On the prediction of residential loads in India

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***Abstract*—The Indian Energy grid is growing rapidly and there is a large simulation to improve not only the grid reliability, but also provide power for all by 2027. To this aim the Government of India has launched the Restructured Accelerated Power Development Program (RAPDRP) [1]**

In India, residential loads contribute to about 27% of the total power consumption, and hence understanding the residential power consumption is a key stepping stone to improving the performance of the grid and optimizing energy usage via dynamic load management like demand response programs. While there is a lot of prior-art related to short and long term forecasting residential loads, similar models are still very limited in the Indian context. The Indian power grid is a complex eco-system, where demand and consumption patterns are influenced by weather, socio-economic status, geographic location, political events to name a few. Hence, it is difficult to build a model for energy forecasting at residential level.

This paper is an attempt to build a residential forecasting model depending on the socio-economic factor and geographical location. To this aim, in this paper we first discuss the influence of socio-economic status on the energy consumption in urban and rural area's. The socio-economic status includes number of earning members of the family, age, gender and profession etc. All these factors influence the number of devices within a home, which in turn impacts the overall energy consumption.

Based on some of these observations, recommendation on modeling approaches are made to enable future data driven research into the energy consumption at residential level in India. This can further be used to enable smart grid technologies, especially from a smart demand, response perspective.

***Index Terms*—India, Smart Grid, Residential load, Indian energy grid, load modeling, power consumption**

I. Introduction

India is a country of great differences, both in climate and geography, as well as economically and socially. There is a wide variance in earning capacity [2] and include not only between urban and rural India, but also between different professions in the country. A significant population in India is at the bottom of the economic pyramid [3]. There are extremely densely populated urban centres, which puts immense pressure on the power distribution infrastructure, and uninhabited stretches of rain forest, where extending the power grid is a huge issue. There are big cultural differences between the northern and the southern states of India. All this impacts energy use, in both magnitude and time of use. India currently is about 6% energy deficit, and an average *Aggregated and Commercial Losses (ATC)*losses of 26% [4]. Out of this 26%, about 10-20% are pure technical losses. It is our belief that *Information and Communication Technology (ICT)* intervention can help reduce these technical losses to manageable levels and improve grid efficiency. Load shaping is one way to improve the grid efficiency, for example by peak reduction [5].

Load shaping is a technique to shift peak or valley loads via load curtailment or via voluntary user participation. For load shaping to be effective, peak and valley loads need to predicted well in advice, so that participating user can be altered well in advance. Load modeling helps predict such peak and valley loads well in advance [6]. Apart from predicting peak and valley loads, Load modeling is further used to give a better understanding of the energy grid, its users, and underlying mechanisms [7]. When it comes to energy usage, residential energy consumption constitutes 93% of all building energy consumption in India [8]. It is our belief that an optimized management of the residential energy loads will significantly improve the energy availability and grid performance, especially for Urban India.

There has been a lot of research into electricity consumption in developed nations citeCapasso94,Shao13,Vlachopoulou14,Dickert11,Chuan15, but very little into residential modeling of power consumption in developing nations. The Indian government is already planning to improve the electricity grid into a so called smart grid [9] and introduce new technology to help decrease deficit and losses [10]. This upgrade brings technical challenges for which pilot projects have been started under the RAPDRP program [11]. All of these developments can help understand the power consumption, but need to be driven by a clear understanding of the underlying system and possible relations therein.

In this paper we take a critical use residential users and derive parameters that influence energy consumption. To this aim, first the socio-economic situation of urban and rural India is described, and its impact on the residential power load. This is done in terms of wealth, education,and employment. Then, the different geographical influences are looked at. These are split up into the climatic influence, specifically looking at the impact of monsoon on the load consumption. The paper also investigates the impact of population density on power consumption. The paper takes a thorough look into Indian culture and its impact related to the energy use specific to India will be described and substantiated. With this information a modeling approach is suggested. And to conclude the consequences of the differences in developing and developed grids and their impact is discussed.

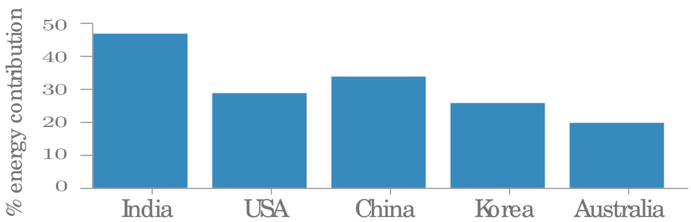


Fig. 1. Contribution of buildings to overall energy consumption, reproduced from [12].

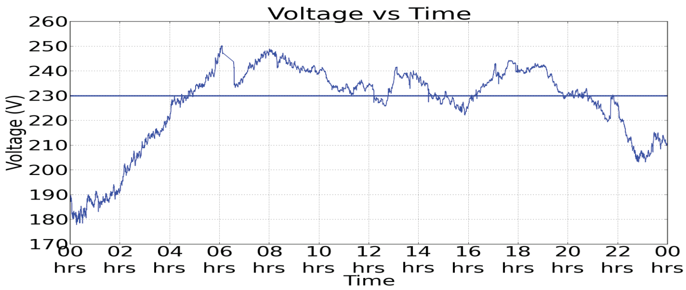


Fig. 2. Typical power quality fluctuations in Delhi, reproduced from [8].

II. Influence Engineering

The difficulty in engineering for influence is to determine scope and impact of a large number of "influence" parameters. Often times there is little data on the parameters themselves (the scope) and even less on the impact these have on for example, energy use.

Therefore this section is mostly used to talk about a number of large "influence" parameters, where information on these was (and can be) found and what their proposed scope is. The focus of the "influence" parameters will be on residential and building energy consumption and not on industrial energy consumption. This is mostly because industrial consumption is more predictable, but also because energy consumption in India in particular is heavily dominated by energy consumption by buildings [12], as can be seen in fig. 1

In the modeling section a more detailed look at the impact of these parameters and how one could optimize a model to fit the true impact based on estimates and true measurements is done.

A. *Socio-economic influences*

From an energy point of view the socio-economic influences vary wildly between rural and urban population in India [13]. This has to do both with the electricity availability and reliability (and grid penetration) as well as appliance costs. Grid reliabilty is a huge issue in India, and even in urban environments the power quality has very large fluctuations [8] as can be seen in fig. 2 . Because of this large difference they will be discussed separately.

1) Urban: Urban area's are characterized by the high population density and relative high average income compared to rural area's. In urban area's, the energy distribution network is more organized and mature as compared to rural area's. This does not always mean a high reliabile distribution network. The distribution networks in urban area's are often characterised by overloaded distribution transformers and poor quality of transmission line wiring and connections, to name a few. All of these contribute towards losses in the power distribution network. The monsoon plays key role in the distribution network. The presence of foliage near transmission lines, often forces the distribution companies to force a shutdown, due to the risk of electrocution. Not to mention the sparking that results in power outages. However, this is often offset by local energy generation due to personal electricity generators.

TABLE I
Home appliances and data source of statistics on their use.

Appliance	Data source	Year
Washing Machine	Euromonitor	2013
Microwave	Euromonitor	2013
Fan	NSSO Round 66	2009
AC/Cooler	NSSO Round 66	2009
Refrigerator	NSSO Round 66	2009
TV	NSSO Round 66	2009
Lighting	DSCL Household Survey	2005
Electric Water Heater	DSCL Household Survey	2005
Oven	DSCL Household Survey	2005
Toaster	DSCL Household Survey	2005
Booster Pump	DSCL Household Survey	2005
Computer	NCAER/Maryland	2004

In delevoping countries like India, wealth, employment and population density (or type of dwelling) considerably impact power consumption patterns.

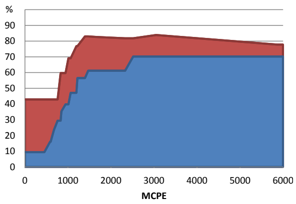
a) Wealth: There are multiple ways to measure wealth. The monthly per capita consumer expenditure (MCPE) is a measure that is relatively easy to come by and often used in government census information.

Of interest is specifically the influence of wealth on the electricity use of the consumer. The majority of the residential energy consumption comes from home appliances Wealth influences these in two ways, appliance availability and frequency of use. First appliance availability is considered , and after that the frequency of use, as well as the typical use case.

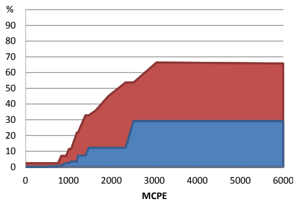
b) Appliance availability: It is difficult to get reliable information on the use of appliances in India [14]. There have been a number of studies and surveys, most notably by the NSSO India (National Sample Survey Office). An overview of recent surveys can be found in table I. One major drawback of most of the survey data available is that it is old. Extrapolation and projection of data can be done to adjust these to present day distribution of appliances, however the accuracy of this is questionable.

While DSCL [14] and the National Council of Applied Economic Research (NCAER) data sets provide valuable insight into appliance distribution in India, the data is too old (2009) to be considered for modeling. This with the exception of lighting, which is not expected to have changed much.

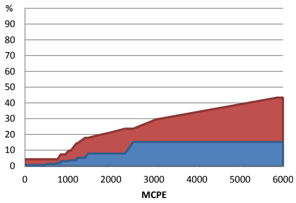
The results from these surveys are given in fig. 3. From this figure it is clear that there is a relation between wealth and appliance availability, and also between rural and urban



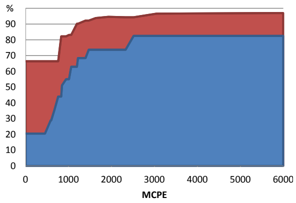
(a) Television



(b) Refrigerator



(c) AC or cooler



(d) Electric fan

Fig. 3. Appliance availability compared to MPCE, data from NSSO Round 66. Red is the urban, and blue the rural availability.

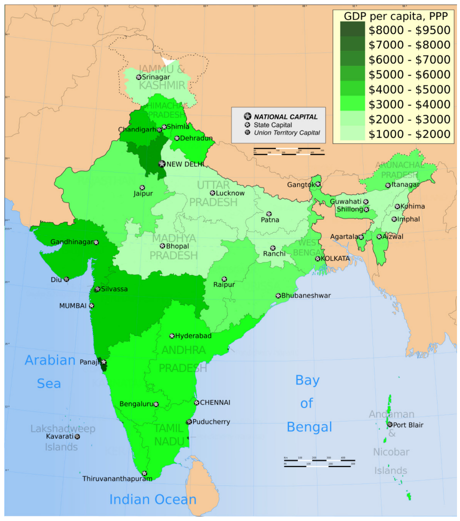


Fig. 4. Average GDP per capita in Purchasing Power Parity (PPP) . Image from Wikimedia (Februari 2015).

appliance availability.

Some identified trends are enumerated below:

1) The availability of a television saturates at 80%, with most household having at least one television.
2) The availability of fans is close to 100%, with over 60% availability even for the most economically backward classes.
3) Air conditioners (AC's) and coolers are possessed by the middle class and upward household, with more than 1 AC ownership shown only in higher middle class onwards.
4) Refrigerators are highly correlated with wealth. Further, refrigerators only enjoy a little over 60% availability at their peak, which is less than televisions and fans.

Of course this does not yet say anything about the amount of televisions, ACs, fans and refrigerators that are available in a household.

c) Appliance use: Appliance use is influenced by the number of people in the household and the size of the dwelling of said household. A larger household will for example have more laundry than a smaller household, and will therefore use their washing machine more frequently.

However, on a per capita basis, the energy use will go down as the household size increases. This is because more efficient use of the appliances can be made (a refrigerator or washing machine will generally be used in a more efficient manner in a bigger household) [13].

The size of a dwelling has an impact on the amount of fans, ACs, coolers, and light fixtures available. How many of these are in use at any one time is related to the household size, so a straightforward relation between per capita energy use and dwelling size is difficult.

The wealth of the household also plays a role in this. First of all because the average income of a household in a larger dwelling will be higher, so the energy use is expected to be higher. On the second hand, a wealthy household will have one AC unit in every room, whereas a middle class one will have only 1 for a whole household, and ceiling fans throughout the dwelling.

2) Population Density: Population density helps distinguish between urban and rural areas, and can give an indication of household size. It can also show the difference in dwelling (size and type) in urban areas specifically.

In a very densely populated area a reasonable assumption is that most people will live in flat type buildings. On the other hand, if we have a less densely residential urban environment we can safely assume that most households in that area live in independent houses.

The influence of dwelling type (and size) has a direct impact on the energy consumption per capita [13]. The most notable is the fact that a flat type house will on average have an about 40% higher energy consumption per capita. Nota Bene: This is also related to the fact that the average income in a flat will be a lot higher (about 80%) than that of a household living in an independent house.

3) Rural: Rural environments are very different from urban ones in the sense that the average dwelling size will be smaller, and the average income lower. All of these influence energy use in much the same way as described above for the urban environment.

There is one big caveat however and that is that energy availability is the limiting factor, and most available grid energy is used in agricultural applications.

Another problem of rural area is that there is very little data available on actual energy use. Some of the reasons for this are (a) According to distribution companies, the investment towards metering rural households does not justify RoI. (b) Energy consumption cost is subsidized by the government, and hence there is limited metering at house hold level.

Unfortunately, due to above mentioned difficulties it is impossible to speak about the influence parameters specific to rural environments at length, although much can probably be derived from studies in more urban environments.

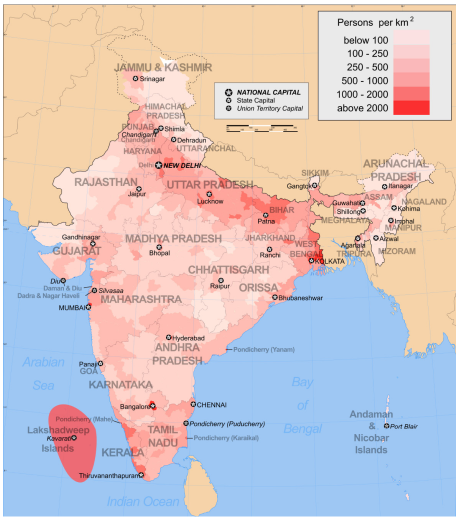


Fig. 5. Population density in India. Image from Wikimedia (Februari 2015).

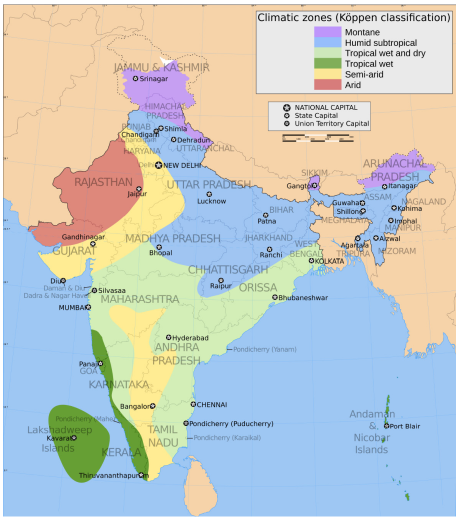


Fig. 6. Climatic zones in India, based on the Köppen classification system. Image from Wikimedia (Februari 2015).

B. Geographic influence

India is a very large country with an area of over 2.8 million square kilometres. It is the third largest country of Asia. This means that there are a lot of different climates, the monsoon hits different areas at different times, and with a different magnitude, and the population density varies between different areas.

What the effect of all of these is on the electricity use will be discussed below.

1) Climate: The climate of a region defines the average temperature, wind, humidity, precipitation and other meteorological variables. In fig. 6 an overview of the Indian climate can be seen.

a) Wind and humidity: There is little information on the direct impact of average wind speeds and humidity on energy consumption. Wind speeds play a factor in wind energy production, and humidity can have an impact on the use of ACs or (de)humidifiers. As the market penetration of both of these is not very large in India humidity (and wind) will not be taken into account when modelling the electricity load.

b) Temperature: Temperature has a very high correlation with cooling (and heating) requirements [15]. Making a comparison between rural areas and urban areas concerning the relation of temperature to energy requirements is difficult, as the ventilation possibilities as well as the cooling requirements differ vastly.

Both the *average* temperature as well as temperature *variance* play an important role on residential energy use. Steep rises in temperature can for example cause peak load behaviour as ACs will turn on to compensate for such an event.

c) Precipitation and Monsoon: The term monsoon is used to describe seasonal changes in atmospheric circulation and precipitation associated with asymmetric heating of land and sea [16]. It is a major source of precipitation for a large part of India. The effect of the monsoon is twofold. On one side the monsoon replenishes fresh water stores, which feed the hydro power generation of India, thus helping in the generation of more power. On the other side, very heavy rainfall often times leads branches of trees to droop, and causing flooding, instigating failures in the electric grid.

It is very difficult to model the influence of the aforementioned as the disruption of the power grid done to the power grid, and the subsequent changes in power quality as well as load configuration are highly unpredictable and non-linear.

III. Modeling

As a modeling approach, there are two major options to consider. A top down, or a bottom up approach. Top down approaches focus on aggregated load forecasting using large scale statistical data, while a bottom up approach starts from the behaviour of the individuals in the household.

Due to limited availability of load measurements, grid structure, and grid layout, a top down approach may result in inaccurate results.

Therefore this paper investigates a bottom-up approach This approach uses available information on appliance, demographic and housing statistics for the area to be modeled.

Apart from data provided by the government of India census, in this paper we use the data acquired by instrumenting a home in Delhi for over 70 days. The data set known as India Dataset for Ambient Water and Energy [8]) provides energy consumption patterns for every device at 15 minute granularity. A small statistic derived from this data is given in fig. 7 where the averages over the full time period are displayed.

Another study has looked into improving energy efficiency of buildings through data [12]. This requires extensive monitoring of very relevant data for such a bottom up model as we propose, and shows that there is already ongoing active research that can provide input information to a load forecasting framework.

However, for proper model validation purposes a broader data set of (urban) residential energy consumption is necessary. This is because one cannot infer statistical significance to a single household and more is needed both to model (and other data sets are needed for validation to prevent model bias).

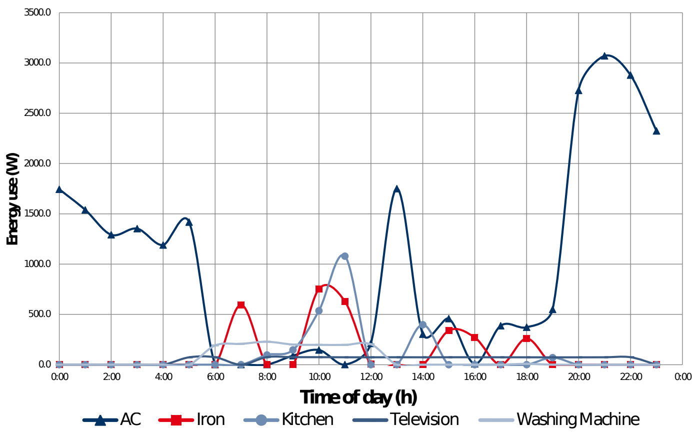


Fig. 7. Average power consumption as a function of time of day per appliance from the iAWE dataset [8].

A. Algorithm

To further illustrate how a bottom up approach to residential load modeling is adapted to an Indian application algorithm 1 is proposed. This algorithm exploits differences between Indian and more developed nations electricity users as well as the lack of data to base the model on.

Socio-economic data in this algorithm is used to specify average income, dwelling size and number of inhabitants of a residential area.

One disadvantage of this approach is that all accuracy information from the data it is based on is convoluted through the probability density functions generated in step 3.

Given the generally low accuracy of the data this can be used as an advantage, by enabling some optimisation parameters that can be tweaked independently to make the predicted load fit a measured load.

Through adding these optimisation parameters the only additional information required are load measurements, which can be done at any resolution (i.e. house, housing block, district, city).

Algorithm 1 Predict energy use for a residential area

Require: Socio-economic data D of residential Area (A)

1: **for all** Residence Types t in A **do**
2:   **for all** Appliances a **do**
3:     Determine probability distributions $(P_{t,a})$ of appliances from D
4:   **end for**
5: **end for**
6: **for all** Residences r in A **do**
7:   Determine number of residents N_r
8:   Determine at home probabilities P_r
9:   Combine P_r and $P_{t,a}$ to determine actual appliance probability P_e
10:   Draw Appliance usage profile L_a from P_e
11:   Determine total household energy use L_r
12: **end for**
13: $\sum_r L_r$ = total energy use L
14: **return** L

IV. Conclusions

We have shown a large number of influence parameters that need to be accounted for when doing smart grid and load forecasting research. In each area of influence the scope of knowledge on the parameter was presented as well as what is necessary to fully understand the system.

After this, a bottom up load modeling framework is proposed with some initial input data considerations. However, due to the lack of proper large scale survey data on multiple households, as well as measurements on their energy use spanning a larger timescale model results and validation are not possible at this time.

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