solar panels. Solar cells are arranged in arrays which are in turn arranged in a panel. A set of solar panels have a common circuit breaker. These breakers are then connected to individual inverters. Inverters are then connected to the transformers rated 300/415 V, 250 KVA. The outputs of these transformers are connected to the Low Tension Switchgear, which in turn is connected to another transformer rated 0.415/11 kV, 1250 KVA. Then there is a High Tension switchgear which is connected to the grid. Being static in nature, integration with grid doesn't create much problem with assured amount of energy delivered in most of the day-time of the year. In fact by December 2009, first 2 MW grid-connected solar plant set up at Jamuria, near Asansol, West Bengal, India in its first three month of operation generated over three hundred thousand units of power [5].

V. NEED FOR INTERCONNECTION

In order to take benefit of large amount of dispersed Renewables, integration is a necessity. Hitherto planned, designed, constructed, and operated grid meant for haulage of large amount of power from conventional sources has to accommodate the need of such DGR too. Again to take care of uncertainties in this category of generation resources, means of storage too to be accommodated. This may not limit to only pumped storage plant, but also may be battery storage system in conjunction with inverter system for ac grid. It calls for development of smart or intelligent grid that with the application of extensive information and communication technology can be operated and controlled. Distribution system so long carrying power in one direction may have to be bi-directional to carry the power in reverse direction, say, may be from roof-top solar PV generation from customer with proper metering arrangement. In other words, even there would be possibility of re-shaping of load curve to the advantage of all stake-holders. Even problem of congestion management may be easy with the ease in pressure on supply company. However, for this upgrading of grid system is a must. With the active participation of consumers a smart grid would employ communication and information technology to optimize energy usage from generation including green energy as well as stored with proper metering. In India with the Distribution system and consequently with the Transmission system initiative towards achieving the same has been taken.

VI. REGULATION AND CERTIFICATION

As the state power utilities were initially reluctant to connect Green Plants (mainly Wind and Solar based) to the grid, in India Regulators have reduced Renewable Energy Plant Size for grid connection to 50 MW. Of course this may not solve the problem of connection of solar plants created under JNNSM to the grid. In this context it is worthwhile to note that in most of the countries to promote Renewables, priority is being accorded to access the grid.

Keeping all these into consideration, Central Electricity Authority (CEA) is contemplating regulations [6] on technical standards and grid connection as present regulations on grid connectivity do not cover Distributed Generation and Renewables (DGR) to accommodate small generators below 33 kV level also. The one for 33 kV and above under general connectivity standard stipulates limits of

- Harmonic current injections as per IEC 61727
- Flicker as per IEC 61000
- Power factor from 0.95 lagging to 0.95 leading
- Range of frequency from 47.5 to 52 Hz with capability to deliver rated output in the range of 49.5 to 50.5 Hz
- DC injection up to 0.5% of full rated output at interconnection point

Similarly on specific issues salient features of regulation stipulate that

- All wind farms connected at 66 kV and above shall remain connected to the grid when voltage at interconnection point on any or all phases dips to the level, based on Voltage Ride Through (VRT) Characteristics.
- While synchronizing fluctuation should be within ± 5% at the interconnection point with no objectionable flicker.
- Permissible limit of voltage fluctuation to unit step change is 1.5% while for other changes it is 3%.
- While individual voltage harmonic distortion is limited to 3%, total shall not exceed 5% and similarly for current, total shall not exceed 8%.
- Over and under voltage trip functions for above 110% and below 80% respectively with clearing time of 2 seconds and similarly over and under frequency trip functions for above 52 Hz and below 47.5 Hz with clearing time of 0.2 seconds.

Additionally, there shall be provision of

- Voltage and frequency sensing and time-delay function to prevent DGR from energizing a de-energized circuit and to prevent DGR from reconnecting to grid until and unless voltage and frequency stabilize within prescribed limits for at least 60 seconds
- Ant-islanding to prevent DGR contributing to the formation of unintended islanding
- Prevention of back feed due to fault in connectivity as well as protection and coordination of increase in short circuit contribution from DGR as well as isolation of faulty section in cluster of renewable
- Reactive power compensation as reflected through voltage regulation including monitoring of VRT Characteristics
- Monitoring spinning reserve as per grid requirement

At the same time with smart grid requirement of DGR stress has been laid for

- Forecasting for predicting wind generation and solar, if possible
- Maintaining database for hourly generation, reactive power, voltage, etc. to assist to develop a real-time solution and investigate problem
- Active load management scheme and development of islanding scheme for frequency regulation and grid security, particularly when large concentration of Renewables exists
- Redundancy in distribution system with large generation from DGR
- Self-healing with automatic power factor correction device, dynamic voltage restorer, balancing power supply in real-time
- Remote communication of important parameters due to grid connectivity
- Installation and operation of meters, particularly for large size plants and due to bi-directional power and energy flow
- Energy storage mechanism

In general from the era of predictable generation dispatch, now smart grid has to cope up with variable generation. With more and more of Renewables task has become difficult until and unless regulatory mechanism vis-à-vis storage and / or quick starting system is in vogue and handy in operation to meet demand from time to time. This has resulted in increasing installation and in placing gas turbines to offset variable generation from Renewables. Alternatively battery storage with inverters connected to grid can provide the deficit at the time of need, although it is not so economic till now. However, considering pricing mechanism in force it, could be a good option for certain time of the day or season. In India this option is not in vogue whether in a centralized or decentralized way (through utilization of electric vehicle, etc.).

In India in order to promote the development of Renewables for green energy certain obligatory provisions have been enacted. For meeting Renewable Purchase Obligation (RPO) state specific RPO compliance requirement exists. Competitive procurement of power has been mandated in the Electricity Act 2003 and the National Electricity Policy 2005. Of course states with insufficient renewable resources face difficulty in meeting their RPO targets.

There is need for market based mechanisms for promoting investment and penetration of renewable energy on a large scale basis. In this context it is worthwhile to note that registry of Renewable Energy Generators comprises of basically four stages, namely

- Accreditation
- Registration
- Issuance
- Trade and Redemption

While Fig. 4 shows Renewable Energy Certificates (REC), Fig. 5 depicts conceptual market mechanism on Renewable Energy Generation.

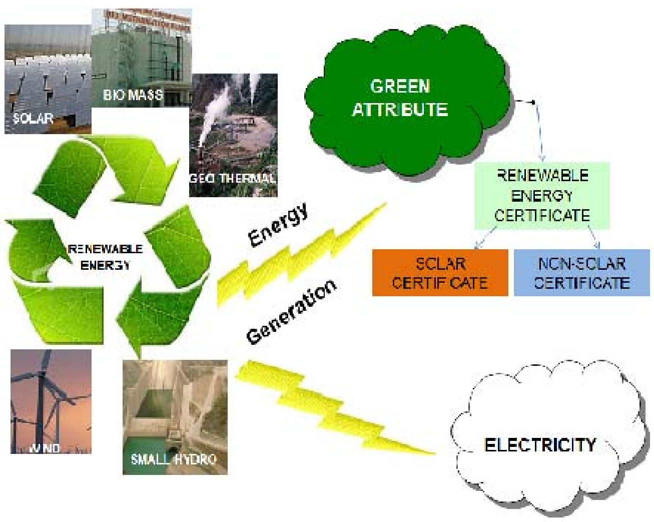

Fig. 4. Renewable Energy Certificates (REC) in India

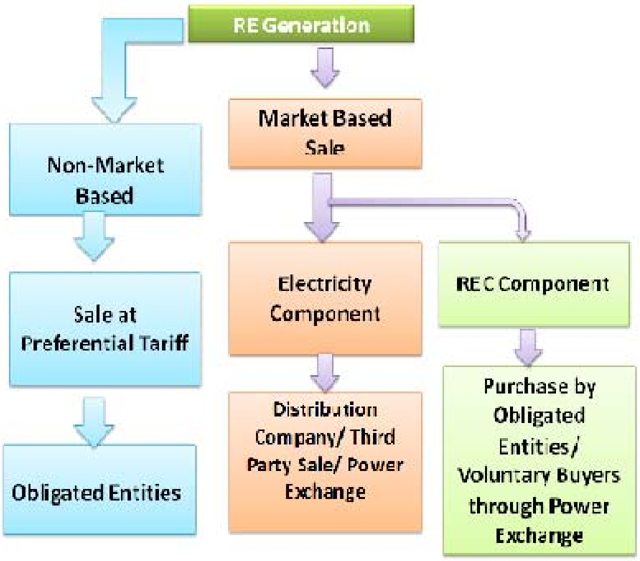

Fig. 5. Conceptual framework model

VII. Conclusions

With Renewables coming as big source of electric energy and due to its high potentials, particularly in the areas of wind and solar power, in the years to come it will form sizable part of generation feeding the grid. However, as it comes with unpredictable and variable contribution, while integrating smart grid utilizing advanced technologies of digital computing and communication has to operate and control the power system within the acceptable ranges of parameters. Regulatory mechanism in India, some already in vogue and others gradually coming to be in force encourages to promote Distributed Generation and Renewables and protects the concerned Green Energy Sources to meet the electricity demand at every instant of time along with centralized conventional thermal or nuclear generation. But at the same time stringent measures need to be complied with in operation while connected to grid, of course taking advantage of advancement in technologies as available to the smart grid which over the years has changed from what it was in the past in terms of operation and control.

VIII. Acknowledgment

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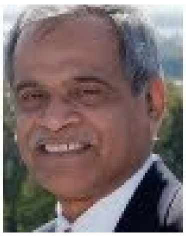
X. BIOGRAPHIES

Subrata Mukhopadhyay (S’70, M’70, SM’80) graduated in Electrical Engineering from Jadavpur University, Calcutta in 1968 and had his Master's and Doctorate Degrees from Indian Institute of Technology, Kharagpur and Roorkee in 1970 and 1979 respectively. His employment experience of about four decades includes teaching and research in Roorkee, IILM Academy (as Director and Professor in EE), Lingaya’s University (as Acting Vice Chancellor), and GTBIT, GGSIP University, and power system planning, design and operation with the Central Electricity Authority of Government of India. He had been Director of HVPNL, the TRANSCO of the state of Haryana, also. Currently he is with the GTBIT. He has authored two books and thirty-six papers, won IEEE Third Millennium Medal in 2000, IEEE PES Delhi Chapter Outstanding Engineer Award and IEEE PES Asia-Pacific Regional Outstanding Engineer Award for 2001, IEEE Regional Activities Board Leadership & Achievement Awards in 2002 and 2004 respectively. He is a Senior Member of IEEE, Fellow of the Institution of Engineers (India) as well as Institution of Electronics and Telecommunication Engineers, India, and Member of ASME. He is associated with the Technical Activities Board of IEEE, and Power & Energy Society of the latter in various capacities.



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