Towards Indian Smart Grids

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***Abstract*—India is struggling to meet the electric power demands of a fast expanding economy. Restructuring of the power industry has only increased several challenges for the power system engineers. A major chunk of the power losses is a direct derivative of the poor management of distribution networks. Distribution automation (DA) has been aimed at reducing losses, and improving reliability and financial viability of state utilities. Firstly, this paper presents various benefits achieved by major Indian utilities in transitioning towards automation. Enroute to the proposed vision of introducing viable Smart Grids (SG) at various levels in the Indian power systems, it is recommended that an advanced automation mechanism needs to be adapted. This is then projected to be feasible through invariable dependance on several open standards, whose integration for interoperability, flexibility, scalability, modularity and vendor neutrality is deemed pivotal. Various examples of existing structures of automation in India are employed to underscore some of the views presented in this paper. Finally, a potential SG architecture for Indian power systems is proposed with a discussion on its implications.**

I. INTRODUCTION

The economic growth of a developing nation like India depends heavily on reliability and quality of its electric power supply. Generally, rigorous planning is done for the addition of new generation and the expansion of existing transmission networks. However, distribution systems have grown in an unplanned manner resulting in high technical and commercial losses in addition to ending up delivering poor quality of power. Efficient operation and maintenance of distribution systems is hampered by non-availability of system topological information, historical data and real-time health information of distribution system components such as transformers and feeders. Supplementary reasons include the lack of efficient tools for operational planning, and advanced methodologies for quick fault detection, isolation, and service restoration, etc. All these eventually lead to increased system losses, poor quality and reliability of power supply apart from witnessing increased peak demand and poor return of revenue. Hence the increased reliance on DA and its subsidiaries to mitigate the existing bottlenecks. All across the world, DA has been acknowledged as being indispensable [1]–[4] in overcoming the consequences arising out of this shortfall.

Next in line in the bottom-up approach to optimally strengthen a power system design is substation automation for sub-transmission and transmission systems. With the prevailing deregulatory environment in India, the onus is definitely on DA to maximize efficiency, reduce investment in primary equipment and increase reliability.

When economic reforms were initiated in 1991, the Government of India also embarked on reforms in the power sector [5]. Reference [6] discusses reforms related to accelerated power development and reforms programme (APDRP) in India, which have started yielding strategic results. The projects funded under this scheme have been aimed at improving financial viability of state utilities, reducing T&D losses, improving reliability and bringing about transparency. The recourse to these aims centered around automating the distribution systems, and subsequently the Indian government heavily funded various state DISCOMS. With the introduction of Electricity Act 2003 [7], the APDRP was transformed to restructured APDRP (R-APDRP), paving way for the espousal of advanced automation functions. Improving the operation and control, and attempting at a seamless integration of generation (including distributed energy resources), transmission and distribution systems through the usage of intervening information technology (IT) that uses high speed computers and advanced communication networks, and employing open standards with vendor-neutrality is deemed a cornerstone for embracing the up-and-coming conceptualization of ”Smart Grid” for the Indian scenario. Ref [8] gives an overview of Intelligent Grid (IG) initiatives in India with an discussion on practical issues of operating the control centres and the key requirements for the future EMS Architecture.

This paper builds upon these requirements and aims at creating a platform for a framework that captures the essence of SG in the Indian context. Beginning with developments of DA in the distribution sector, building upon the Government policies in vogue with demonstrative examples, the paper sets out the transmission substation automation status. Identifying the significance of open standards with the allied obligatory requirements, we converge towards the potential application of SGs at various levels of Indian power systems, finally providing a visionary approach for building Indian SGs.

This paper is organized as follows: Section II provides an overview of the functions of DA and advanced distribution automation (ADA), including the emergent issues. Section III explains the developments in the field of automation in India with some examples. The current status of progress towards creating the Smart Grid philosophy in India, and the proposed vision for realizing Smart Grids are explained in section IV, followed by conclusions.

II. Overview of DA and concept of ADA

A. Distribution Automation (DA)

IEEE has defined Distribution Automation (DA) system as "a system that enables an electric utility to remotely monitor, coordinate and operate distribution components, in a real-time mode from remote locations" [9]. A typical DA system is composed of field instrumentation, remote terminal units, communication systems and distribution automation software.

DA performs varied primary and secondary functions [10], [11]. The primary DA functions typically include the installation of equipment, communications, and/or basic data systems. Each primary DA function is described in terms of what its purpose is, the key technologies needed by the function, the technology challenges, and the potential benefits.

The Secondary DA functions typically utilize the data provided by the primary DA functions. Each secondary DA function identifies which primary DA functions it depends on, its description, and its primary purposes.

The economic evaluation and cost/benefits in progressing towards DA is explained in references [12]–[15]. The new information that will be made available by the implementation of DA system will encourage researchers to develop new algorithms and software for protection & control, distribution automation and diagnostics, which will ultimately reduce operation and maintenance (O&M) costs. The information will also be very useful for system planners and operators for preparing cost effective maintenance schedules. This will increase productivity, improve asset management and distribution system availability and help earn customer loyalty.

In the future, the advances in distribution operations technology will add a new set of challenges:

- Customer demand for better power quality and less outages
- Utility business pressures to minimize capital and operational expenses
- Market opportunities that are beginning to reach into the distribution arena, such as "demand response" and "real-time pricing"
- Regulatory pressures for system reliability and performance
- Increased interconnection of distributed energy resources (DERs) to the distribution system, either at substations or within customer premises. All these DER systems will interact among themselves and with all other controllable devices and systems connected to the same distribution area.

To handle the above mentioned challenges, IntelliGrid project in North America floated the concept of advanced distribution automation [16], which is detailed in the following subsection (ADA).

B. Advanced Distribution Automation (ADA)

It describes the extension of intelligent control over electrical power grid functions to the distribution level and beyond. The electrical power grid is separated logically into transmission and distribution systems. Electric power transmission systems typically operate above 110kV, whereas electricity distribution systems operate at lower voltages. Normally, electric utilities with SCADA systems have extensive control over transmission-level equipment, and good control over distribution-level equipment. However, they often are unable to control smaller entities such as DERs, buildings and homes. To incorporate all these extended functionalities, the term "Advanced Distribution Automation" has been floated.

More functionalities added to a system imply the increase in operational complexity. The identified issues related to ADA are the integration of DERs, enhanced distribution system reliability, moving towards implementing the standards and finally combining all the resolved issues of ADA [17] with transmission and market operations to form a "Integrated Smart Grid". Major projects have been undertaken for the intelligent operation of power system around the world [18], a clear sign of march towards SGs as per the respective regional requirements.

III. Developments in India

In India, city electricity distribution automation system (CEDAS) was the first initiative towards power system automation systems under R-APDRP. The focus of the programme was on actual, demonstrable performance in terms of loss reduction through adoption of information technology and strengthening & up-gradation of sub-transmission and distribution networks. Project area selected was towns and cities with population of more than 30,000 (10,000 incase of special category states). Rural areas with heavy loads requiring feeder segregation were also included in the project area. Projects under the scheme were taken up in two Parts - Part-A included the projects for establishment of baseline data and IT applications for energy accounting/auditing & IT based consumer service centers; Part-B included regular distribution strengthening projects. The initial allocation under this scheme was 40,000 crores rupees.

A. Distribution Automation in India

Total number of DISCOMs in India is 40, where both State and private owned ones have embarked on a progressive approach in bringing about CEDAS. The DRUM project in Aurangabad and electric distribution companies such as NDPL, BESCOM, REL and DHBVNL have taken a lead in this direction. The common objectives set for employing distribution automation system are:

- Reduce peak load and power losses to overcome prevailing power shortages and defer construction of distribution facilities.
- Improve the reliability of supply by reducing the number and duration of outages, and improve the quality of service.
- Improve the financial performance of the utility by improved cash flow, safeguarding revenues, and preventing theft of power.

The major benefits accrued in enforcing DA in India are highlighted through the following four examples.

1) Example - I : North delhi power limited (NDPL): NDPL [19] is the first power distribution utility from India to have won the prestigious Edison Award in the international category. NDPL is a joint venture between Tata Power Company and the Government of Delhi with the majority stake being held by Tata Power. It distributes electricity in North & North West parts of Delhi and serves a population of 5 million. The company started operations on July 1, 2002 post the unbundling of erstwhile Delhi Vidyut Board. With a registered consumer base of around 1 million and a peak load of around 1180 MW, the company's operations span across a geographical area of 510 Sq. Km. NDPL has to its credit several firsts in Delhi: SCADA controlled grid stations, automatic meter reading, GSM based street lighting system and SMS based fault management system. To ensure complete transparency, the company has provided online information on billing and payment to its customer base of over one million. This happened in the first year of operations itself. The comprehensive plan of NDPL has the following key elements:

1) Run-repair-replace options
2) Road map for network reliability & N-1 redundancy in place
3) Automation & IT roadmap in place
4) Progress on Ideal Zones
5) Designation of feeders as fault free and & theft free
6) Peer competition through monthly score cards.

Figs. 1,2and 3 show the utility's decrease in transformer failure rates, improvements in reliability indices and revenue enhancement. In the first year of its operation, the achieved

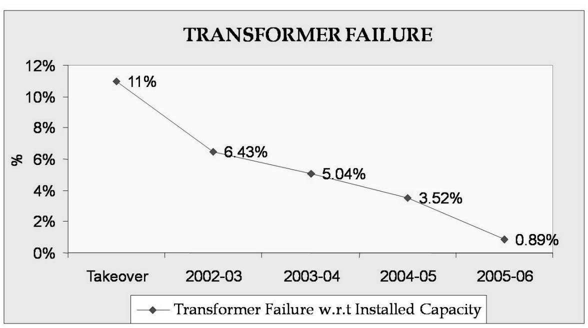

Fig. 1. Failure rate of transformers (w.r.t Installed capacity (Source: NDPL presentation to power ministry, India))

targets were:

- Aggregated transmission and commercial losses reduced from 54% to 47.6%
- Distribution transformer failure rate reduced from 8% to 4% by better maintenance and load planning
- SAIFI improved from 41 to 23 and SAIDI improved from 56 to 47 minutes
- Billing data of the 0.9 million customers was made available on the web and payment of bills made possible by credit cards.
- 40000 nos of high bill (100%) and 0.15 million (19%) low bill meters converted from electromechanical to digital

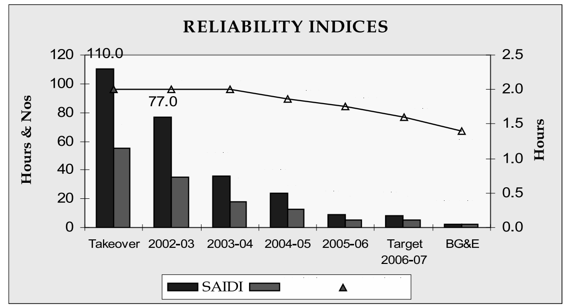

Fig. 2. International benchmarks -reliability indices - system average interruptions duration & Frequency index - (SAIDI, SAIFI & CAIDI) (Source: NDPL presentation to power ministry, India)

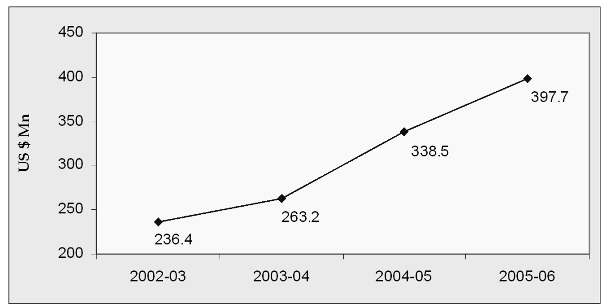

Fig. 3. Revenue enhancement - indicator of increase in the coverage of billing net (Source: NDPL presentation to power ministry, India)

2) Example - II : BESCOM: Bangalore Electricity Supply Company (BESCOM) is responsible for power distribution in eight districts of Karnataka [20]. BESCOM covers an area of 41,092 Sq. Km. with a population of over 16.8 million. At present, the outage faced by a customer on an average is 86 hours per year with large interims per outage. BESCOM plans to drastically reduce the outage average by 80 percent, ensuring that any interruption does not last for more than 3 minutes. There is a tangible benefit of increased revenue gain over a period of time. Intangible benefits involve the organization becoming free of perennial debts (loss reduction), ensuring reliable and quality power with least interruptions, quick turnaround on breakdowns and helping the company become socially responsible and accountable.

3) Example - III : CEDAS: The "City Electricity Distribution Automation System" (CDEAS) project was started to initiate the DA programme in India. Several projects have attracted the attention of many global and domestic engineering consultants and contractors. Indian electrical system closely aligned with IEC Standards (most Bureau of Indian standards are derived from IEC). Due to this, Europe based consultants are finding increasing acceptance in the Indian context. Transnational funding agencies have funded CEDAS projects in India such as JBIC of Japan [21] to the tune of $120m to $150m per project.

4) Example - IV : Andhra Pradesh state electricity board (APSEB): Reference [22] gives the overall picture of devel-

opment and evaluation of a utility DAS in Andhra Pradesh. To fight the menace of power theft, modern techniques like high voltage distribution system (HVDS)and LT arial bunch conductor have been adopted.
Additionally, the identification of poor management of distribution networks in India has led to the introduction of the concept of private franchises for distribution network management. Bhiwandi distribution circle of the state of Maharashtra is a prime example of the success story of this initiative.

B. Role of DER and DG

One of the most interesting technological innovations during the past several years has been associated with distributed energy resources. DERs are small power generation and storage applications, usually located at or very near customer loads. The application of these small-scale power technologies is gaining widespread interest and acceptance due to their ability to further customer choice. Ref [23] explains the role of distributed generation in Indian Scenario. Use of existing standards and development of new standards for integrating DG and DERs in the Indian environment is the task ahead towards developing Smart Grids at the distribution level.

C. Enhancing system reliability

The distribution network reliability will increase owing to the faster service restoration times and reduced customer outage times [24]. Main objectives reported in the literature for improving reliability using DA are as follows:

1) Developing different approaches to assess quantitatively the adequacy of a particular automated distribution scheme designated as the “low interruption system” (LIS)
2) Automated scheme to reduce drastically the number of interruptions, interruption time and the area affected by the fault
3) Simple and cost effective way to the restoration of healthy sections through alternative routes

OLTC Operations	Communication failure analysis	Voltage profile analysis	Reliability Indices evaluation
Command failure monitoring	Sympathetic tripping	Intelligent alarm processing	Situational awareness
Hunting in capacitor bank switching	Smart switching techniques	Cable load monitoring	Monthly MVARH calculation for D.Transformer
Number of Switching operations	Under voltage and over voltage buses	Correlation between current and temperature	Frequency trend analysis

Fig. 4. Functions Identified for Enhancing Distribution Systems Efficiency and Reliability

Fig. 4 shows the various analytics that are identified for improving the system reliability and quality of supply in India.

D. Towards defining and implementing the Standards

Implementing Standards is a major issue in transitioning towards advanced automation, and also is a crucial step in creating Smart Grids. As the automation systems in India are from different vendors with their own legacies, they are proprietary and have no dual interoperability. The identified standards which govern the necessary integration of different functions are:

- IEC 61968 - Distribution Management
- IEC 61970 - Common Information Model
- IEC 60870 - Inter-control center communication protocol
- IEC 62210 - Data and Communication Security
- IEC 62357 - Reference Architecture
- IEC 61850 - Standard for Design of Substation Automation
  - IEC 61850-7-420 - Integration of Distributed Energy Resources
  - IEC 61850-7-410 - Integration of Hydro Resources
- IEC 61400 - Integration of Wind farms to Utility Communication Network
- IEC 62056 - Communication protocol for DERs and Metering Devices and more...

E. Substation Automation in India

Substation automation covers distribution and transmission/sub-transmission zones. In India, there are different operating voltage levels viz., 110 kV, 132 kV, 220 kV, 400 kV and 765 kV, for which there are central transmission utility substations and state transmission utility substations. Traditionally, automation has been carried out as remote terminal unit-based by different vendors. But due to global adoption of standards, India initiated the usage of IEC 61850 compliant, IED based substation automation schemes. Maharanibagh in Northern region is the first central transmission utility's (POWERGRID) substation with IEC 61850 compliance. Currently, there are several substations in India that have successfully adopted this compliance. They report to their respective control centers using the gateway standard IEC 101/104. Due to the adoption of IEC 61850 standard based automation, the flexibility of reporting critical events at the bay level directly to the human machine interface (HMI) at control centre is achieved [25].

This section presented various real world initiatives and the initial success achieved in the implementation of DA, SA, advanced automation functions with open standards in India. Based on these experiences, the next section takes a boarder view and defines a framework for SG implementation in India.

IV. TOWARDS SMART GRIDS IN INDIA

A “Smart Grid” is a concept for transforming the nation's electric power grid by using advanced communications, automated controls and other forms of information technology. It integrates new innovative tools and technologies from generation, transmission and distribution all the way to consumer appliances and equipment. This concept, or vision, integrates energy infrastructure, processes, devices, information and markets into a coordinated and collaborative process that allows energy to be generated, distributed and consumed more effectively and efficiently. Though the deployment strategy for intelligent Smart Grid encapsulates all stages of the electric power life cycle (generation, transmission, distribution, metering, customer), it should initially focus on sustainable options for customers at the distribution, meter and customer phases. Hence, a "Smart Grid" enables devices at all levels within the grid (from utility to customer) to independently sense, anticipate and respond to real-time conditions by accessing, sharing and acting on real-time information. Simply stated, Smart Grid is the convergence of information and operational technology applied to the electric grid, allowing sustainable options to customers and improved security, reliability and efficiency to utilities. A modernized grid would create a digital energy system that will:

- Detect and address emerging problems on the system before they affect service,
- Respond to local and system-wide inputs and have much more information about broader system problems,
- Incorporate extensive measurements, rapid communications, centralized advanced diagnostics, and feedback control that quickly return the system to a stable state after interruptions or disturbances.

For example, the combination of three emerging technologies i.e., advanced metering infrastructure, distribution automation, and integration of distributed energy resources would constitute a *Distribution Smart Grid* [18], [26]. We have identified that one of the ways to succeed in implementing a Smart Grid that can enable a wide range of intelligent applications well into the future is the usage of "Standards based approach" and the focus on dual interoperability of technologies.

A. Current status

Demand side management (DSM) is essential for optimized and effective use of electricity. In the face of scarce resources, DSM is the major issue identified in the Indian system, where demand is in excess of the available generation, inevitably leading to load curtailment [27]. The non technical losses are more in India. The identified way to fully overcome these problems is by reducing demand through electricity grid intelligence, which requires advanced control and communications technologies integrated with the utility network, thus providing the requirements of "Smart Grid". To facilitate demand side management, distribution networks are to be fully-augmented/upgraded for IT enabling. IT enabling in distribution will help in improved network planning, improved operation and maintenance, energy accounting and auditing at each level, graded load shedding measures to flatten the demand curves, eventually results in improved customer service. Adoption of IT has been mandated in the Restructured APDRP [28]. Ministry of Power [28] also participated in the SMART 2020 event with The Climate Group [29] and The Global e-Sustainability Initiative (GeSI) in October 2008. The aim of this event was to highlight the reports relevant to key stakeholders in India. Unfortunately, the possible "way forward" has not yet been drilled out and is still a question mark for the Government. We identified that Smart Grids can help Governments and utilities manage the crush of demand for energy by improving system performance, reducing energy loss and enabling alternative sources such as wind and solar. A vision for Indian Smart Grids is developed with its applications at various levels presented in the next subsection outlining a 'move forward' approach.

B. Vision for Smart Grids in India

Majorally, Indian power system is operated as five Regional grids viz., Northern Regional grid (NR), Western Regional grid (WR), Eastern Regional grid (ER), Southern Regional grid (SR) and North Eastern Regional grid (NER).

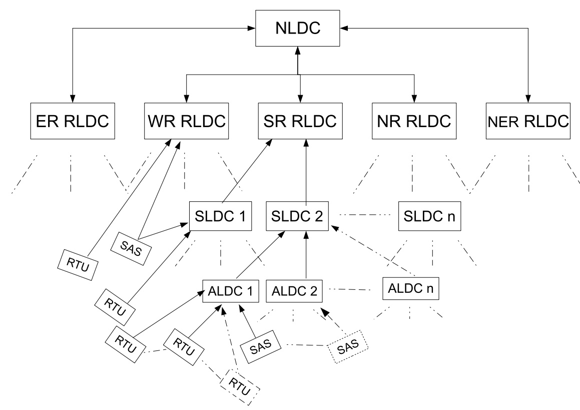

Fig. 5. Typical Indian Grid Control hierarchy

The control of the grid is planned to be done at four levels of hierarchy namely (1) National Load Despatch Center (NLDC), (2) Regional Load Despatch Center (RLDC), (3) State Load Despatch Center (SLDC), and (4) Area Load Despatch Center (ALDC). In all, there are 5 regional grids, 31 state grids and 100 plus area-wise grids in India. Again, internal to area grids, local distribution area grids are also available. Each grid has its own dispatch centers and follows the hierarchy as shown in Fig. 5. Market operations are co-ordinated by Market operators with RLDCs. The vision is to make these power grids 'smart'. Fig. 6 shows the envisioned Smart Grid architecture for Indian power systems.

A three layered Foundation Block as enclosed in the dotted box in Fig. 6 when realized with sufficient granularity would be the reservoir of syntactic information, from which the various entries of the Utilization Block (solid box in Fig. 6) would extract out the relevant information through coordination made possible with pertinent open standards. In effect, this would render effectual operational decisions. Some of the constituents of the Utilization Block are: market operations, national, regional and state transmission utilities, distribution control centres and external corporations.

Lowest in the hierarchy of the Foundation Block is Controls and Sensors which collates the requisite data from the power

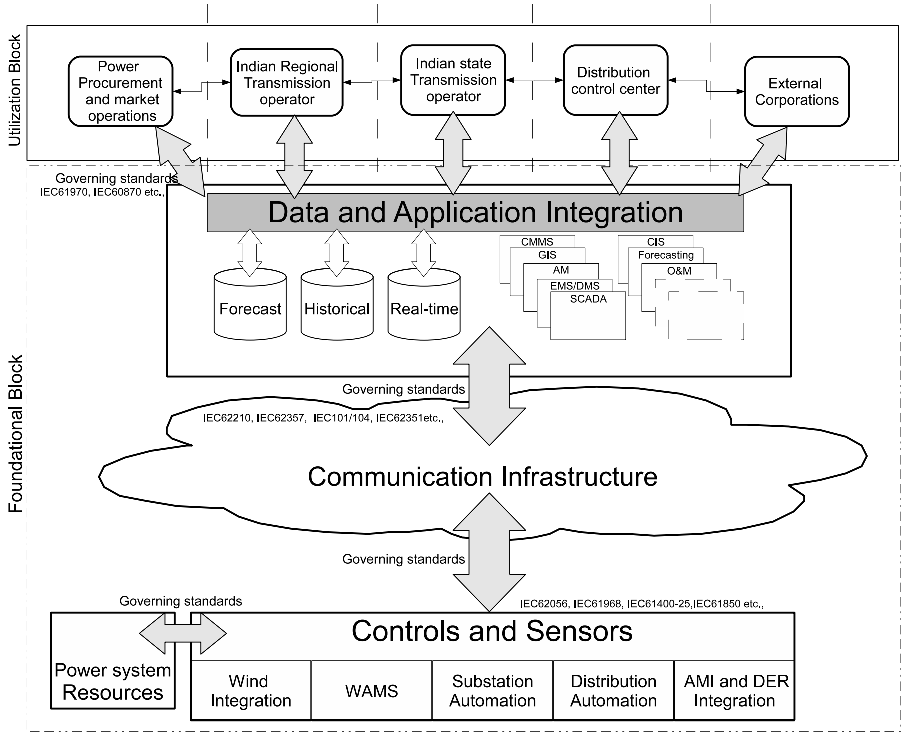

Fig. 6. Proposed Smart Grid Architecture for Indian Power Systems

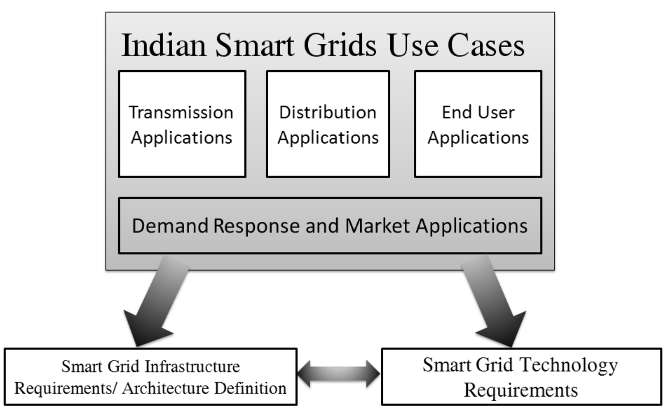

Fig. 7. Approach for Indian Smart Grids

system primary equipment concerning all the substations. This is then transferred through a gateway of Communication Infrastructure comprising public/private networks, optical fibres, satellite communication and other means under the guidance of relevant standards for Data and Application Integration (DAI). The data in DAI layer is segregated into real-time, historical and forecast classifiers, which are continuously updated and on which the applications such as EMS, SCADA, CIS etc. will be developed.

A specific approach for successful implementation of the proposed architecture of Fig. 6 dipicts a paradigm shift from today's technology-based standards to performance-based standards. This requires performing considerable business case analyses to delineate the desired functionalities that are symbiotic to economies of scale and chosen technologies. In this regard, learning from the existing practices around the world is elemental. The conclusive approach for Indian Smart Grids would be to assimilate these insights as shown in Fig. 7.

V. Conclusions

This paper presents a discussion on the unified approach to evolve the conceptualization of Smart Grids for the Indian Power Scenario. Starting from a review of the developments in India in the field of automation, it emphasizes on the deployment of open standards for achieving modularity and interoperability. A model architecture is then proposed, recommending a transformation from current technology based standards to performance based standards. In view of the multitude of benefits that could be accrued, it is suggested that there should be ample Government regulatory support and policy initiatives to move towards Smart Grids. India is in its nascent stages of implementing standards for ADA, requiring a revamped outlook to modify the existing standards as per its identified conditions and needs. Dedicated collaborative research should be encouraged to facilitate a smoother transition towards creating and integrating modular Smart Grids for a nationwide evolution of this revolutionary approach in India. In this connection, this paper should act as an initiating pointer in bringing forth the significance of championing the Smart Grid philosophy and implementing it on the basis of the proposed architecture in the Indian subcontinent. Further, transformations in terms of standards, financial mechanisms, technology sharing and policy frameworks need to be rigourously addressed.

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