Smart Grid in Indian Power System

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Abstract–**Recent developments in the field of power system are adding to complexities in safe, secure and reliable grid operation. Indian power system is suffering from large AT & C losses, high outages etc. affecting reliability. Application of smart grid technology in all fronts of power sector shall enable real time measurements, improved visualizations and control. POWERGRID is deploying intelligent technology in all the sector of electricity supply chain. Synchrophasor pilot projects have been undertaken for real time dynamic measurement of system. Based on the experience of pilot projects large scale deployments of PMUs are being undertaken in the form of "Unified Real Time Dynamic State Measurement" (URTDSM) scheme. Smart grid in distribution is being deployed at Puducherry through open collaboration, as a pilot project. The smart grid shall bring efficiency and sustainability in power sector, meeting the growing electricity demand with reliability, resilience, stability and best of the quality while reducing the cost of electricity. This paper presents various attributes of smart grid and its deployment in Indian Power System along with their benefits. Initiatives taken by POWERGRID for development of pilot smart grid at Puducherry have been elaborated.**

Keywords- AMI; Energy Storage; PMUs; Renewable; Synchrophasor

I. INTRODUCTION

ELECTRICITY plays a major role in overall development of a nation. To have sustainable supply of electricity its efficient use through energy conservation and efficiency plays a significant role. Although India has seen an impressive increase in installed capacity, to about 205 GW as on Jun'12, still there is shortage of energy.

The increasing appetite for energy has been further complicated by limited energy resources in the form of fossil fuels like coal, oil, gas etc. There are serious questions raised about pursuing a fossil fuel-led growth strategy, especially in the context of environmental concerns. Towards this, emphasis has been given to develop renewable sources of energy (wind, solar, biomass etc.) on a big scale and its integration with the grid towards energy efficiency measures.

In transmission front, dimension of network is growing manifolds. With the establishment of synchronous interconnectionbetween NEW (North, West, East & North-East) grid and Southern Grid by 2014, a single grid of more than 250 GW capacity shall be operated. Such geographically spread meshed network would bring complexities in monitoring and operation of grid.

In distribution, almost 26.15 % of the energyis being lost.[1]Other aspects like reliability in supply, outages, power quality etc. as well as visualization and situational awareness of energy consumption pattern / price to both utility and consumers also necessitates due attention.

To address above aspects, latest technological development shall be used to introduce intelligence, advanced information and communication technology, intelligent computing in all fronts of power sector through real time monitoring, operation, metering and other control applications of smart grid technologies.

II. SMART GRID

The increasing complexity and management of power system, high penetration level of renewable generation, growing demand and quest for digital-quality at reasonable price, expectations in terms of system reliability, efficiency and security in addition to environmental energy sustainability concerns, have triggered the evolution of smart grids. It shall facilitate efficient and reliable end-to-end intelligent two-way delivery system from source to sink both electricity and information. Such grids will be able to co-ordinate the needs and capabilities of all generators, operators, distribution utilities, end users and electricity market stakeholders in such a way that it can optimise asset utilization, resource optimization, control and operation. In the process, smart gridsminimise costs, improve efficiency and reduce environmental impacts while maintaining system reliability.

Renewable Generation and its grid integration, wide area measurement system, advanced metering infrastructure (AMI) comprising IT enabled Smart Meters and other intelligent functionalities along with communication infrastructure are part of Smart Grid Development. Intelligent appliances used at the consumer end are also the ingredients of Smart grid.

This paper describes various attributes of smart grid and deployment of intelligent technologies in Indian Power System along with their benefits. It also highlights the initiative taken by POWERGRID for development of pilot smart grid at Puducherry through open collaboration.

III. SMART GRID INITIATIVES

In order to bring efficiency in the electricity sector as well as energy conservation and clean development, application of intelligence through smart grid in all three (3) value chain i.e, generation, transmission and distribution is essential. Following paragraphs describe the various features of Smart grid.

Smart Grid in Transmission*:*

With the increasing number of grid interconnections, geographical spread, open access and increasing share of short term & collective transactions and large scale renewable generation integration, it has become necessary to design, monitor, control and operate Indian grid as a Smart Grid through intelligent tools with communications. In this direction, certain control features like HVDC, FACTS devices, substation automation, System Protection Schemes etc. have already been introduced into grid development. Existing SCADA/EMS has the capability to provide steady state view of the power system with large data flow latency. Synchro-phasor measurements using Phasor Measurement Unit(PMU), advanced communication technique, fast computing and global positioning system (GPS) technologies over wide-area would facilitate dynamic real time measurements and visualization of power system which are useful in monitoring safety and security of the grid as well as enable in taking control/corrective actions.

The Synchrophasor technology has brought about a paradigm shift from state estimation to state measurement. POWERGRID has taken initiative in this direction and executed WAMS pilot project in northern region and demo projects in the western and southern regions.[2][3] This has facilitated building an understanding of the technology towards better visualization and situational awareness of grid events such as grid robustness, oscillations, angle/voltage instability, system margin etc. as well as decision support tools. A detail report titled “Synchrophasors Initiative in India” on various case studies of system events along with description of direct and indirect benefits accrued by Indian Power System based on pilot / demo project have been published.[4]

For full scale implementation of Synchrophasor technology for Wide Area Monitoring(WAM), POWERGRID has developed a roadmap “Unified Real Time Dynamic State Measurement System (URTDSM)” integrating State and Central grids i.e, PMU placement at all HVDC, 400kV and above substations/generating stations including 220 kV level, PDC(Phasor Data Concentrator) at strategic locations, analytics using PMU measurements etc.[5] The Scheme shall enhance the efficiency in overall grid management in electricity market regime.

Smart Grid for large Scale Renewable Integration:

India has been continuously progressing in conventional as well as renewable generation capacity addition. Share of renewable capacity has increased to 12% as on June’12 as per CEA monthly reports and energy mix to about 4%. With such multi fold growth and penetration of renewable generation, Indian renewable energy scenario is now at par with some of the developed nations. Presently, in our country about 25 GW gridconnected renewable generationsare available. Out of this about 71% is contributed by the wind alone[6]. Large renewable capacity addition about 30-40GW (about 70% wind and 20% solar) has been envisaged in next 5-6 years[7].

Generation from renewable sources is characterized by intermittency and variability which may affect demand-supply balance as well as grid stability.Since wind tends to pick up and generate most energy at other than peak time, energy from wind turbines is usually out of synch with peak energy demand. In the past, many utilities have managed this unpredictability and reduced their power-balance risk by limiting their reliance on renewable energy sources. Major developments and initiatives of integrating large quantum of renewables into grid, requires attention in the following areas:

- Forecasting of renewable generation and demand
- Strong Grid interconnection
- Real time measurement/monitoring through Synchrophasor technology
- Flexible generation, reserves, energy storage etc. for power-balancing(supply)
- Demand Side management, demand response and storage for load balancing
- Establishment of control centre integrating above functionalities with reliable communication infrastructure and software.
- Policy and regulatory advocacy for development of power-balance market and pricing mechanism and standards(grid code, connectivity standards, real time monitoring etc.)

POWERGRID evolveda comprehensive strengthening requirement for renewable capacity addition in 12th plan including interconnection of farms with network along with other State-of-the-Art requirements through smart grid applications. [8]

Smart Grid in Distribution*:*

In an intelligent distribution system as part of Smart Grid, various nodes are to be interconnected to share data and information as and when required. It envisages providing choices to each and every customer for deciding the timing and amount of power consumption based upon real time price at a particular instant, besides other choices to the consumer and motivating them to participate in energy conservation and efficiency and accommodating all renewable generations as well as storage options.

Smart Grid would provide continuous monitoring of the distribution system and technologies like smart meter, meter data management systems, demand response, outage management system would help in flattening the demand curve by shifting of load. Smart appliances with two-way communication features could respond to utility/consumer on their signal for energy efficient application and better usage of infrastructure.

The reliability of the grid increases substantially by implementing Outage Management System, where the smart devices like Ring Main Units (RMUs) would help in the self-healing of the system and devices like Fault Passage indicators (FPIs) reduce the time in restoration by providing a real time indication of fault and also the location.

Smart grids allow a bi-directional flow of energy, thereby increasing the scope and share of renewable and distributed generation. Energy storage systems are crucial part of the system which would form a core part of Smart Grid. Electric vehicle along with renewable energy sources can make a new role model towards green environment. It shall not only reduce petrol/diesel consumption but also be used as an energy storage solution.

POWERGRID is developing pilot smart grid at Puducherry jointly with electricity department, Govt. of Puducherry through open collaboration.

IV. PUDUCHERRY SMART GRID PILOT PROJECT

Main objectives of the Puducherry Smart Grid Pilot project are as listed below:

1. Indigenization of Technology
2. Common Information sharing platform
3. Scalable and replicable at other places
4. Shall help in demonstration of effectiveness of each functionality
5. Help in evolving policy advocacy, Regulations, etc. for successful implementation
6. Help in evolving commercial mechanism

The schematic of Puducherry Smart Grid Pilot Project area is as shown in Fig-1 below.

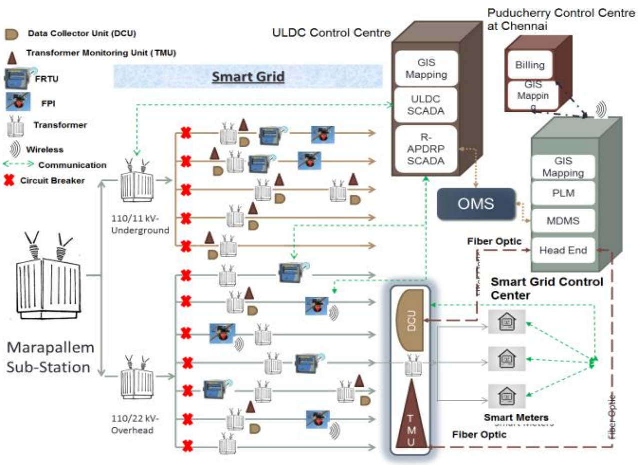

Fig-1: Puducherry Smart Grid Pilot Project Schematic

The electricity distribution system in Puducherry is well established with 100% electrification for all the Towns and villages. Pilot Project is being developed in PuducherryDiv - Ihaving about 87,075 nos. of consumers, dominated by domestic consumers (79%). The per Capita consumption is about 1850 KWh. Total area of about 23.17 km^2. This area receives power supply from 110/22/11kV substation at Marapallem within the Puducherry City having peak demand of about 70 MW.

Schematic of power supply to Puducherry urban division-1, where Pilot project is being implemented is shown in fig-1. Various components of Smart grid Control center like smart meters, DCU, MDAS, MDMS, OMS etc. are also indicated in this schematic. Interaction among SCADA system (ULDC control center), SMART grid control center and billing section at Puducherry are indicated in schematic at fig-1. For the FY 2012, UT of Pondicherry has to comply with fulfillment of 2% RPO which is around 3.8 MUs.According to draft policy document of Renewable Energy Agency Puducherry(REAP), Renewable energy potential in the Puducherry area is about 160 MW.

The city to be considered for Pilot Smart City should be such where population is small, people are educated, has high per capita consumption of electricity and all types of renewable energy sources including solar, wind are available. In case of Puducherry, the population is about 9.5 lakh (small) with 84% people educated which is much higher than national average. These indices are ideal for implementation of Smart Grid. The average per capita consumption of electricity in Puducherry is more than double the national average which leaves good cushion for experimenting demand response as well as scope for NegaWatts.

Major enabling intelligent technologies which are building blocks of the "Smart Grid" are as under:

i. Advanced Metering Infrastructure(AMI)
ii. Outage Management System (OMS)
iii. Peak Load Management (PLM)
iv. Power Quality Management (PQM)
v. Electricity Storage devices
vi. Distributed Generation(DG) and microgrid
vii. Electric vehicle (EV) and energy storage
viii. Smart appliances

Some of the major components of Smart Grid in distribution are described in following section.

V. ADVANCED METERING INFRASTRUCTURE

AMI is the backbone for intelligent distribution system to deal with the issues of PLM, OMS, PQM and promoting energy storage / distributed generation.

It provides a two way intelligent communication, monitoring and control between consumers and utilities as shown in Fig-2.The main features of AMI are as under:

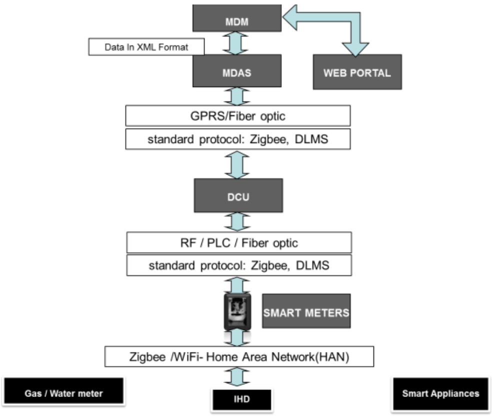

Fig-2: AMI Architecture

- Recording energy consumption data for consumer and utility (kWh,kVARh voltage, power factor, maximumdemand etc.)
- Automatically send the consumption data to the utility at pre-defined intervals
- Time-based pricing signal for Demand Response
- Bi-directional communication ability
- Net metering to facilitate integration of Distributed Generation in the form of Roof Top Solar etc.
- Loss of power (and restoration) event notification
- Remote Load limiting for Peak Load management
- Remote connection and disconnection of individual supply
- Energy prepayment
- Power quality monitoring
- Reporting meter tampering in real time to the utility
- Communications with other intelligent devices in the home
- Gateway to communicate other meters data (Gas/water)

In addition to the electricity consumption, the smart meters shall have enabling feature for gas & water consumption recording.

Home Area Network (HAN)

A HAN interfaces an In Home Display (IHD) device to smart meters and controllable electrical devices (switches/home appliances). It helps energy management functions by:

- Enabling consumer awareness of energy used and at associated cost
- Execute/respond to price signals by curtailing/ shifting consumption based on Utility/consumer-defined preferences
- Control of loads with consumer engagement.

Data Concentrator Unit (DCU)

The data from the field meters are aggregated by a data concentrator and then send to the utility control centre. It also sends messages /signals received from the utility / consumer for a particular/all meters to the intended recipient.

Communication system

The AMI needs continuous interaction between the utility, the consumer and the controllable electrical loads. It employs open, bi-directional and secure communication. Various communication media like Power Line Carrier (PLC), Optical fibre, Wireless (GPRS/RF/Zigbee), either centralized or a distributed mesh, combinations of the abovecan be deployed.

Meter Data Acquisition System (MDAS)

MDAS is critical component of AMI system. It acts as primary agent of interface between AMI control centre and meters.Two way communication, polling meters for data collection, send remote firmware upgrades/programmable parameter inputs to meters, sending load control / curtailment signals, connect / disconnect and sending of pricing and other signals to the Smart meter are some of its features. MDAS interface with MDMS with standards compliant data exchange models and protocols.

Meter Data Management System (MDMS)

MDMS is the heart of AMI. MDMS is a single repository of all meter data mapped to GIS and consumer indexing data. It facilitates Billing, Collection, Energy Accounting, Load Research, Load management. The Customer Portal and many other utility/consumer centric applications depend on the data & insight generated by MDMS.

Master Station/Control Centre

A Control centre houses all hardware for Meter Data Management System (MDMS) and the operator(s) are seated in this centre to manage the AMI system through their workstation. Master station is normally co-located with Load Management, Energy auditing, metering & billing system.

AMI also facilitate continuous Energy Audit and Peak Load Management as described below.

Continuous Energy Audit

Control centre will collect data at regular interval from the smart meters. These readings will be summed up and based on these summations utility will know what is being injected in the grid (reading of meter at S/S or feeder or DT) and what is output (aggregate of readings of all meters under that S/S or feeder or DT). Thus, utility can continuously audit the energy transfer. A large difference in the input and output will alert the system operator about the anomaly which may be due to pilferage/theft. All these when followed up will reduce the AT&C losses.

Peak load management

The PLM system collects information from various systems like the load forecast, SCADA, and MDM sub systems. Based on these inputs power demand-supply is determined for present and the next time block and the deficit/surplus is worked out.

Based on the deficit/surplus demand response signals are sent out to the consumers.

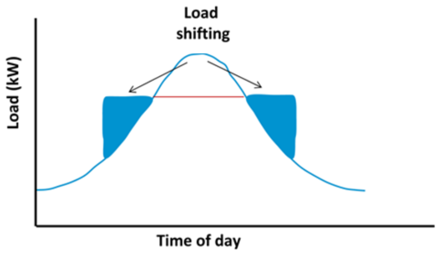

Fig- 3: Peak Load Management

The system then aggregates the consumers' response to these signals. Peak load management would also require shifting of load, segregation of critical and non-critical load etc as shown in Fig-3.
Peak load management is categorized into two parts:

1) Demand Side Management
2) Demand Side Response

Demand Side Management:
During peak time the utility can control the load of the consumers by using either Settable Relay designed for operation beyond a threshold or through Direct Load Control (DLC) relay in non-critical load circuit critical, that can be operated either from the control centre or meter for PLM or by controlling the individual appliances at the consumer end. It can communicate with devices over Home Area Network (HAN) to turn them on/off or regulate thermostats in heating and cooling devices, if supported by equipment, thus, regulating their consumption.

***Demand Response**:*
In demand response scenario, the consumer manages his demand in response to some signals/incentives given by the utility. The target area selection will be based on assets under stress (transformer overload) or high consumption / high losses area. Dynamic/ Time of Use (ToU) pricing of electricity and other incentives/schemes are communicated to the consumer via smart meter/ Web and SMS. To aid this consumer has an in home display device (IHD) which displays the consumption, ToU tariff rates, other related information.

Outage management system
The Objective of the outage management system is to improve availability and reliability of electricity supply, customer satisfaction and to provide information, early warnings for proactive maintenance to avoid outages and avoid failures. Outage management system manages outages by way of self-healing and crew management. Brief description of Outage Management system is given below.

Feeder RTU (FRTU):

FRTUs communicate switches status & electrical parameters like voltage, current etc. from different feeder points / DT/ RMU at field locations to control centre. These FRTUs will be capable to receive command from control centre for operation of switches at site to achieve faster restoration / isolation.

Fault Passage Indicators (FPI):

Fault Passage Indicators identifies fault location & type of faults through visual indications and event signal update to control centre. The Identification of section under fault will be used to direct maintenance crew for quick recovery and using Ring Main Units (RMUs).

Transformer Monitoring Units (TMUs):

The TMUs monitor oil levels, oil temperatures, loading conditions and internal developing fault conditions in distribution transformers. This will also help in taking proactive actions for maintenance of Distribution Transformer.

Operation of OMS:

OMS shall have customer database of project area completely with GIS mapping and Consumer indexing. It shall also monitor online customer premise connectivity to Network and availability of power through AMI. Whenever fault occurs information such as operation of the fault passage indicators (installed on the respective distribution line to give approximate location of the fault), de-energisation status of the consumer through AMI, Position of the circuit breaker, auto reclosure (AR) switches through SCADAreaches control centre. Schematic of OMS is shown in Fig-4 below.

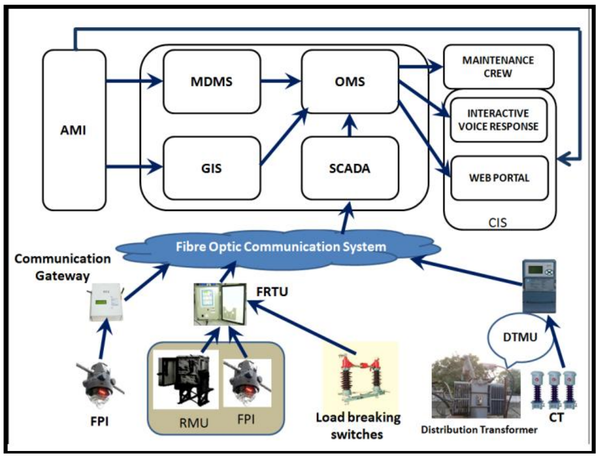

Fig-4: Schematic of Outage Management System

OMS analyses these information and identifies fault location. After that it explores the network topology for restoration of supply to affected consumers through alternate routes and suggest operator for suitable alternatives. At the same time maintenance crew are directed to fault location immediately. This system significantly reduces the outage time.

OMS shall provide the information to GPS aided maintenance crew services for quick approach to fault location. Maintenance crew shall take repair action according to fault and after repair information shall be passed to OMS which will forward the same to customer care centre. Also the restoration action shall be taken through SCADA after the receipt of repair information from maintenance crew.

OMS shall also keep the record of outages / maintenance, root cause, no. of customers affected, duration of outage etc. OMS shall also calculate key performance indices such as SAIDI, SAIFI, CAIFI, etc. which shall also help in planning / budgeting maintenance activities and condition based maintenance.

VI. Conclusion and Scope for future work

Challenges of modern complex power system can be effectively tackled with deployment of Smart Grid technologies. Synchrophasor technology has been found to be useful in application of operation and monitoring of the grid. Advanced Metering Infrastructure is very helpful in taking up the challenges in distribution sector for reducing AT & C losses, Peak load Management, Outage Management, energy storage etc.. For deploying large Scale distributed generation in the form of renewables (wind / solar), development in the field of Smart Grid is going to play a major role.

For successful implementation of Smart Grid in power system, apart from development/integration of intelligent technology into the network, commercial mechanism through suitable market design shall also be required. Innovating consumer tariff structure based on "time of use/day" which will incentivize consumers on the basis of energy consumption during off-peak period need to be established. In addition, suitable tariff mechanism through "Net-metering" may also be introduced to facilitate grid interactive renewable energy generation at distribution level.

In order to make city to be competitive and sustainable with increase population density and high energy consumption, smart grid endeavor can be extended towards development of Smart City to take care of various citizen services like security system, transport system, water management, public services, smart building & home, e-education, mobile-medical etc. in a holistic manner.

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