What IT Can and Cannot do for the Power Sector and Distribution in India: Link to Reforms, Incentives, and Management

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Abstract

The recent phase of power sector reforms has focused on distribution reforms, under the APDRP, and Information Technology (IT) is seen as a savior for the power industry, whereby advanced technologies such as digital metering will bring in much greater efficiency, theft reduction, and collection. While somewhat true, it is important to recognize that not all IT based solutions are equal, and poor designs can hamper long-term benefits. We present some analysis and results looking at different technologies and systems in the Indian context. In particular, we highlight some non-IT issues relating to reforms and tariff design that impact on IT's potential and pitfalls. A full "smart" system will offer long-term benefits beyond simply theft reduction, and should be the focus of planners, analysts, and industry.

What IT Can and Cannot do for the Power Sector and Distribution in India: Link to Reforms, Incentives, and Management

Dr. Rahul Tongia

Introduction

India's power sector has grown 80-fold since independence to over 107,000 MW,[1] but the per capita power consumption is very low, approximately 350 kWh/year. This number is not precisely known, since a significant fraction of the consumption is unmetered, and there is a large proportion of theft. Ostensibly, transmission and distribution (T&D) losses are about 25%, but only some fraction of the losses are technical losses; the theft is bundled together as "commercial losses." The fundamentals are very poor – with every kWh sold, the utilities lose over 1.1 rupees on average (Planning Commission, 2002). This results in enormous losses for the utilities and the government, despite billions of rupees in explicit and implicit subsidy. One major reason for the system non-viability is the skewed retail tariffs, whereby agricultural consumers receive virtually free power (with flat-rate pricing averaging under 0.50 Rs/kWh) and even domestic consumers receive modest subsidies. Together, these are about half the consumption. The remaining paying customer (primarily commercial and industrial) cross-subsidize these sectors through very high tariffs. Worse, industry cannot rely on the grid for power supply. When not suffering from hours of blackouts or brownouts, the supplied power is of very poor quality, with voltage and frequency deviating well beyond the norms of 6% and 3% deviation, respectively.

Improving India's power sector performance requires multiple steps along many dimensions. The decades old system of primarily state-owned utilities, the State Electricity Boards (SEBs), is giving way to new structures under various reforms initiated in the 1990s. Many states have unbundled their generation, transmission, and distribution into separate corporations (still government owned), while Orissa and Delhi have gone as far privatizing distribution. An important feature of the reforms has been the creation of independent Electricity Regulatory Commissions (ERCs), which attempt to rationalize tariffs and usher in operational improvements. Importantly, the current thrust of reforms, under the Accelerated Power Development and Reform Program (APDRP), focuses extensively on improving distribution (reducing losses and theft). Within this, there has been much talk of using Information Technology (IT) for improving operations and reducing theft. In this paper, we examine the potential of IT for improving India's power sector, and attempt to determine what goals are achievable or realistic. In addition, we perform a preliminary cost-benefit analysis on an IT-driven distribution system. We also present an overview of some applicable IT technology.

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[1] This excludes captive and self-generation, which is estimated between 15 – 20,000 MW. Even this number excludes many small (backup) generators.

Goals for Using IT

Virtually every discussion thus far on using IT in India's power sector has focused on loss-reduction, especially theft.[2] This has been the case with the IT Task Force Report for Power Sector (2002), which gives an indication of the potential and need for IT in India's power sector. They focus on the need for Management of Information Systems (MIS) to help manage power transactions, both at a supply side (auditing) and at a customer management level (billing, customer interface, etc.)[3] They mention two illustrative projects—"quick win pilots"—that promise a 29% IRR. One focuses on an integrated billing system for Commercial and Industrial consumers (who provide most of the revenues) that would reduce theft/tampering/etc. and improve collection. The second focuses on an energy accounting system to calculate losses at the 11/0.4 kV distribution transformer (DTR) level, as well as 11-33 kV feeder levels, and integrating these at the circle level.

In fact, many ERCs (and funding agencies like ADB) have started asking the utilities to install meters at the DTR level, in an attempt to determine the loses in the system. These are expensive 3-phase, digital meters, with high accuracy and a means for communicating billing information for accounting purposes. This is typically envisaged as a serial port connection (optical, infrared, or even short-range wireless). As we will show, this system means well but ultimately falls short in its intentions.

Virtually everything the IT Task force report talks about is what can be called "fatherhood," things that should be done anyways and that offer reasonable returns on investment. Most modern utilities in the developed world do indeed have sophisticated IT/MIS systems in place. The important question remains *is that all we are after?*

Drivers and Specifics for India

High theft and poor collection are obvious reasons for an IT solution to India's power distribution. Today, given most agricultural pumpsets are unmetered, with flat-rate pricing based on nameplate capacity, we actually have a situation whereby utilities have no physical means of knowing the losses in the system. Most of the transmission systems within the utilities are reasonably secure, in that commercial losses are relatively low. For starters, many utilities have invested in newer meters for increased accuracy, and the moves towards unbundling have mandated greater accounting accuracy as now power changes hands from the TransCo to the DistCo. In addition, it is vastly more difficult for consumers to steal power at higher voltages, especially considering that there are long spans of low-hanging fruit (no pun intended) in the form of Low Voltage (LV) distribution (or even Medium Voltage – MV – distribution). So, while utilities often

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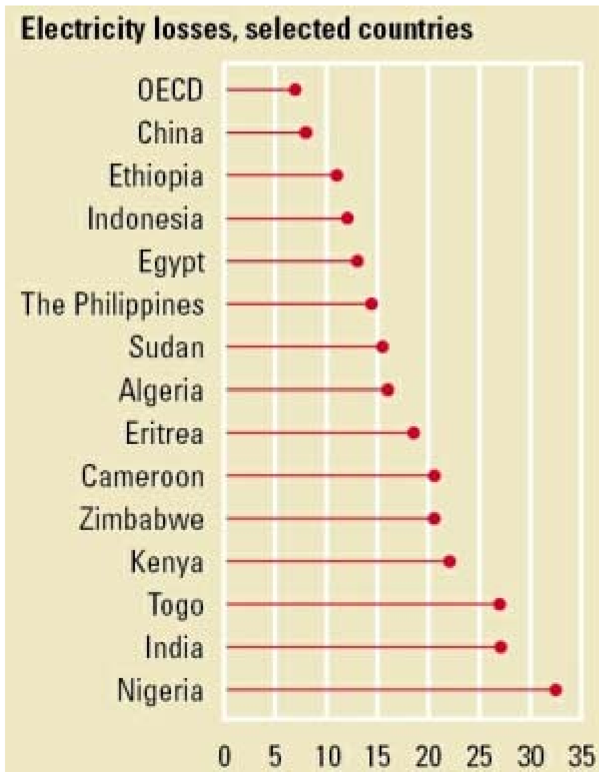
[2] There is already use of IT for SCADA (Supervisory Control and Data Acquisition) at transmission and generation levels, and this paper does not focus on this aspect of IT.

[3] This Report also talks of IT to raise voltage and frequency, which is somewhat naïve in that such improvements can only be facilitated by IT. Voltage can be improved with variable tap transformers or variable capacitor banks, but frequency variation requires action at the generator level.

know the power entering a substation, from that point onwards they have three unknowns to account for: technical (distribution) losses, theft, and agricultural consumption. Thus, we can see that there is significant leeway for errors, both purposeful and best-effort. If consider total T&D losses across various countries (Figure 1), we see India ranks very poorly. Not only do OECD countries average about 7% losses (many of them are smaller countries), even China and the US have about 8% losses.



Source: World Development Indicators 2004

Figure 1: Electricity Losses. In many of the countries, the losses include theft and poor accounting practices.

One underappreciated fact is that the technical losses in the system are very high, limiting the benefits of an IT-based system. India, with its current infrastructure, cannot hope to reduce its losses to 10%; even 15% might be difficult. For starters, transmission losses are very high. Some State ERCs (e.g., Andhra Pradesh), in their analysis, have recently allowed an 8% transmission loss level, which is just at the state level! This excludes national losses that are internalized elsewhere. The reasons for the very high losses are several fold. For starters, the grid itself is not optimized in terms of generation and transmission lines. In part this is due to fuel locationalities, such as coal in the East, but in part this is due to the fractious nature of SEB/REB designs. Secondly, the transmission voltages are very low, with 220 kV the norm in many instances, and 400 kV the newer standard. Higher voltages are limited to several HVDC (long-distance) lines. In contrast, the US began standardizing on 765 kV as early as the 1960s. This alone accounts for I^2R losses being several times higher for transmission. In addition, the transformers used throughout the system (more so at the distribution level) have higher losses than international norms. In addition to high transmission losses, distribution losses are very high (and unknown, as indicated above). For rural areas, analysis shows that in the absence of voltage correcting equipment like capacitor banks, the technical distribution losses can be on the order of 10% (Bharadwaj and Tongia, 2003). This is based on minimized LV distribution, which is itself not the norm and an operational challenge for many utilities. While the split between rural/urban at a feeder level has not been calculated here, we can estimate that technical distribution losses are also a good deal higher than in OECD countries. Thus, without massive upgrades to the physical infrastructure, IT alone cannot reduce losses beyond, perhaps, 15%. Even this might be somewhat optimistic.

IT Technology for Power Distribution

Fundamentally, IT is a means of creating, transmitting, analyzing, and storing information. In the power sector, this includes granular information on consumption by type of user, location, time, etc. Conventional wisdom has been that it is too expensive (and not worthwhile) to measure real-time flows for most consumers. What has changed is IT itself, improving to the point where the marginal cost for information can truly approach zero. In addition, given advances in electronics, hardware costs are falling dramatically. Figure 2 shows a generic IT system for power distribution. It involves transmitting information over the power lines themselves using PowerLine Carrier (PLC) communications. Of course, other networking options could be used, such as modems or wireless. This system typically involves aggregating data from consumers, such as at the Distribution Transformer (DTR). For detailed descriptions of the technology, please refer to papers such as (Tongia, 2003).

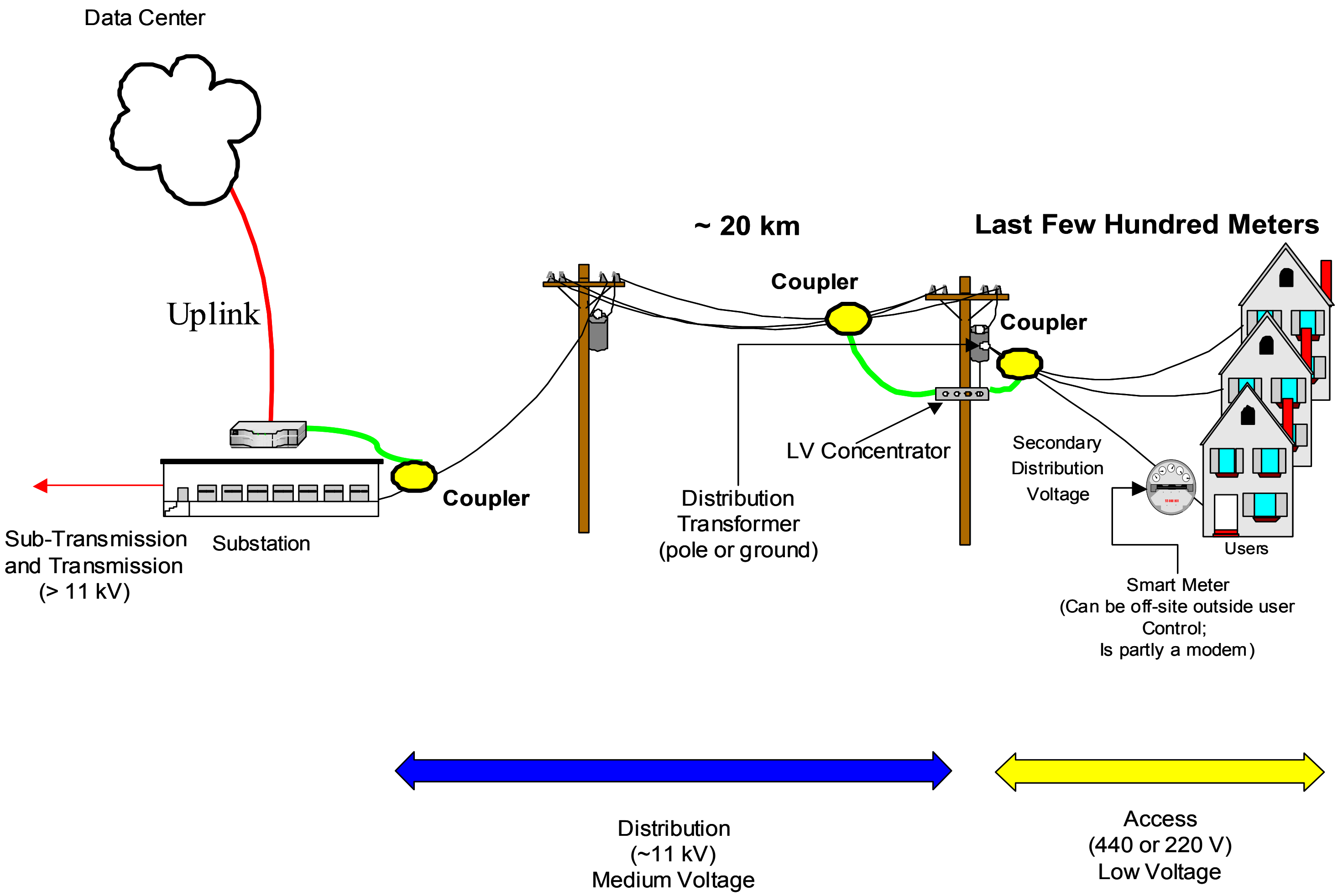


Figure 2: Generic IT Power Distribution System. This shows a generic diagram at the power distribution level, downstream from a substation. This assumes the use of PowerLine Carrier (PLC) technology, but other communications options can be used as well. PLC typically requires devices at either end that take signals on/off the grid (modems, essentially). At the consumer end (or on the pole if required), this can be integrated with the meter. Because of impedence through a transformer, one usually has to bypass the DTR. The Low Voltage portion is shown as only a few hundred meters, but in practice, some rural runs can be much longer. APDRP is addressing such issues by upgrading distribution voltages.

One major use of this might be for automated meter reading (AMR), for which several pilot trials have been undertaken in India (and there are indications of broader deployment in some areas). Worldwide, AMR has been seen as attractive given the high costs of Customer Relations Management (including meter reading), estimated at nearly $5/month in the US. In India, given very inexpensive labor (especially when we consider some utilities outsource this to local players, sometimes for just over a rupee per meter read!), this limits one benefit of AMR. The flipside of the Indian arrangement today is that it is very easy for human error, manipulation, and connivance.

Today, given difficulties with metering pumpsets, many ERCs have mandated metering at the distribution transformer (DTR) level. As these are not widely deployed, they are presently being sought and tendered by the utilities. However, these devices are meant for auditing purposes, and not control or real-time operations. Communications are typically for once a month reconciliation (or other modestly long timeframe). The IT task force report talks of meters that appear expensive, but have only modest communications capabilities, over wireless of serial ports. If we estimate 5 or just 15 minute intervals—the latter being the interval for the new Availability Based Tariff (ABT)—that would imply on the order of 100,000 or 35,000 readings per node per year. Only a dedicated communications system would prove cost-effective.

Instead of such a system, analysis indicates that there are significant benefits for designing a system that includes real-time (or near-real time) communication and control, at the consumer interface and/or DTR level. Given the modest *incremental* cost of adding communications to digital meters at the manufacturing level, for perhaps $5-10 more per node, we can add full communications to the envisaged meters. However, this is not a trivial design issue, and we should ensure we do not rush into one specific technology or design.

Table 1 compares different metering/IT technology in terms of their capabilities. Of course, the differences might not be so distinct, in that some features of the "full" system might be found in other designs.

	Accuracy	**Theft Detection**	**Communications**	**Control**	**Capabilities**
Electro-mechanical Meter	Low (has threshold issues for low usage)	Poor	Expensive add-on	nil	
Digital (solid state)	High	Node only	External	Limited	Historical usage reads only
Next Gen. Meter (proposed)	Arbitrarily high	High (network level)	Built-in (on-chip)* *Can do much more than Automated Meter Reading (AMR)	Full (connect/dis-connect); Extending signaling to appliances	Real-Time control; DSM

Table 1: Capabilities of Different Metering Systems. Digital meters are now becoming the norm for India, especially for larger-scale and utility-level metering. These improve accuracy and reduce threshold errors, but fall short of the "full IT" solution proposed.

Vision for IT

A "full" IT system would allow the utilities to micro-monitor and control every kWh across the system. This would allow controlling loads and customers, with capabilities like remote connect/disconnect, and local-level feedback for grid disturbances and accounting discrepancies. In addition, such a system could offer consumers higher availability and quality of power, increasing their satisfaction and willingness to pay. In fact, poor quality power is responsible for implicit costs to farmers far greater than the average tariff, perhaps as high as 75-100 paise/kWh (World Bank, 2001). With an IT system improving delivered power, farmers might be less resistant to tariff changes—limited use of diesel for pumpsets indicates some willingness to pay for reliable power. In the long run, IT could enable new and improved services, such as consumer appliance control. E.g., today, many consumers only turn on air conditioning or water heating manually. Smart systems could turn these on exactly when need (perhaps slightly in advance), and give higher value to consumers.[4]

If a "full" IT system were in place, instead of merely theft reduction, we could expect significant operational and cost improvements in the power sector, especially if coupled to consumption equipment (appliances and Heating/Ventilation/Air Conditioning – HVAC – systems). Demand side management (DSM) is viewed as beneficial for utilities worldwide, but conventional wisdom is that it only becomes cost-effective for larger consumers (typically industrial or commercial). If—and this is where more work needs to be done—there were a way to easily (even passively) control the loads to off-peak periods, then there could be significant savings for the utility (who could avoid new peak capacity, especially from newer plants that are more expensive) and to consumers, who might receiving specialized pricing or might simply be able to receive more reliable and better quality power. IT offers a means for such a system.

In the Indian scenario DSM has significant potential for a number of specific reasons. Much of India's consumption is from several classes of devices, often synchronous motors. Pumpsets are nominally 30% or so of the consumption, and this load is certainly time-shiftable. Already, today, agricultural supply is curtailed due to supply unavailability, and farmers often compensate for erratic night-time supply by leaving their pumpsets on overnight, causing waterlogging and salinity problems. Even within homes and other establishments, an estimated 4-5% of the total Indian load comes from refrigeration. For refrigerators, a defrost cycle can certainly be delayed to off-peak periods. Even regular cooling could be optimized with increments of half to one hour.

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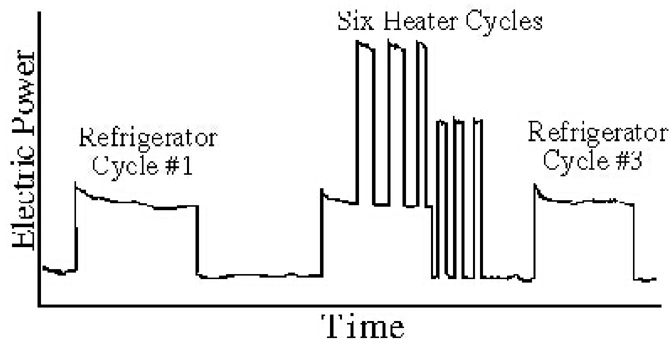
[4] Powerline Carrier can also provide broadband Internet access, but the technology is young and the business case is yet unproven. In addition, Indian conditions are very different from other countries, both in terms of the power system as well as networking.



Source: G. W. Hart (1992)

Figure 3: Modern Refrigerator Power Consumption Cycle. This figure shows a generic power consumption curve, with multiple cycles of cooling, and several periods of heater cycle (defrost cycle). If we consider the absolute peak, with both the cycles coinciding, then the majority (over 75%) of the load could be delayable.

In addition, supply in India is peak-clipped (ignoring the throttling of agricultural supply). Looking at demand curves for many parts of India, the peak is often bimodal, with a mini-peak in the morning, and the daily peak in the evening. This indicates significant commercial and residential load, load that is "human-interfacing" and thus might benefit from a Smart IT power system. Of course, such a system would require interfacing with appliances and HVAC systems.

A priori systems for determining "peak" and "off-peak" such as through timers might be limited in value. For starters, they reduce operational benefits to the utility, especially at unusual or emergency conditions. They also are more prone to human error and manipulation. In addition, the entire concept of "off-peak" depends significantly on the chosen agricultural supply. Data from Andhra Pradesh for late 2002, when agriculture was given 9 hours guaranteed supply—much higher than most states—indicate a night-time "off-peak" load as high as 98% of the daytime peak!

However, to realize the benefits of DSM, one needs pricing and incentive structures that convey the microeconomic realities of power generation. Today, not only is virtually all retail consumption flat-rate (which is not unusual), even generation contracts and power purchase agreements are largely flat-rate![5] Every generator attempts to behave as if they are a baseload generator, which ignores the realities of a load-duration curve (integrated demand curve). If there were better pricing system at the bulk supply and generation levels, analyses from other countries indicate that a 5% peak reduction can lead to 20+% reductions in generation costs.

Prepayment Schemes

One benefit that such a system might have would be to allow prepayment schemes for improving penetration of electric services. Utilities have been wary (not just in India) of

[5] Newer Availability Based Tariff modifies this, but only somewhat in practice. In part, this is because it only applies to companies under Central ERC jurisdiction, mainly the central generators like NTPC.

extending service when the willingness (or ability) to pay is doubtful. South Africa has pioneered the use of prepayment to extend electricity into the rural townships. They have about a dozen years of experience, and consumers seem to approve of such an option (Tewaria and Shah, 2003). This system need not be regressive; rather, it can direct subsidies to more efficiently help the truly poor. E.g., there can be limits or variable pricing ranging from nearly free for subsistence usage (like Kutir Jyoti Schemes), to almost regular tariffs for higher loads. Consumers like the budgetary guidance prepayment offers (no surprises), and utilities often give a small break as they receive higher collection. Given the ubiquity of prepayment schemes for cell phones, it is not unreasonable for India to develop a Universal Prepayment Card, for a whole host of utility and consumer services, which could be serviced through a distributed financial system (e.g., sold at post offices).

Case Study

To examine the potential for IT, we present a cost-benefit analysis for a major utility in South India, whose name is withheld as this is work in progress and the utility is sensitive about any claims and promises made. We consider the case of near blanket deployment, with the exception that this does not cover all the domestic consumers. This is a rational implementation strategy given that the majority of consumers utilize less than 50 kWh/month. However, all larger consumers are part of such as system, as are all pumpsets.

We estimate the total capital costs per node at $75,[6] excluding some higher voltage equipment, uplinking costs, back-office, etc. It includes all power equipment nodes, and will extend to capacitor banks and relays as well.

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[6] The use of USD is only because of international experience and vendor equipment pricing. This number is based on personal communications with technology vendors.

	Number of Nodes	Equipment cost ($)	Cost ($)
Domestic (applicable)	200,000	75	15,000,000
Commercial	383,000	75	28,725,000
Agricultural	673,000	75	50,475,000
High-Tension	5,000	150	750,000
Distribution Transformers	70,306	500	35,153,000
Substations	714	5,000	3,570,000
		subtotal	133,673,000
		Other IT and infrastructure (capitalized)	15,000,000
		Total Investment	148,673,000
	15%	Annualized cost of capital rate incl. Amortization	
Needed Annual Savings	$22,300,950		
11,625,000,000	kWh sold annually		
0.07	Electricity Costs ($/kWh)		<- Average only;
$813,750,000	Annual Utility Costs		
2.7%	← Needed improvements to justify investment		

Table 2: Case Study for Smart IT system for power distribution. The required upfront investment for the entire utility would be roughly $150 million dollars. This does not cover all the users, just most of relevant ones. This annual investment would be amortized at 15%, implying the need for an annual saving of just over $22 million. This same utility sells over 11 billion kWh annually, at an average "cost of supply" over $0.07/kWh. Thus, out of the annual utility costs of over $800 million, this IT investment would require simply a 2.7% improvement.

We see that the system provides a 6-7 year payback with just a few percent improvement in operations (e.g., theft/loss reduction). The above calculations assume that the utility can avoid expenditure at the average level through reduction of theft, and this is somewhat of a simplification. However, in reality, reducing agricultural/rural/household theft (or even consumption) might have greater benefits than average numbers would indicate since it costs more to serve them than the average number. One artifact of Indian power pricing is that utilities base loss calculations per consumer class on average "cost of supply" numbers (Planning Commission, 2002). In reality, the losses due to agriculture might be significantly higher as it costs much more to supply intermittent power to an remote rural feeder than bulk industrial consumers.

If we consider agricultural consumption alone, this was almost 3.9 billion kWh (estimated). If we find savings to the farmer from improved service and power quality of just 50 paise/kWh (or $0.01/kWh), then the annual benefits from this alone are almost $40 million per year.

The calculations ignore benefits to the utility from improved operations, and also from load management (peak demand reduction). As indicated before, this could be significant. However, such savings would require a change in how bulk (and perhaps retail) tariffs are structured, to reflect the different costs of supply based on demand and grid conditions. Other benefits not factored in would arise from the ability to offer new services to consumers, and increased consumer satisfaction (and willingness to pay the rationalized tariffs).

This investment shown is the amount required for building this system from scratch. If we recognize that many utilities are undergoing a drive to meter DTRs (or even pumpsets), the *incremental* costs for such a system would be much lower.

What is Needed – The Road Ahead

An IT vision for India's power sector needs to be considered carefully, with long-term goals. The entire value of leapfrogging is negated when interim solutions are chosen that require expensive retrofits.

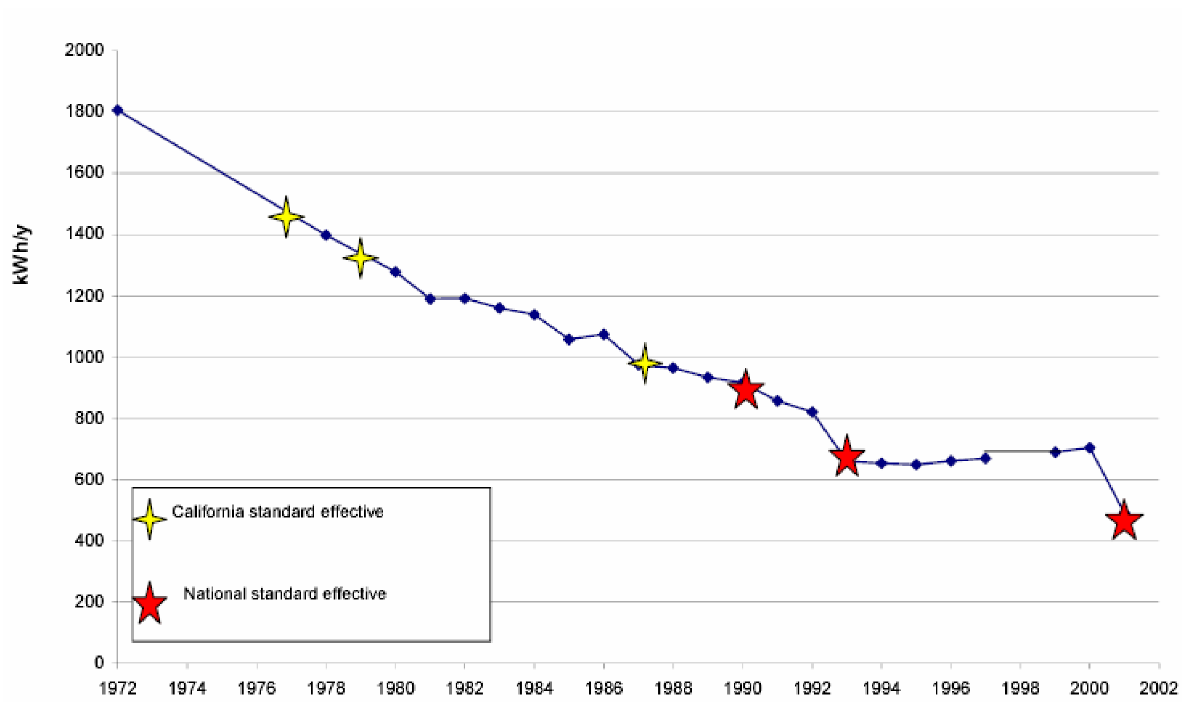
There are a number of difficulties and unanswered questions in this. For starters, Indian utilities are cash-strapped, and typically risk-averse (this is true worldwide). However, money for such projects should be available, e.g., under APDRP or donor agency funding. It is a different matter that utility staff might resist such a change since it reduces their discretionary (and sometimes illegal) power with consumers.

At a technical level, this technology is just emerging, and there are a number of design and communications protocol issues. How does one avoid losses through transformers? What are the implications of long rural lines? What of the noisy Indian line conditions? Like other IT, we should expect significant improvements in price-performance over the coming few years. Such systems are not yet the norm, so one can legitimately ask why should India consider it just yet? For starters, a number of utilities (esp. in Asia and Europe) are already doing such systems, from AMR all the way to full Smart Systems. Their claims indicate a payback in just 4 years!

There are other issues that need analysis and resolving. Given the large upfront capital expenditure, coupled with the very low consumption levels from the bulk of the consumers, any solution must be modular and scalable over time. How would such a system behave if only 10% (or 30% or 50%) of users were on it? In addition, while such a system might have benefits from a utility perspective, how are incentive signals passed on to consumers? Real-time pricing might be difficult, and modest experiments such as in Washington, US, showed little consumer interest in modifying their lifestyle in response to modest pricing changes. However, it must be stressed that that trial lacked the full-fledged IT solution we envisage. With such a Smart system in place, most changes could be passive, and consumers might simply be allowed to either opt in or out of such a plan (with appropriate pricing incentives). Here, there remain technical issues of how to segregate and manage millions of appliances and devices. How is security and control to be maintained, especially if consumers want Internet or Web access to monitor or control their home appliances (home automation)?

The biggest requirement for long-term benefits is a vision for how such a system would allow consumer demand management. We need to accept (or create—India's IT capabilities are easily up to the challenge) standards for appliances and consumer devices so they can interface with such a smart system. We should rely on open protocols and standards to foster competition and reduce a technology lock-in. This truly is a chicken and egg problem. Smart appliances do not exist yet (ones where the extra cost of control and communications is just a few dollars), and so there is reduced justification for Smart IT distribution systems. But without such appliances, many of the long-term benefits (let's think beyond theft reduction) will be missing. One mechanism for improving the situation is the creation of standards – industry, utilities, and government working together – that can become used in millions or hundreds of millions of devices. The new Bureau of Energy Efficiency might play the central role, provided they reorganize to steer such a national plan. Alternatively, like in the US where California led the way (see Figure 4 below), different states could innovate first. We at Carnegie Mellon (working with Indian utilities, companies, analysts, and other professionals worldwide) are developing a roadmap for such a Smart IT system.

If we look back to refrigerator standards for efficiency (Figure 4), we see that California mandated standards well before the US government did, and while manufacturers initially complained of unreasonable demands, they innovated to exceed the standards. In addition, consumers responded to appliance labeling standards (Menanteau, 2003) and choice, which rewarded the manufacturers who innovated.



Source: **www.standardsasap.org**

Figure 4: Refrigerator power consumption in the US. We see that the average consumption has gone down significantly, driven by government standards. This is despite an increase in the average size of refrigerators. It is also interesting to note that the typical Indian refrigerator is about a third (or more) less efficient than US ones.

The biggest issue with effecting such a change would be the political economy of reforming the system, with entrenched interests favoring the status quo. This ranges from subsidized consumers like agriculture to utility employees. Even the act of inducting technology into utilities is illustrative. Distribution utilities have virtually no R&D budget, and their primary means of buying equipment is through tenders. While offering some transparency,[7] this system does not allow for cooperative development and iteration, and is best for discriminating solely on price (appropriate for a mature technology).

It is beyond the scope of the paper to address all the issues as India considers IT for its power sector (especially distribution). Nonetheless, we must ensure that we do not rush into solutions, especially given the enticement of billions of rupees being made available under APDRP. We have to think of IT for a next-generation system, leapfrogging the West, instead of simply for reducing theft and losses. Truly, India can lead the way in harnessing IT for power systems, with increased service and sustainability.

[7] Critics will note that tenders are not as fair as intended, with many bids conditioned to favor specific vendors. In addition, these reduce the incentive for technology solutions providers to beat the technical specs, e.g., by building low-loss distribution transformers that could save perhaps 0.5-1% of the country's power.

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