Design and Deployment Strategy for Advance Metering Infrastructure in India

Summary of Ph.D. Thesis

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1 Indian Power Sector

Electricity is the resource that drives the modern economy. Over the course of the last century, growth in electricity use has closely matched growth of the US economy and the same experience has been found with other developed and developing nations. Therefore electricity consumption should be measured accurately and should be priced economically. The difficulties in measuring electricity accurately is largely due to the fact that electricity consumption need to be recorded in smaller time interval such as 5 minutes, 10 minutes, 15 minutes etc. The difficulties in pricing electricity economically is; electricity need to be generated on demand (Electricity cannot be stored) and demand varies with time. To serve the time varying demand different generation units with different generation prices on account of different efficiency and different fuels are being used. Since the demand of each customer of electricity varies independent to other customers, ideally a separate tariff should be devised for each customer. Theoretically, it might be possible but it gets severely limited by the capabilities of meter and billing and ability of the electricity user (‘customer’) to comprehend such complex tariff structure. Secondly, meters are the cash register of the utility and failure of these devices to function properly can have significant consequences for financial performance and customer service due to provisional billing, wrong billing and customer billing disputes. The metamorphosis of the electric utility meter is in progress as it continues the change from tracking consumption for billing to be a high tech, network addressable component on a large scale utility network.

It will be useful to briefly review the historical developments and current status of the Indian Power Sector and of meter and metering technology before we start formulating our research problem which can support the need of the modern metering infrastructure for Indian Power Sector.

1.1 Power Sector

The journey of Indian power sector started with small generators and small licensees generally confined to one district in the pre-independence era e.g. before 1947, operating under Indian Electricity Act 1910. After independence, Government of India (GOI) has given special importance to electricity realizing its value in economic and social development of the country. Indian Supply Act 1947 was enacted immediately after independence. Under the Indian Supply Act 1947, State Electricity Boards (SEB) were created in each state (Combination of several districts) and were made responsible for generation, transmission and distribution of electricity within their states. All the existing small generating and
distribution licensee were brought under the respective SEBs. Central Electricity Authority (CEA) was established at federal level to coordinate and monitor the working of SEBs at central level.

Item 38 in List III of the Seventh Schedule of the Constitution of India places electricity in the concurrent list, that is, on which both the central and state governments have jurisdiction. In practice this has meant that the Centre takes charge of all interstate and international matters, as well as where the ownership is rests with the Centre. The state government is responsible for matters within the state. Initially, electricity was considered state subject with minimal participation of private sector. SEBs helped in development of vast electricity network and accelerated the economic activities in the country. As the electricity has become more and more important in the life of the citizens, it has become politically important in a democratic system. SEBs being under the direct control of State Governments were unable to keep pace in increasing retail tariff vis-a-vis rising cost particularly that of fuel. As a result SEBs and state Government started incurring huge losses. SEBs were also blamed for their inefficiencies, non-accountability and for all other reasons which can be attributed to an ailing public sector. This decelerated the development of new generation capacity and other investments in the sector for development. On the other hand, electricity demand kept on increasing due to increase in population, economic activities, improvement in social life and shift of irrigation from canal based system to ground water based tube-wells.

In order to provide insulation from political interference of the State Government and regulate the sector by independent professional body regulatory commissions were created by The Electricity Regulatory Commission Act 1998. At the same time, Government of India (GOI) started liberalizing economy and invited private players to invest in several sectors including electricity particularly in generation. One of the reasons identified for limited response from private players to invest in generation was legal enforcements which were not conducive to create competitive atmosphere. As a result GOI enacted a new Act called Electricity Act 2003 (EA) repealing the Indian Electricity Act 1910, Electricity Supply Act 1947 and Electricity Regulatory Commission Act 1998. The EA disintegrated SEBs into generation, transmission and distribution companies (generally 3-4 distribution companies in a State) with the hope that corporatization will bring private sector skill sets and improve the sector. Focus was on increasing generation as average demand supply gap reached to about 20% (in year 2001-2002). Generation was completely liberalized and techno-economic approval from CEA for putting thermal power plant was waived off. Captive generation was encouraged and captive generators were permitted to sale power to third party. Open access was introduced to customers. Universal right of electricity of the citizens was recognized.
The EA was considered a radical change in the power sector and open the gate of private investment in the sector. To achieve the objectives of the EA, several policies, rules and regulations followed. Table 1.1 provides the summary of the important act, policies, rules and regulations pertaining to the electricity sector along with brief about the document and related link.

**Table 1.1: Indian Power Sector - Important Act, Policies, Rules and Regulations pertaining to Electricity Generation**

<table>
<thead>
<tr>
<th>Acts/Polices</th>
<th>Objective</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>The Electricity Act, 1948</td>
<td>Rationalization of the production and supply of electricity (Mandated Creation of SEBs)</td>
<td>(Repealed by Electricity Act 2003)</td>
</tr>
<tr>
<td>Electricity Act, 2003</td>
<td>Creating liberal and competitive environment for power sector &amp; facilitating private investments</td>
<td>Existing and twice amended</td>
</tr>
<tr>
<td>National Electricity Policy, 2005</td>
<td>Competition &amp; protection of customer</td>
<td>Existing</td>
</tr>
<tr>
<td>National Electricity Tariff Policy 2016</td>
<td>Installation of smart meter mandatory for all customers</td>
<td>Existing</td>
</tr>
<tr>
<td>Electricity Act 2003 (draft amendment 2014)</td>
<td>Promote competition, efficiency in operations and improvement in quality of supply of electricity in the country resulting in capacity addition and ultimate benefit to the customers.</td>
<td>Draft stage yet to be passed in parliament</td>
</tr>
</tbody>
</table>

Source: [www.powermin.nic.in](http://www.powermin.nic.in)
In the following sub sections, we will briefly describe the key Acts, Policies, Rules and regulations and their impact on the power sector.

1.2 The Electricity Act, 2003

Recognizing the need for the reform process covering the entire facets of the electricity sector comprising generation, transmission and distribution, a comprehensive Electricity Bill was drafted in 2000 following a wide consultative process. After a number of amendments, the bill finally sailed through the legislative process and was enacted on 10 June, 2003. It replaces the three existing legislations governing the power sector, namely Indian Electricity Act, 1910, the Electricity (Supply) Act, 1948 and the Electricity Regulatory Commissions Act, 1998 and is titled Electricity Act, 2003 (EA).

Under EA, transmission, distribution and trading of electricity were made licensed activities. Generation has been freed from licensing. EA empowers regulatory commission to decide the tariff for generation, transmission or retail/distribution. For the activities confined to the state, State Electricity Regulatory Commission (SERC) will decide and where more than one State is involved Central Electricity Regulatory Commission (CERC) will decide the things. The CERC can issue guidelines for deciding the tariff. But SERC can deviate from the guidelines issued by CERC by recording reasons for deviation. The EA also mandated non-discriminatory open access of the network and gradual implementation of open access in the distribution system. This paved the way for creation of power market in India. The EA mandated Regulatory Commissions for encouraging competitions in the market. The other main provisions of the EA are:

- Provision for license-free generation and distribution in rural areas in the notified areas where there are challenges in extending grid power.
- Provision for management of rural distribution by Panchayats, Cooperative Societies, non-government organizations, franchisees, etc.
- Multiple licensing in distribution.
- Mandatory metering of all electricity supplied to the customer.
- Adoption of multi-year tariff principles.
- Provision for cross-subsidy surcharge on direct sale to customers.
- Power Trading recognized as a distinct activity with ceilings on trading margins to be fixed by the Regulatory Commissions.
• Upfront payment of subsidies by the States.
• Setting up of an appellate tribunal to hear appeals against the decisions of the CERC and the SERCs.
• No surcharge on captive generation.
• Penalties for theft of electricity
• Standard of performance regulations
• New connection within specified time period.

The EA aims at providing an investor friendly environment for potential developers in the power sector by removing administrative hurdles in the development of power projects and provide impetus to distribution reform to be undertaken in India. It envisages that reform in distribution sector will enhance collection from customer, will improve financial position of distribution companies and thereby provide better confidence to the generators for their payment for sale of electricity to distribution companies. Provisions like de-licensing of thermal generation, open access and multiple licensing, no surcharge for captive generation shall be the basis for a competitive environment in the Indian power sector. Provisions of open access are instrumental in the development of competitive power markets, and multi-year tariffs shall bring in necessary incentives for performance improvement and reduce regulatory risk.

1.2.1 Meter Related Provisions in Electricity Act 2003
Meter has been mentioned in Section 2, 45, 50, 55, 73, 135, 136, 138, 163 and 177 of the EA. Section 2 (22) defines meter: “a meter used for ascertaining the quantity of electricity supplied to any premise” under the definition of ‘Electrical Plant’. Section 45 (3) (b) permits discoms to recover from customer the rent or charge for the meter. Section 50 specifies that SERC would make Electricity Supply Code which will provide regulations about damage of meter, replacement of meter, testing of meter etc. Section 55 deals exclusively with meters. It prohibits licensee from supplying power without proper meter. Section 73 and Section 177 authorizes CEA to make regulations for installation and operation of the meters. Section 135, 136 and 138 specifies punishment for interference with meter or for shifting the meter. Section 163 authorizes licensee or its representative to enter premises at reasonable time and on informing the occupier of his intentions, for installing, inspecting, and testing, repairing, removal etc. of the meter.

1.2.2 Amendments to the Electricity Act of 2003
Electricity Act 2003, underwent two amendments. First amendment was done in Year 2007 and the second amendment came in Year 2014. First amendment was made effective from June 15, 2007. The
amendments were made to strengthen the assessment, fines and legal framework to check the commercial losses due to theft and unauthorized use of electricity. The sections 6, 9, 38, 43, 50, 61, 126, 127, 135, 150, 151, 176, 178 and 181 were amended. The second amendment to EA was made effective from January 27, 2014. It tuned sections 14, 42, 121, 135, 139, 140 and 146 of the EA to remove some of the operational bottlenecks in the implementation of the EA. These amendments are related to the open access, appellate tribunal and theft. Timeframe for introducing distribution open access was defined as 5 years and overriding importance of Appellate tribunal was reduced by these amendments.

1.2.3 Latest Proposed Amendments in Electricity Act 2003

To liberalize the power sector, GOI has proposed further amendments to the EA. In the proposed amendments carriage and content will be disintegrated. Wire will be considered a separate business and supply as a separate business. This is similar to UK model. This will drastically change the current operation of the power sector. These amendments have been debated and passed by the lower house (“Lok Sabha”) of the parliament. Currently these amendments are under scrutiny by the Standing Committee of the Parliament. Key changes proposed in the amendment are illustrated in the following subsections.

1.2.4 Separation of Wire and Supply Business

To strength the distribution segment the proposal to separate the distribution and supply business is introduced which would be helpful to improve the efficiency of the distribution companies (discom) which are currently under heavy debts. The propose changes are:

- Distribution and supply businesses to be recognized as separate licensed activities
- Distribution licensee to be responsible for development, operation and maintenance of distribution network business and shall have an obligation to provide connection on demand to any customer in its area of distribution
- Incumbent supply licensee to be carved out of the existing distribution licensee
- Supply licensee will be responsible for arranging supply of electricity for all the customers in its area of supply
- Licenses to be granted to other applicants in the area of supply of the incumbent supply licensee based on the load of the customers (say 1 MW and above)
- Enabling provision for gradual reduction of threshold connected load and grant of supply license for the purpose of open access
• Intermediary Company to hold all the PPAs as per re-organization scheme
• Supply licensees so designated by Appropriate Commission to be Provider of the last resort
• The generators and traders to continue to be eligible to supply electricity directly to the customers
• Tariff for the open customers (customers who are mandated to choose their supplier) not to be regulated - only ceiling tariff
• Tariff for the remaining customers of the incumbent supply licensee to be regulated
• Sections amended: 14, 20, 24, 42, 44, 45, 47, 48, 49, 50, 69A, and introduction of new part VI and VI B as consequential changes

Figure 1.1 depicts the existing framework as per EA, 2003 while Figure 1.2 represents the framework after implementation of the proposed amendments in the EA.
1.2.4.1  **Grid Security**
For security of grid and to minimize the faults in the grid, the penalties in various clause has been increased for the defaulting generators or discoms. Considering the need for strengthening Grid Security and high stakes involved increase in penalty from INR 1.5 million to INR 100 million (Section 29), INR 0.5 million to INR 10 million (Sections 33) and INR 0.1 million to INR 10 million and recurring penalty of INR Six thousand/five thousand to INR 0.1 million on every day of non-compliance (Section 142 and 146) of the instructions of the state/central load dispatch center.

1.2.4.2  **Promotion of Renewable Energy**
For security of energy and better environment the renewable share in the energy mix has been increased. Certain changes have been mentioned in the draft like Renewable Purchase Obligation (RPO) penalty has been increased to INR 10 million.

- Definition of 'Decentralized Distributed Generation', 'Obligated Entities', and Renewable Energy service Company & 'Renewable Energy Sources' have been introduced or amended (Section (15a, 46a, 57a, 57b)).
- Notification of 'National Renewable Energy Policy' (Section 3).
- Development of Renewable Energy industry (Section 3(4)).
- Introducing Renewable Power Generation obligation on new conventional thermal power plants (Section 7).
- Exemption of sale of electricity generated from renewable energy sources from cross subsidy and open access charge (Section 42(2)).
- Bringing RPO under penal provision with penalty up-to INR 10 million. (Section 142).

1.2.4.3  **Open Access**
To minimize the misuse of section 11 of EA by the State Governments.

- Section 11 proposed to be amended to restrict powers of State Governments to give directions for curtailing Open Access (Section 11)
- Clarity of status regarding 1 MW and above customers as deemed Open Access customers (Section 49)

1.2.4.4  **Rationalization of Tariff**

- Allowing licensees to recover cost of electricity without any revenue deficit. (Section 61(d))
- Promotion of hydro power generation (Section 61 (ha))
- Provisions of Tariff Policy made mandatory for Tariff determination (Section 61(2))
• Determination of Tariff under back to back arrangement involving an intermediary electricity trader or any other licensee incorporated (Section 62)
• Pass through of the effect of fuel and power purchase cost more than once in a year (Section 62(4))
• Provision for initiating suo-motu proceedings for determination of tariff. (Section 64)

1.3 National Electricity Policy, 2005

The Policy aims at achieving the following objectives:
• Access to electricity - Available for all households in next five years
• Availability of power - Demand to be fully met by 2012. Energy and peaking shortages to be overcome and adequate spinning reserve to be available.
• Supply of reliable and quality power of specified standards in an efficient manner and at reasonable rates.
• Per capita availability of electricity to be increased to over 1000 units by 2012.
• Minimum lifeline consumption of 1 unit/household/day as a merit good by year 2012
• Financial Turnaround and Commercial Viability of Electricity Sector.
• Protection of customers’ interests.

1.4 National Tariff Policy, 2006
• In compliance with section 3 of the EA the federal government notified the Tariff policy on 6th Feb 2006 and thereafter amended it in 2008 and in 2011. The Policy notified objectives to ensure availability of electricity to customers at reasonable and competitive rates, ensure financial viability of the sector and attract investments, promote transparency, consistency and predictability in
regulatory approaches across jurisdictions and minimize perceptions of regulatory risks and promote competition, efficiency in operations and improvement in quality of supply.

The key provisions are:

- From 2011, the power procurement by the discoms to be based on competitive bidding
- A two-part tariff structure should be adopted for all long term contracts to facilitate Merit Order Dispatch (MOD).
- Power Purchase Agreement should ensure adequate and bankable payment security arrangements to the Generating companies.
- Coal based generating stations, the cost of project will also include reasonable cost of setting up coal washeries, coal beneficiation system and dry ash handling & disposal system.
- Implementation of Multi-Year Tariff (MYT) framework
- Tariff design: Linkage of tariffs to cost of service
- Cross subsidy surcharge is to be paid by open access customers. This is calculated as the difference between the customer tariff and the cost of supply.
- Amendment (Mar 08) on Hydro tariff (transparent bidding, long term PPA for 60%, R&R, development fund etc.
- The MYT framework in distribution sector is to be adopted for any tariffs to be determined from April 1, 2006.
- Tariff fixation for all electricity projects (generation, transmission and distribution) that result in lower Green House Gas (GHG) emissions than the relevant base line should take into account the benefits obtained from the Clean Development Mechanism (CDM) into consideration, in a manner so as to provide adequate incentive to the project developers.

1.5 National Electricity Tariff Policy 2016
The GOI amended the National Tariff Policy (NTP). Several reform measures have been announced in this change. NTP 2016 has increased focus on renewable energy, sourcing power through competitive bidding and the need for ‘reasonable rates’. The salient features of the policy are
• The SERC to mandate smart meters for customers with monthly consumption of 500 units or more by December 31, 2017 and for customers with monthly consumption above 200 units by December 31, 2019.
• Co-generation from non-RE sources to attract RPO
• Competitive bidding to be the norm for RE procurement (maximum 35% of installed capacity can be sourced from determined/preferential tariff)
• Provisions for Renewable Generation Obligations (RGO) announced
• Long term RPO to be announced by Ministry of Power
• Vintage and technology multiplier allowed in REC
• Inter-state transmission charges waived off for RE power
• Solar RPO to be 8% by 2022 (excluding hydro power)
• Calculation of Cross-subsidy methodology is suggested to be changed to make it less arbitrary

1.6 Upcoming Developments and Reforms in Indian Power Sector
• The latest development in the Indian Power Sector is the draft amendment to EA, which is already approved by the cabinet and understudy with Standing Committee of the Parliament and likely to become law soon. If passed, separation of carriage and content will change the dynamics of industry.
• Power ministry is preparing cabinet note on tariff policy with changes such as extension of Section 62, under which the electricity regulatory commissions have been empowered to determine tariffs, beyond financial year 2017. (Under the cost plus tariff structure, Central Govt generators such as NTPC and NHPC charge a lump sum fee as well as a per-unit charge from distribution companies).
• Another proposed change is having a formula which would ensure that variation in fuel and power purchase cost is recovered.
• Under ‘Make in India’, program certain initiatives are planned to be completed in next one year. These include
  o Provide policy guidance to Financial Institutions (FIs) (e.g. Exim Bank) to extend "supplier credit" to Indian manufacturers in similar fashion as done in China or USA.
  o Mandate requirement of service center/ service provide network in India for power projects e.g. introduce this as part of SBD (Standard Bidding Document) for Case 1 and 2 bids for generation
  o Amend Public Procurement Policy to allow the criteria for procurement to include "economic value" instead of "lowest cost"
o For cost calculations consider "Life cycle costs" wherever possible, instead of just upfront purchase price.
o Concessional duties on raw materials and intermediary goods.
o Rationalize duties for domestically manufactured goods to provide a level playing field with imported finished goods.
o Ensure that all components used in the Indian power network are tested and approved by certified Indian test house.
o Mandate vendor development programs to help substitute imports by local manufacturing for public sector companies.

- It is expected that bids for four UMPPs will be held in next 6 months under above guidelines.
- All the coal based power plants under 13th five year will be based on super critical technology.

1.7 Observations
The Indian power sector has achieved a lot, over the last decade in the areas of policy reforms, private sector participation in generation and transmission; new manufacturing technology and capabilities, but there is still much to achieve and a number of challenges to overcome before the opportunities can be leveraged.

The enactment of Electricity Act (2003), notification of Mega Power Policy (1995), National Electricity Policy (2005 and 2016) and National Tariff Policy (2006), have all led to a much liberal power sector, which then saw active investments from private sector across the value chain. However, most of the participation by private investors has happened in generation sector, driven by de-licensing of generation, fiscal incentives for large scale capacity additions and competitive procurement of power. The reforms in the sector have restructured the vertically-integrated market structure to a competitive structure. Market efficiency has been improved over time as many laws and regulations have achieved the desired result. Mobility has increased in the power market and so have the number of players; the regulation has created a competitive market place, which in future will completely open the market in power sector.

In the latest development of the sector the government has proposed the amendment in Electricity Act 2003 with the aim to promote competition, efficiency in operations and improvement in quality of supply of electricity in the country resulting in capacity addition and ultimate benefit to the customers. It would be helpful for central, state and private power plant developers as one of the major proposed change is separation of carrier and content business of distribution which would be helpful for distribution companies to strength its financial position in future which further would be helpful for generator to get
their payment for power supply on time. The private developers would benefit most from this as the investors mostly hesitate to invest in private projects because of payment security and with this proposed change the investor may get confident as this proposed change would strength the discoms financial. The central and state developers in which investors generally feel confident on investment may also benefit from this change as it would also strength their payment security.

The sector has benefited a lot from the proposed changes specially the private sector as the proposed amendment would bring confidence in the developer and investor and would help in increasing the private sector participation in the power sector.

2 Evolution of Electricity Meter

The electricity meter is vital component in the power sector. It measures the generation of electricity by a power plant, transmission of electricity by a electric line and supply/consumption of electricity by discom/customer. All commercial transactions are based on the flow or consumption recorded in the meter. The accuracy and speed of meter recording directly impacts the reliability of commercial transactions and speed of commercial settlement among various players such as generators, transmission line owner, discom, customer etc. Therefore, any improvement in meter and metering technology improves commercial transactions in the power sector. Therefore, it will be of interest to trace its history of evolution.

The first half of the nineteenth century brought brilliant discoveries in electromagnetism. In 1820, the French André-Marie Ampère (1775-1836) discovered the electrodynamic interaction between currents. In 1827, the German Georg Simon Ohm (1787-1854) discovered the relationship between voltage and current in a conductor. In 1831, the British Michael Faraday (1791-1867) discovered the law of induction, on which the operation of generators, motors and transformers is based. By the second half of the century, the soil was well prepared for practical applications. With the invention of the dynamo (Anyos Jedlik in 1861, Werner von Siemens in 1867) electrical energy could be generated in large amounts. The first mass application of electricity was lighting. When this new product – electrical energy – started to be sold, it was obvious that the cost had to be determined.

It was not clear, however, what the units billed should be, and what would be the most suitable measuring principles. The earliest meter was Samual Gardiner’s (USA) lamphour meter patented in 1872. It measured the time during which energy was supplied to the load, as all the lamps connected to this meter were
controlled by one switch. Subdividing lighting circuits became practical with the introduction of Edison’s light bulb, and this meter became obsolete.

2.1 Electrolytic Meters

Thomas Alva Edison (1847-1931), who introduced the first electrical distribution systems for lighting using direct current, held that electricity must be sold just like gas – also used extensively for lighting at that time. His “Electric meter” patented in 1881 (USA patent No. 251,545) used the electrochemical effect of current (Ref Figure 2.1). It contained an electrolytic cell, into which an accurately weighed strip of copper was placed at the beginning of the billing period. The current passing through the electrolyte caused a deposition of copper. At the end of the billing period, the copper strip was weighed again, and the difference represented the amount of electricity that had passed through. The meter was calibrated so that the bills could be rendered in cubic feet of gas. These meters remained in use until the end of the 19th century. There was, however, one large drawback – meter reading was difficult for the utility and impossible for the customer. Edison later added a counting mechanism to aid meter reading. There were other electrolytic meters, like the German Siemens-Shuckert hydrogen meter and the Schott&Gen. Jena mercury meter. Electrolytic meters could measure only ampere-hours and were not suitable when the voltage fluctuated.

![Edison Electric Meter](image)

2.2 Pendulum Meters

Another possible principle upon which to build a meter was to create some motion – oscillation or rotation – proportional to the energy, which could then drive a register to read. The principle of the pendulum meter was described by the Americans William Edward Ayrton and John Perry in 1881. In 1884, without knowing of their invention, Hermann Aron (1845-1902) in Germany constructed a pendulum meter (Ref
Figure 2-2). In its more advanced form this meter had two pendulums, with a coil on both pendulums connected to the voltage. Below the pendulums there were two current coils winding in opposite directions. One of the pendulums therefore was running slower and the other faster than without load. The difference between the oscillation times drove the counting mechanism. The role of the two pendulums was swapped every minute, so that the initial difference between the oscillation times of the pendulums could be compensated. At the same time, the clock was wound up. These meters were expensive because they contained two clocks, and they were gradually replaced by motor meters. Pendulum meters measured ampere-hours or watthours, but could be used only for direct current.

![Pendulum Meter](image)

Figure 2-2 Pendulum Meter

2.3 Motor Meters

Another possibility was to use a motor to build a meter. In such meters, the driving torque is proportional to the load and is balanced by a braking torque, so that the rotor speed is proportional to the load when the torques are in equilibrium. The American Elihu Thomson (1853-1937) developed his ‘Recording wattmeter’ in 1889 for General Electric (Ref Figure 2-3). It was an iron-less motor, with the rotor excited by the voltage through a coil and a resistor, using a commutator. The stator was excited by the current, and the driving torque was therefore proportional to the product of voltage and current. The braking torque was provided by a permanent magnet acting on an aluminium disk, fixed to the rotor. This meter was used mainly for DC. The big disadvantage of the motor meters was the commutator.
2.4 Induction Meters

In the early years of electricity distribution, it was not yet clear if direct current (DC) systems or alternating current (AC) systems would be more advantageous. However, an important disadvantage of DC systems soon became apparent – the voltage could not be changed, and therefore it was not possible to build larger systems. This lead to the development of transformer. With this, the AC electricity system became feasible, and from the beginning of the 20th century it gradually took over from DC systems. In metering, a new problem had to be solved – the measurement of AC electrical energy. The discovery of the effect of rotating fields in 1888, led to the development of an AC ampere-hour meter. The braking torque was provided by a fan. This meter had no voltage element to take the power factor into account; therefore it was not suitable for use with motors. These discoveries opened the way to induction meters. In 1889, the Hungarian Otto Titusz Bláthy (1860-1939), working for the Ganz works in Budapest, Hungary, patented his ‘Electric meter for alternating currents’ (Germany No 52,793, USA No 423,210). As the patent describes: “This meter, essentially, consists of a metallic rotating body, such as a disk or cylinder, which is acted upon by two magnetic fields displaced in phase from one another. The meter used a brake magnet to ensure a wide measuring range and was equipped with a cyclometric register (Ref Figure 2-4). Ganz started production in the same year. The first meters were mounted on a wooden base, running at 240 revolutions per minute, and weighed 23 kg. By 1914, the weight was reduced to 2.6 kg.
Oliver Blackburn Shallenberger (1860-1898) developed an induction type watthour meter for Westinghouse in 1894. It had the current and voltage coils located on opposite sides of the disc, and two permanent magnets damping the same disc. It was also large and heavy, weighing 41 pounds. It had a drum-type register. Ludwig Gutmann, working for Sangamo, developed the “Type A” AC watthour meter in 1899. The rotor was a spirally slotted cylinder positioned in the fields of the voltage and current coils. A disk riveted to the bottom of the cylinder was used for braking with a permanent magnet. There was no power factor adjustment.

2.5 Further Improvements

In the following years, many improvements were achieved: reduction of weight and dimensions, extension of the load range, compensation of changes of power factor, voltage and temperature, elimination of friction by replacing pivot bearings by ball bearings and then by double jewel bearings and magnetic bearings, and improving long term stability by better brake magnets and eliminating oil from the bearing and the register. By the turn of the century, three-phase induction meters were developed using two or three measurement systems arranged on one, two or three disks (Ref Figure 2-5).
2.6 New Functions

Induction meters, also known as Ferraris meters and based on the principles of the Bláthy meter, are still manufactured in large quantities and are the workhorses of metering, thanks to their low price and excellent reliability. As the use of electricity spread, the concept of the multi tariff meter with local or remotely controlled switches, the maximum demand meter, the prepayment meter, and the maxigraph were quickly born, all by the turn of the century. The first ripple control system was patented in 1899 by the French César René Loubery, and was perfected by Compagnie des Compteurs (later Schlumberger), Siemens, AEG, Landis&Gyr, Zellweger and Sauter and Brown Boveri, just to name a few. In 1934, Landis&Gyr developed the Trivector meter, measuring active and reactive energy and apparent demand.

2.6.1 Electronic Meters and Remote Metering

Electronic technologies did not find their way to metering until the first analogue and digital integrated circuits became available in the 1970s. This can easily be understood if one thinks of the power consumption limitations in the closed meter boxes, and the expected reliability. The new technology has given a new impetus to the development of electricity meters. Initially, high precision static meters were developed, mainly using the time division multiplication principle. Hall cells were also used, primarily for commercial and residential meters. Hybrid meters consisting of induction meters and electronic tariff units were constructed in the 1980s. This technology had a relatively short run.
2.6.2 Remote Metering
The idea of remote metering was born in the 1960s. Initially, remote pulse transmission was used, but this has gradually been replaced by using various protocols and communication media. Today meters with complex functionality are based on the latest electronic technology, using digital signal processing, with most functions being implemented in firmware.

2.6.3 Standards and Metering Accuracy
The need for close co-operation between manufacturers and discom was achieved relatively early. The first metering standard, the ANSI C12 Code for electricity metering, was developed as early as 1910. Its Preface says: “While the Code is naturally based upon scientific and technical principles, the commercial side of the metering has been constantly kept in mind as of very great importance”. The first known IEC metering standard, Publication 43, dates from 1931. The high standard of accuracy is an outstanding characteristic that was established and maintained by the metering profession. Leaflets from as early as 1914 feature meters with an accuracy of 1.5% over the measuring range of 10% or less to 100% of maximum current. IEC 43:1931 specifies accuracy class 2.0. This accuracy is still seen as adequate for most residential applications today, even for static meters. In order to have a common protocol for downloading the data from the meters of various manufacturers, IEC TC13 WG14 has established the IEC 62056 series of standards: Electricity metering - Data exchange for meter reading, tariff and load control. Meters complying these standards are called ‘Device Language Message Specification (DLMS) Meters’. As per the directions provided in EA, the CEA has also developed the specifications for static CT/CVT operated tri-vector meters for LT/HT supply [1.4]. These standards are based on IEC 687 and IS 14697. In June, 2013, the CEA released updated specifications for Single Phase Smart Meters to be used in India. This contained 4 categories of meters which was further amended to two categories of meters vide CEA Order No. CEA/DPD/Smart Meter/2013/8916 Dated 18.02.2014. However, there is a view amongst several stakeholders that further clarity on areas such as meter display, meter data storage, specifications of In-Home Display and Data Concentrator Unit, etc. is required. On the other hand, several other agencies are engaged in developing smart meters/standards as summarized below:

- BIS (ET 13 Panel 4) is working on modifying the CEA report with the aim of converting it to a BIS standard for smart meters.
- BIS LITD is preparing a standard on Advanced Metering Infrastructure (AMI), which will be a guideline document to the utilities explaining the actors, benefits and enablers of AMI. This work is assigned to Panel 7 of LITD 10.
Power Grid invited tenders for appointment of consultants to design smart meters that Power Grid intends to sell.

The Department of Telecommunications (DoT) nominated C-DOT for developing a prototype of a smart meter based on the IPv6 for advancement of M2M communications in the country.

Central Board of Irrigation and Power (CBIP) has also decided to prepare specifications/manual for Net Metering.

Under NaMPET program, a smart meter development project is under consideration.

3 Advance Metering Infrastructure (AMI)

Most of the discom in the globe have combination of above three types of meters (Electro-mechanical, electronic and AMR). Some of the progressive discom have replaced their all electromechanical meters by electronic meters. High end customers have been provided with AMR. But these meters do not provide sensing and measurement capability to track much more information regarding both the usage and the quality of the power and capability to support multiple rate forms.

3.1 Introduction

Smart meters provide all the above features of meter with additional communication capability that allows remote access of the meter by the utility. Thus smart meter establishes an information link between the utility supply side of the electric system and the customer side (demand side). This enables utility to better inform the customers about rate and pricing of electricity that reflect the dynamic and time varying changes in generation costs and adds several other functional capabilities to the smart meter such as connect/disconnect pre-payment, load control etc. It is also possible to provide more detailed and timely information to educate customer how they use electricity and how they can modify that usage to reduce their cost and environmental impacts. Utility also get more detailed and timely information from the smart meter to support better outage detection, improved load forecasts and fuel purchasing, and more responsive customer services. To provide all these functions, smart meter is used in association with two way communication link and data processing capability (commonly called MDM-Meter Data Management System). All this combined together, is called Advance Metering Infrastructure (AMI) (Ref Figure 2.1). AMI not only performs core function of recording accurately electricity consumption of the customer but supports host of other optional functions as listed in Table 3-1 below.

<table>
<thead>
<tr>
<th>Table 3-1 : Functions of AMI</th>
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<tbody>
<tr>
<td>Core Functions</td>
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## 3.1.1 AMI IS FIRST STEP FOR SMART GRID

Therefore, meter is no longer an instrument to measure and record customer consumption of electricity but nowadays it is considered a gateway for communication and control among utility (grid), customer and his load. AMI gives customers the information they need to make intelligent decisions, the ability to execute those decisions and a variety of choices leading to substantial benefits they do not currently enjoy. In addition, discom are able to greatly improve customer service by refining operating and asset management processes based on AMI data. AMI is considered as first step out of the following four major essential steps for making the grid smart.

- Advanced Metering Infrastructure (AMI)
- Advanced Distribution Operations (ADO)
- Advanced Transmission Operations (ATO)
- Advanced Asset Management (AAM)

AMI reinforces the following important characteristics of the smart grid:

- Motivation and inclusion of the customer is enabled by AMI technologies that provide the fundamental link between the customer and the grid.
- Generation and storage options distributed at customer locations can be monitored and controlled through AMI technologies.
• Markets are enabled by connecting the customer to the grid through AMI and permitting them to actively participate, either as load that is directly responsive to price signals, or as part of load resources that can be bid into various types of markets,

• AMI smart meters equipped with Power Quality (PQ) monitoring capabilities enable more rapid detection, diagnosis and resolution of PQ problems.

• AMI enables a more distributed operating model that reduces the vulnerability of the grid to terrorist attacks.

• AMI provides for self-healing by helping outage management systems detect and locate failures more quickly and accurately. It can also provide a ubiquitous distributed communications infrastructure having excess capacity that can be used to accelerate the deployment of advanced distribution operations equipment and applications.

• AMI data provides the granularity and timeliness of information needed to greatly improve asset management and operations.

Therefore, AMI is not a single technology implementation but rather a fully configured infrastructure that must be integrated into existing and new utility processes and applications. This infrastructure includes home network systems, including communicating thermostats and other in-home controls, smart meters, communication networks from the meters to local data concentrators, back-haul communications networks to corporate data centers, meter data management systems (MDMS) and, finally, data integration into existing and new software application platforms. Additionally, AMI provides a very “intelligent” step toward modernizing the entire power system.

3.2 Components of AMI System

An AMI system is comprised of a number of technologies and applications that have been integrated to perform as one. Following are the essential technologies and applications included in AMI which will be studied under this work.

• Smart meters

• Communications infrastructure

• Meter Data Management Systems (MDMS)

• Home (local) area networks (HANs)
The graphical representation of AMI to be studies under this research has been made in Figure 2.1 below.

Figure 3-1 Graphical Representation of AMI

In this research work, AMI infrastructure best suited for Indian conditions will be developed considering the global experiences where AMI has been deployed in several discom, status of Indian power sector, upcoming policies of Government of India and behavior of Indian electricity customer. None of the utility in India has implemented AMI so far. In the following text we will provide brief overview of the available technology and applications of each of the four components of the AMI and how we propose to design them for Indian discom. For each component of the AMI the probable and expected research output will also be mentioned.

3.2.1 Smart Meter

Conventional electromechanical meters served as the utility cash register for most of its history. At the residential level, these meters simply recorded the total energy consumed over a period of time – typically a month. Smart meters are solid state programmable devices that perform many more functions, including most or all of the following:

- Time-based pricing
- Consumption data for customer and utility
- Net metering
- Loss of power (and restoration) notification
- Remote turn on / turn off operations
- Load limiting for “bad pay” or demand response purposes
➢ Energy prepayment
➢ Power quality monitoring
➢ Tamper and energy theft detection
➢ Communications with other intelligent devices in the home

![Figure 3-2 A Modern Solid State Smart Meter (Left) and an Older Electromechanical Watt Hour Meter](image)

And a smart meter is a green meter because it enables the demand response that can lead to emissions and carbon reductions. It facilitates greater energy efficiency since information feedback alone has been shown to cause customers to reduce usage.

In this work various available technology for smart meters and their features will studied, analyzed and procurement grade smart meter specifications will be developed for Indian requirement. Keeping Indian conditions in mind, features of smart meter will be identified. Full features of smart meter for all, categories of customers will enhance the investment. Therefore smart meter with limited features will be recommended for low consuming residential customers and smart meters with full features for industrial and commercial customers depending upon the expected participation of the customers in managing the grid. For example low consuming residential customers may not be participating in advanced demand response programs of the discom but load limitation and remote disconnection and connection will be the key requirement of the smart meter for this category of customers. Two or three specification of smart meter will be developed. Each customer category will be recommended a particular set of smart grid specifications depending upon their participation level in the smart grid environment.

### 3.2.2 Communications Infrastructure

The AMI communications infrastructure supports continuous interaction between the utility, the customer and the controllable electrical load. It must employ open bi-directional communication
standards, yet be highly secure. It has the potential to also serve as the foundation for a multitude of modern grid functions beyond AMI. Various communication architectures can be employed, with one of the most common being local concentrators that collect data from groups of meters and transmit that data to a central server via a backhaul channel. Various media can be considered to provide part or all of this architecture:

- Power Line Carrier (PLC)
- Broadband over power lines (BPL)
- Copper or optical fiber
- Wireless (Radio frequency), either centralized or a distributed mesh
- Internet
- Combinations of the above

Above communication technologies will be studied with their pros and cons. The global experience and experience of pilots conducted by various Indian discom will be analyzed. Mostly private discom such as CESC Ltd, Tata Power and Reliance in India have conducted several pilots to ascertain the effectiveness of the various communication technologies. It appears difficult that one particular communication technology will serve the purpose for whole India due to different geographies, environment and varying density of the people & building and the reliability of the communication needed for various applications. Following outcome is expected from this aspect of the research:

1. Matrix of various communication technologies suitable in Indian contest with advantage, disadvantage, reliability and cost.
2. Recommendation of communication technology for each application.
3. Communication architecture options for deployment of AMI
4. Integration of AMI communication architecture with Utility communication architecture.
5. Reliability and cost considerations

3.2.3 Meter Data Management System (MDMS)

A MDMS is a database with analytical tools that enable interaction with other information systems of the utility such as the following:

- Customer Information System (CIS), billing systems, and the utility web site
- Outage Management System (OMS)
• Enterprise Resource Planning (ERP) power quality management and load forecasting systems
• Mobile Workforce Management (MWM)
• Geographic Information System (GIS)
• Transformer Load Management (TLM)

One of the primary functions of an MDMS is to perform validation, editing and estimation (VEE) on the AMI data to ensure that despite disruptions in the communications network or at customer premises, the data flowing to the systems described above is complete and accurate.

India will take significant time to adopt some of the applications such as MWS and TLM. Therefore, it will not be prudent to take MDMS as taken by discom in developed countries. The existing information systems of the Indian discom will be studied and based on existing polices of the Government (such as RAPDRP program, proposed amendments in EA etc and by survey of the discom, the information systems Indian discom are expected to adopt in future will be identified. Their integration architecture with MDMS will be developed.

3.2.4 Home (local) Area Networks (HANs)

A HAN interfaces with a customer portal to link smart meters to controllable electrical devices. Its energy management functions may include:

• In-home displays so the customer always knows what energy is being used and what it is costing.
• Responsiveness to price signals based on customer-entered preferences
• Set points that limit utility or local control actions to a customer-specified band
• Control of loads without continuing customer involvement
• Customer over-ride capability

The HAN/customer portal provides a smart interface to the market by acting as the customer’s “agent.” It can also support new value added services such as security monitoring. A HAN may be implemented in a number of ways, with the customer portal located in any of several possible devices including the meter itself, the neighborhood collector, a stand-alone utility-supplied gateway or even within customer-supplied equipment.

The HAN requirement for Indian customer will be established by analyzing, utility requirement and expected customer behavior. The devices at customer end which utility will like to control will be
identified. These devices will be different for different categories of customers. For example air conditioners, geyser, washing machines and water pumps for residential customers through programmable controller and central air conditioning, lighting and nonessential load through a circuit by directly linking it with grid frequency. The device, display, control, communication and HAN architecture will be recommended for AMI in India.

3.3 AMI Need for India

The Power sector in India has traditionally seen a unidirectional flow of electrons, information and money. With an installed capacity of 258 GW, the Indian power system is the second largest synchronous grid in the world covering an area of over 3 million sq km and about 200 million customers. Yet, almost 79 million households in the country do not have access to electricity and the per capita consumption is one-fourth of the world’s average. Transmission and Distribution losses are also relatively high, in comparison to global standards. Largely dominated by government owned utilities (both central and State), the private sector's role is about 35 per cent in generation, less than 1 per cent in transmission and about 5 per cent in distribution. Several policies and reform programs have been introduced in the power sector starting with the EA which heralded the process of a profound change in the sector. The Accelerated Power Development and Reforms Program (APDRP) and Restructured – Accelerated Power Development and Reforms Program (R-APDRP) for urban and semi-urban areas and the Rajeev Gandhi Grameen Vidyutikaran Yojana (RGGVY) (now Dean Dayal Grameen Vidyutikaran Yojana) for rural areas. Other existing programs such as the Jawaharlal Nehru National Solar Mission (JNNSM) under the Ministry of New and Renewable Energy (MNRE), the Smart Grid Mission under Ministry of Power, the National Electric Mobility Mission (NEMM) under the Ministry of Heavy Industries, and the 100 Smart Cities program under the Ministry of Urban Development (MoUD) etc cannot be made successful if do not change fundamentally the way we operate the grid currently. Globally, the century-old model based on centralized generation, transmission and distribution is giving way to a new era of distributed energy resources. The combination of environmental concerns, government support and rapidly falling technology costs have pushed wind, solar and other renewable energy resources into the mainstream. This has led to challenges for grid operators as they deal with changing power flows and intermittent generation profiles. Demand patterns are also changing – energy efficiency improvements in advanced economies have led to flat or declining overall electricity demand, while the ratio of peak to off-peak demand continues to rise in many markets. Electric vehicles, energy storage, smart thermostats and demand response programs can all enable more demand side flexibility but also present their own challenges. Meanwhile, ageing infrastructure, energy security concerns and the need for improved grid
reliability are pushing grid operators to seek out cost-effective solutions. India has to adopt these changes if it wishes to achieve its target:-

- Supply of 24x7 electricity to all at affordable price.
- 75 GW of solar power by 2022.
- Making the power system demand curve flat by demand response
- Engaging customer for supply of power to grid from their solar roof top installations, car battery, invertors, captive power plants etc.
- Reducing carbon emission
- Making power sector financially viable by reducing the technical and commercial losses to single digit.

The first step for modernizing India's grid system and for converting such complex bi-directional flow of electricity into commercial transaction, is AMI. Customer is longer a customer but prosumer and has an important role to play. The meter is no longer a metering instrument to record the consumption of electricity but a gateway of communication with customer and appliances installed in his premise.

3.4 AMI Benefits to Discom
In particular, AMI will improve broadly three key features of India's grid system including: [2.1]

**System Reliability:** AMI technology improves the distribution and overall reliability of electricity by enabling electricity distributors to identify and automatically respond to electric demand, which in turn minimizes power outages.

**Energy Costs:** Increased reliability and functionality and reduced power outages and streamlined billing operations will dramatically cut costs associated with providing and maintaining the grid, thereby significantly lowering electricity rates.

**Electricity Theft:** Power theft is a common problem in India. AMI systems that track energy usage will help monitor power almost in real time thus leading to increased system transparency.

**Demand Response:** Globally utilities are looking for demand response as an cost effective means to meet peak shortage instead of building peaking power plants. Utilities are also using demand response to meet grid variations due to increase in generation from renewable energy sources. All this require AMI.

3.5 AMI Benefits to the Customer
The customers would be benefited to:

a. View their consumption of electricity accurately on a regular basis
b. Manage loads in different manners based on the design, ranging from remotely turn ON/OFF their appliances to managing total demand to allow curtailed supply instead of load-shedding

c. Save money from Time of Use (ToU) tariffs by shifting non-priority loads

d. Face reduced outages and downtimes, and even lower or zero load-shedding.

e. Can supply power to grid during peak time

f. Can participate in demand response program of the utility

Noting the tremendous important of AMI, the Ministry power in the tariff policy notified on Jan 28, 2016 has made installation of smart meters for all customers necessary. The policy states that

“Appropriate Commission shall, therefore, mandate smart meters for: (a) Customers with monthly consumption of 500 units and more at the earliest but not later than 31.12.2017; (b) Customers with monthly consumption above 200 units by 31.12.2019. Further, two way smart meters shall be provided to all prosumers, who also sell back electricity to the grid as and when they require.”

In addition to reduction of AT&C losses the other argument in favor of smart meter deployment is, it would become essential in future for load-generation penetration of intermittent type of generation like wind and solar power. But there are several challenges in deployment of AMI pan India in view of finance and efforts it require for such a large customer base.

### 3.6 Challenges of AMI Deployment in India

In spite of proven benefits of AMI deployment to the discom and to the customer, at present, there is nowhere complete deployment of AMI. Not even at pilot stage. However, the smart meters have been deployed at few places as a pilot but their total number is so miniscule that did not even represent a percent of the total number of meters in India, which is about 200 million. Similarly some pilots in a discrete way are conducted or are under process of conduction for communication technologies and for Home Area Network (HAN) and appliances/devices. In the present scenario, following are the challenges for AMI rollout in India:

- **Financing.** The financial position of discoms are already very bad. Recovering money from customer is a big political challenge in a democratic set up.
- **Limitations in various last mile connectivity solutions**
- **Availability of limited RF spectrum**
- **End-to-End interoperability standards to integrate AMI systems**
• Latency in the reception of signals
• Coverage of the communications network not 100%
• Consensus on specifications of low cost single phase smart meters by all stakeholders
• Industry readiness for manufacturing of smart meters
• Utilities lack clarity on functional requirements and business models
• Security concerns especially balancing firmware upgradability with usability
• Manpower limitations for deployment, usage, and management - both in the discoms and in the industry.
• Regulatory approval
• Capability and capacity of the discom to make full use of AMI.
• Data security and customer privacy.
• Customer acceptance

4 Formulation of Research Problem

Thus AMI is necessary and Government of India has made installation of smart meter mandatory but its deployment has several challenges. The mitigation of challenge requires technical solution, policy and regulatory changes, finance, standards and deployment strategy. Global experience can provide clues but same solution cannot be replicated due to uniqueness of India and large size. Therefore a solution suited to India need to be tailored for installation of AMI pan India. The technical solution is most important as it will reduce other challenges. A sound deployment strategy is equally important. Thus the topic for this research work is “Design and Deployment of Advance Metering Infrastructure (AMI) for India”. This will involve functional and technical design of smart meters for India and strategy to replace about 27 crore meters. It is anticipated that this research work will help in providing smart meters to all customers in a cost effective manner. This research work will also help in deployment of AMI structure in India in a planned manner. The cost effectiveness will be obtained by design of smart meter. Some of the specific areas proposed to be addressed in this research work are as follows:-

4.1 Functional Requirements of AMI

• It will be examined why all customers be provided full functional smart meters. Can a low functionality smart meter be designed for the customers with low monthly electricity
consumption who are not going to participate in demand side management, distributed generation, renewable energy integration etc.

- What should be functional and technical design of such smart meter?
- What all functionalities of AMI can be transferred to the Head End System (HES)?
- What all parameters will be stored at the meter, Data Concentrator Unit (DCU) and HES?
- What are the functionalities that will be offered In Home Display (IHD)?
- What communications technologies will be used in different parts of India? Different geographic areas pose different limitations.
- What will be the specifications of the DCU?
- Preparation of functional requirements and technical specifications of the smart meters.
- What intelligence, logic, and functionality is to be located at which node(s)?
- At what level(s) will interoperability be available?
- What is the expected lifespan of such systems?
- How much of firmware upgradability will be required and in what manner?
- How will security be handled, which extends to firmware, key management, etc., in addition to usability?

4.2 Deployment Strategy

A software model will be developed to find out the optimum strategy for deployment of 27 crore smart meters. The model will be used for evaluating various deployment strategies and considering their impact on the number of meters to be deployed in each year, in each category and in each region. The model will be developed flexible but with proper check and balances. The objective of the model will be to know the number of meters to be installed for low electricity consuming customers and for other categories of the customers. It should be possible in the model to make changes in deployment strategy based on the capacity of the meter manufacturers and capacity of the utility to install number of meter. Thus model will assist in AMI deployment strategy and planning. The model will consists of following three minimum worksheets:-

- Input and Assumptions
- Data and Analysis
• Results

Besides above two main works stated in sub section 4.1 and 4.2, the research work will side by side address following two issues also mentioned in subsection 4.3 and 4.4 below:-

4.3 Regulatory Requirements
• Who will pay for the smart meter? Utilities, customers or third party solution providers??
• Is IHD mandatory?
• If IHD is mandatory, can the meter be outside the premises of the customer?
• At present, there are no regulations regarding operation testing and maintenance of smart meter
• Data privacy - who all will have access to the meter data?
• What are the norms for data access and usage, including but not limited to privacy?
• Are there any options for “opt-out”? There should not be, but this needs to be clarified.

4.4 Requirement of Standards
• Since all smart meters will now have a remote connect/disconnect facility, IS 13779 will not be applicable except for metrology. As of now, IS 15884 is more suitable for smart meters. Need to deliberate and include the relevant standard in the specifications released by CEA.
• COSEM for single phase smart meters needs to be approved on fast track.
• The design of the communication ports shall be standardized.
• The meter should support modular plug-in type communications module (as suggested by CEA). The design, including the pin configurations and the physical size should be standardized so that any smart meter can be plugged with any other make of communications module/communications technology and sealed separately.

5 Research Methodology
Different methodologies have been used for deign of AMI and for deployment of AMI. For design emphasis was on technical and functional characteristics of AMI while a software model was developed for deployment. A brief description of each is provided below:-
5.1 Design of AMI

Based on the customer load profile analysis, 66% electricity customers are those customers who neither have surplus power to feed back into the grid nor likely to participate in demand response. We call these 66% customers as customers under category A and remaining 34% customers under category B. Category A customers can be source for theft and other mal practices for the usage of electricity. Their requirements can be addressed by a smart meter with limited functionalities. MoP with the help of Central Electricity Authority (CEA) has made efforts for developing the design of low cost smart meters for India. Our design has drawn learnings from these efforts of CEA and comply statutory provisions of GOI. We have reviewed following documents in detail:-

- Central Electricity Authority (Installation and Operation of Meters) Regulations, 2006, with its all amendments.
- CEA -Functional Requirement of AMI in India, August 2016
- Smart Metering Scenario in India –A high level summary, by India Smart Grid Forum (ISGF), March 31, 2014
- Smart Meter Specifications of Leading Manufacturers in India- a white paper by ISGF, August 12, 2014

The design is being developed as per standard procedure of AMI design under two categories: 1) Functional Design and 2) Technical Design. The functional design lays down the functionalities expected from the AMI while technical design specifies the technical standards to be followed. The technical standards mentioned complies the Indian regulators and utility requirements.

5.2 Deployment of AMI

For deployment of AMI strategy, whole India has been considered in five regions; 1) Northern Region, 2) Western Region, 3) Southern Region, 4) Eastern Region and 5) North Eastern Region. The same regional classification which is used by Central Electricity Authority for publishing power statistics has been used. A software model has been developed for evaluating various deployment strategies of AMI and considering their impact on the number of meters to be deployed in each year, in each category and in each region. The model has been kept quite flexible but with proper check and balances. The objective
of the model is to know the number of meters to be installed for category A and category B in each customer category. The changes in deployment strategy can be made based on capacity of the meter manufacturers and capacity of the utility to install number of meter. Thus model assist in AMI deployment strategy and planning. The model consists of following five main parts:-

- Definition
- Input Data
- Assumptions
- Analysis
- Results

6 Conclusions
Following key conclusions can be drawn from this research work.

1. AMI is essential for India not just for the purpose of metering and billing the electricity consumption but also for making grid smart, demand side management, integration of renewable energy generation into the grid, distributed generation and better customer services. Therefore Government of India has made mandatory installation of AMI in is recent tariff policy. Each state regulators have been given the task to help utilities in installation of AMI for all customers.

2. Deployment of AMI requires huge investment. Utilities suffering from financial crisis cannot afford it from their own resources. Increasing customer tariff is one option but it should be exercised as last resort. Thus there is a need for new business models.

3. Several countries have already installed or under the process of installation of AMI for all customers. Their experience provides good learning for installing AMI in India for all customers. Following are key learnings:-
   a. Consider replacement of all meters with AMI to have holistic gains. Implementation can be done in phases. The strategy of installing smart meter first and other components of AMI later reduces the advantages of AMI. For example, in order to reduce cost in several countries smart meters have been deployed first and MDM later.
   b. Smart meter impacts several departments (almost all departments) of the utility. Thus create separate unit within utility for deployment of AMI has provided very good results in terms of customer engagement, coordination, vendor management etc.
c. Detailed planning and involving stakeholders including vendors from the beginning reduces backlash of AMI deployment program.

d. Business case should be based on holistic benefits such as loss control (remote connect disconnect, loss control & surveillance, demand response, load management, better consumer service etc.)

4. Deployment of full functional smart meters for all customers will require an investment of INR2757 billion. This research work developed a solution based on design and deployment strategy of AMI which will reduce this expenditure by about 60%.

5. The underlying analysis for new design is that all customers did not require full functional AMI. The customers whose monthly electricity consumption is <=200 units per months will not be going to participate in demand side management, integration of renewable energy generation into the grid, distributed generation. Thus their smart meter can be developed with limited functionalities such as TOD, remote connection/disconnection, over load cut off etc. This category of customers can be provided meter which is named as Category A and rest of the customers as Category B smart meter which has all the functionalities.

6. Therefore, in this research work we have developed design of Category A and category B meter. While designing the meter due care has been taken that the design complies all regulatory requirement and as per Indian standards.

7. The design of category B meters was tested by Calcutta Electricity Supply Company Limited (CESC Ltd), the oldest private utility in India in their smart meter pilots for 1000 customers and results were found satisfactory.

8. Installing meters for about 27 crore customers is mammoth task. It requires planning and good analysis.

9. To develop a proper strategy or plan for deployment of AMI, a software model was developed under this research work. The model helps in developing the strategy for the deployment of AMI in whole India within a period of 5 years.

10. The model is flexible enough to play with several deployment strategies but has check and balances to avoid erroneous results.

11. By using the model, the deployment strategy for installing AMI in whole India over a period of five years has been developed.