**Energy Economics and Policy**
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**Week - 03**
**Energy Demand - Part II**
**Lecture - 02**
**Demand Side Management- Load Management**

Welcome back, this is the 2nd lecture of the 3rd week. Today we are going to discuss one of the very important components of Demand Side Management which is called load management.

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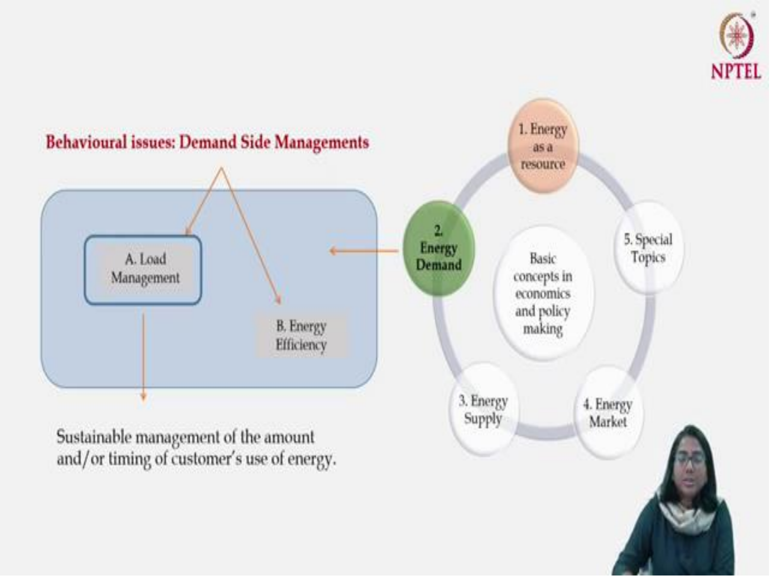


The next topic under energy demand in module 2 is load management. The concept of load management is basically a sustainable management of the amount and/or the timing of the customer's use of energy and this is specifically used in the context of electricity consumption. In the last lecture you have already been introduced to the concept of the load curve and in this lecture we will take a tour to understand in detail what load curve actually means.

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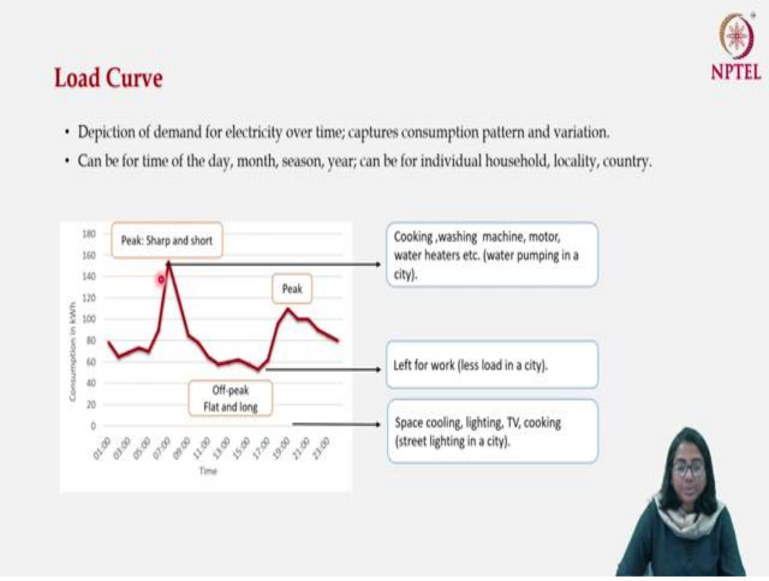


Starting with the concept of load curve, the red line in the figure tells what is the total consumption of electricity of a particular household at every hour. The load curve is basically a depiction of the demand for electricity over a period of time and it captures the consumption pattern, the amount as well as the variation of electricity consumption.

The load curve can be derived for a particular residential customer, particular locality or for a particular country. We can go from micro level to macro level load curve for understanding various concepts and various demand patterns. It depends on what is the question that you are trying to answer.

If you look at the load curve that has been depicted here, you can see that at 1 AM in the morning the consumption of electricity is approximately 18 kiloWatt hour. It remains between 16-18 kiloWatt hour up to the morning time which is up to 6 o'clock. After that there is a sharp peak that can be observed and suddenly the energy consumption goes up to almost 150-160 kiloWatt per hour.

This is a very sharp and short peak, does not stay long and after a while it comes down and there is a valley kind of a curve which is called the off-peak period. This off-peak period is actually prevailing between almost, 10 AM in the morning till 4 PM in the afternoon. Again, there is a peak where the electricity consumption increases for this particular residential household in the evening hours and it stays more or less high and then it comes down and again forms a kind of valley.

There are ups and downs in the electricity consumption during the day for a particular household. Although, we think about an average electricity consumption per day but it doesn't mean that during the entire day the electricity demand remains the same for a particular residential sector. In fact, it fluctuates quite a lot and that is why the load curve is a depiction of demand for electricity. The load curve over time gives the pattern as well as the variation in use of electricity.

Let us have a quick look, to understand what can be the causes of the peak and off-peak period for this particular load curve? The explanation of the load curve may vary depending on the type of household, whether you are talking about a locality or you are talking about a country and so on. The following can be one of the explanations. The peak period of this particular household starts around 7 AM. It may consist of a number of family members who are going out to offices. They may all be working and the children are going to the school. In the morning there is a lot of demand for electricity for cooking, for washing machine, for water motor, water geyser and so on.

There can be various reasons for short and sharp peaks. Once these activities are done, they all leave for the offices or the schools or for some outside activities and therefore, there is hardly any electrical equipment that is running in the house and therefore there is prolonged valley or prolonged off-peak period for this particular household. Basically, the office hour duration coincides with the off-peak period for this particular household as everybody has left for work.

Now, people start coming back in the evening around 4 or 5 o'clock and then the activities again start, maybe space cooling if this is summer, lighting etc. People, maybe, are engaging in some entertainment activities and that again requires a lot of electricity.

As a result, again there is sort of a peak period but there is a difference between the two peaks. The morning peak is a very short and sharp peak as a lot of activities are happening intensively in 1 hour however, evening peak is kind of prolonged. This is not as sharp as morning peak. There is variation in the peak demand, it may vary from household to household. Now let us try to understand the explanation for having the peak and off-peak period for a particular locality for example, the municipality corporation.

During the morning period, the municipality corporation may actually experience a hike in demand for electricity for various activities, one dominating activity being water pumping in the city. Then it might have a valley when there is no water pumping and since it's daytime there is no need for electricity for street lighting but after a while as the night time approaches the street lights are switched on and then again, the demand for electricity goes up.

There can be various explanations for having a peak load and the off-peak load. What are the electrical equipment that are being used during the peak load period and what are the electrical equipment and activities that are carried out during the off-peak period? The understanding of this particular thing is very important in the context of demand side management as this is the foundation of demand side management, to understand the load curve and also to understand what causes the particular shape of the load curve.

The variation in season also plays a role in the shape of the load curve. Although we are saying that this is the load curve for a particular household there can be variation in the shape of the load curve not only from day to day but the variation can be significant if you think about two different seasons.

The kind of load curve that is the peak periods and the off-peak periods or the height of the peak during the summer and the winter may vary significantly. In that case during the summer evening time people may be using space cooling equipment and therefore we get another peak but if you think about the winters then there is no space cooling activities going on and therefore in the night time you can have an even sharper decline in the electricity demand generating a deeper valley. All these points actually show how important it is to understand the load curves at a disaggregate level.

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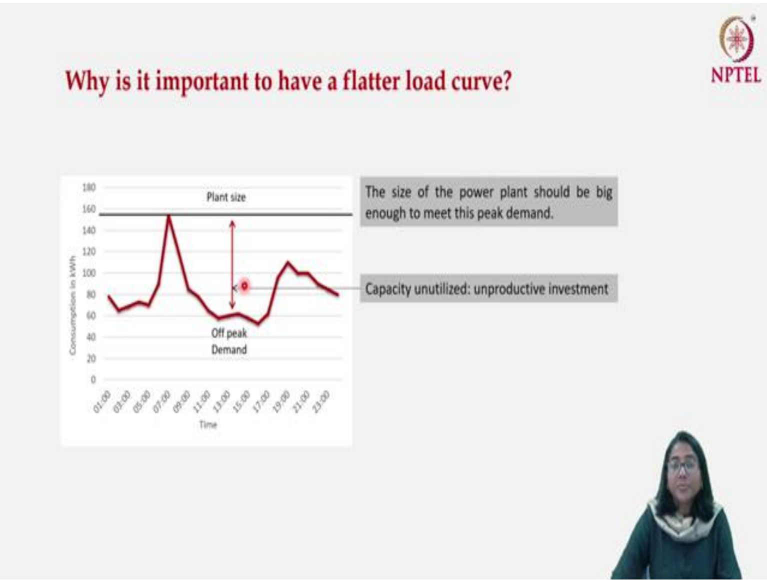

Next, we are going to discuss the importance of having a flatter load curve, where you have less difference between the peak hour demand and the off-peak hour demand. One of the main objectives of load management is to have a flatter load curve. If as shown in the figure is the demand curve in the reference scenario then in order to supply this much of electricity, you actually need the power plant whose size is big enough to meet the electricity demand at the peak period.

The size of the power plant that we want should be commensurate with the size of the peak demand, otherwise there will be a power cut during the peak demand. The figure shows the size of the power plant that you actually need in order to support this kind of a load curve. During the off-peak period, the demand is pretty low, it's much less than what this plant can actually produce. If the off-peak demand is lower than what the plant can produce, the plant can reduce the supply of electricity by keeping some of the units non-operational/non-functional.

But in that case the amount or the capacity of the power plant remains unutilized during the off-peak period. The concern about the unutilized capacity in a power plant is because the level of investment in a power-plant is very high. Therefore, if you have a big power plant and during most times of the day, most part of the power plant remains unutilized; that means a lot of investment that has gone into setting up of this power plant remains unproductive. And this is a very important scenario in the context of a developing country where you have various sectors who are demanding a lot of investment.

The consumers and producer’s optimization behaviour are constrained optimization. The consumer is working within the constraint of a budget space. If you think in the context of a state or a country, the country also has a constraint optimization problem where it has a limited amount of money with diverse requirements for investment and one of them is to invest in the power plants. Therefore, if the investment is made in a power plant then investing in certain other development activities is constrained.

The amount of money which you are investing in a power plant is huge and if a major part of that remains unutilized then one cannot get the maximum productivity out of the investment and therefore it is very important that this unutilized capacity needs to be minimized. This is one of the objectives of load management and if you shift some of the load from the peak period to the off-peak period you will probably require a plant size which is smaller and the size of the unutilized capacity will also become smaller.

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In the reference scenario in this diagram if you have a load curve and the plant size that you require and given is the underutilization of the power plant. Suppose we keep the total daily demand for electricity constant and if you add the electricity consumption represented by the red line and blue line for 24 hours you will see that it represents the same amount of electricity being consumed. However, the difference is that the peak of the blue curve is much lower than the peak of the red curve.

In case of red line the peak happens somewhere between 155 to 160 kiloWatt hour, however the peak for blue line is close to 120 kiloWatt hour. The other difference is the valley where the off-peak demand in case of red line goes down even below 60 kiloWatt hour whereas the off-peak demand is not that low for blue line. It hovers around 60-80 kiloWatt hour. The peak has come down for the blue line and the valley, that is the off-peak has gone up. This has happened as some of the loads that were occurring at the peak period have been transferred to the off-peak period and the curve has been flattened.

A flatter load curve is important because the consumer is consuming the same amount of electricity on the blue load curve and the red load curve, that is, there is no curtailment in terms of the total electricity consumption of the consumer. However earlier the plant size that was required was bigger.

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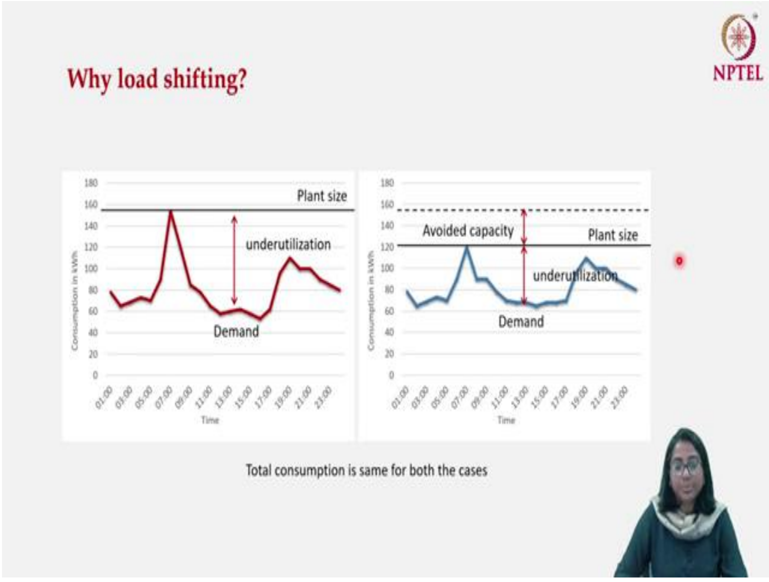


In order to support the peak load which is around 180, the plant size that is actually needed to operate is given by a red line. There is an avoided capacity, so instead of investing in a bigger plant you can actually invest in a smaller power generation plant and this difference is going to be huge because setting up a power-plant in itself is highly cost intensive.

There is a second advantage by way of gain in efficiency. During the off-peak the diagram shows the amount of underutilization of the power plant. The underutilization actually comes down because the off-peak demand has gone up and the plant size has come down as a result there is a squeezing of the red line which shows a lower underutilization and higher economic efficiency of the investment.

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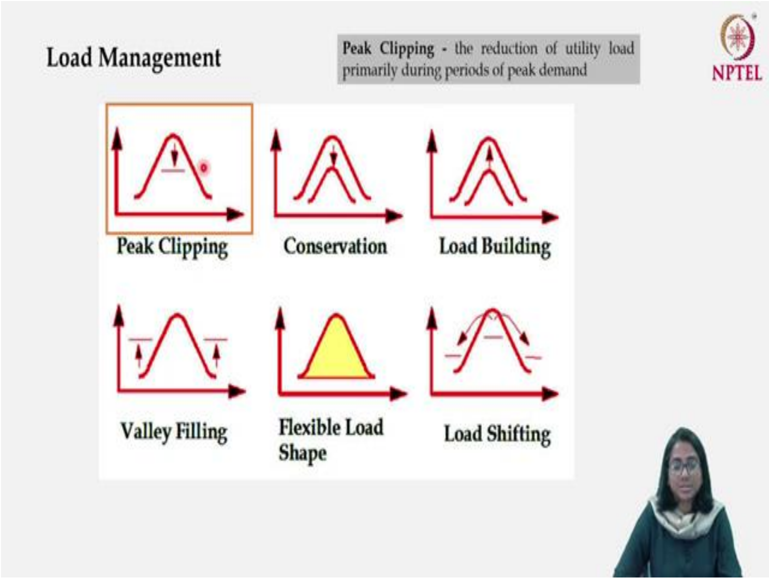


Other than shifting load there are many ways in which the load can be managed called load management. First method of load management is peak clipping. Given the load curve we have a peak and it's very important to have a lower peak because that determines the size of the power plant. The attempt should be to reduce the peak. Suppose in the morning there are lots of activities at around 7 AM which are going on like the geyser, cooking activities, heating of the food and several activities are going on and that is giving the peak. The question is, is it possible for the consumer to switch off the refrigerator for 1 hour during that period or is it possible for the consumer to actually increase the temperature of the refrigerator during that period. If that is possible, there is a reduction in the peak demand. That is what is called peak clipping.

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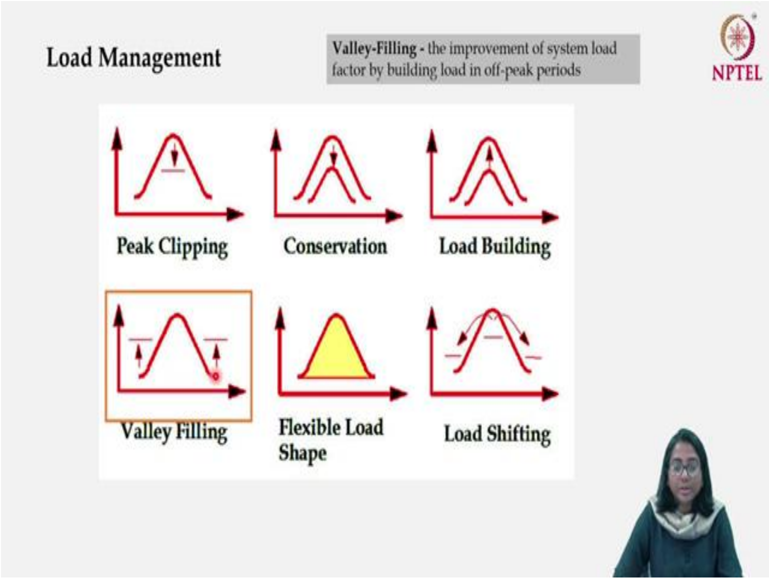


The second one is valley filling. We have an understanding that if we can fill up the valley then the part of the power plant which remained underutilized, that is the capacity which remains underutilized will come down. Therefore, it is important to have a valley filling activity in order to increase the efficiency of the whole investment system. The valley can be filled by undertaking some activities at night or during the periods when there is very low electricity consumption.

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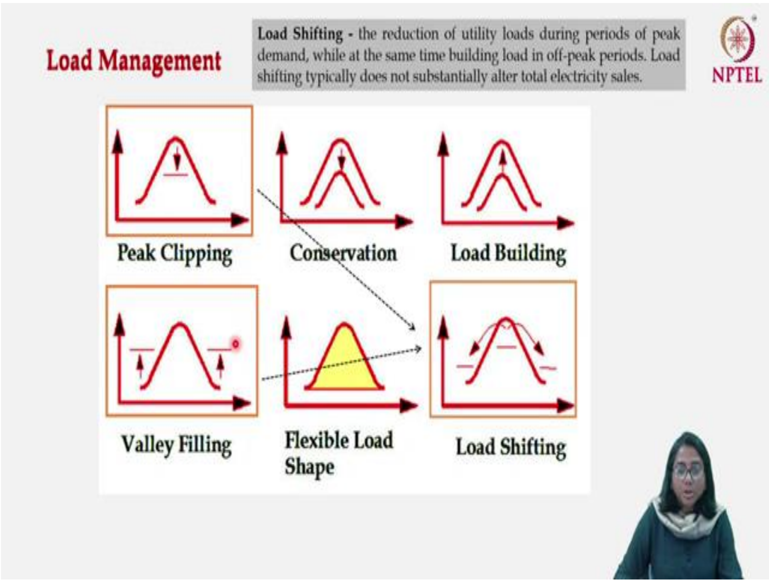


A more plausible option is actually a combination of peak clipping and valley filling. This entails the reduction of utility loads during the peak period demand while at the same time building the load during the off-peak periods.

The load shifting typically does not substantially alter the total sale of the electricity, the use and sale remain more or less unchanged as in case of the red load curve and the blue load curve. However, the shape of the two load curves is very different. If we combine the peak clipping and valley filling and this is one of the most important strategies under load management, we get load shifting. Basically, you are shifting your peak hour load to off-peak hours.

For example, suppose you want a lot of hot water for bathing in the morning for the whole family and have a storage geyser in place. Instead of switching on the geyser in the morning, you can actually switch on the geyser at night where you are having off-peak demand and let the water heat. Let it be stored in the geyser and use it for the next day morning. This is a typical example of load shifting. There are various other examples of load shifting as well and this is actually studied deeply in the context of load management.

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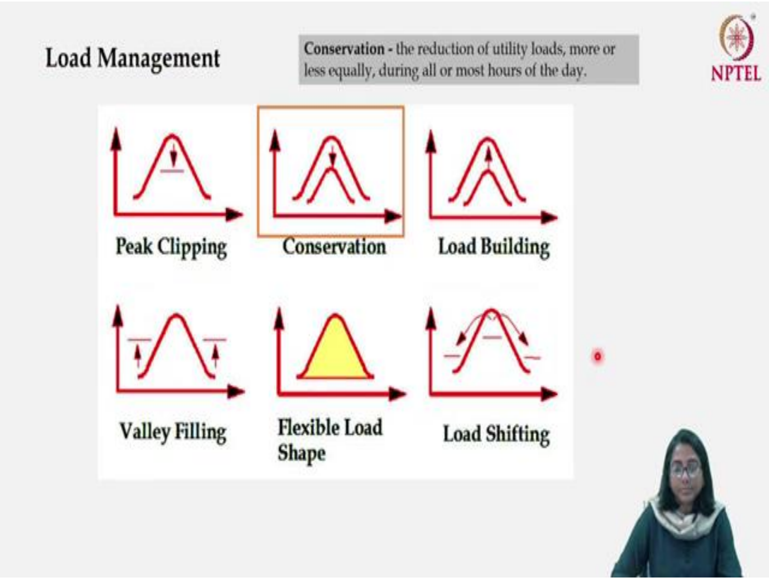


Another important strategy of load management is called conservation. Conservation is the reduction in utility loads more or less equally during the entire period of day. In this diagram there is almost a parallel shift of the load curve, downward. This is actually evident when you employ some sort of energy efficient equipment.

Energy efficiency is one of the main reasons behind having this kind of conservation activity and energy efficiency is considered to be a part of load management or broadly load management and energy efficiency are two pillars of demand side management. However, in the literature you will see that the concepts of load management, energy efficiency and demand side management are all used interchangeably. They actually go hand in hand and all of them act together in order to achieve demand side management.

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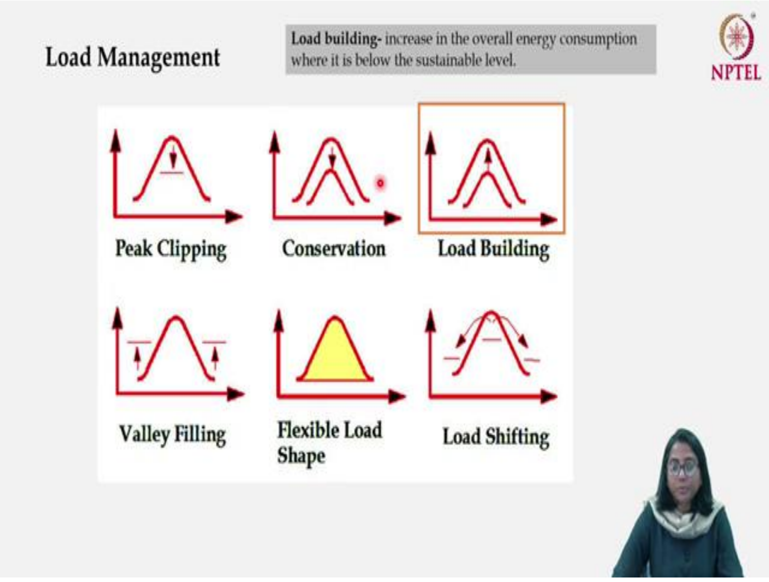


The fifth one that we are going to discuss is load building. As we said for energy conservation the entire load curve shifts downward, here the entire load curve will go upward. One might be very surprised to see that here actually the energy consumption is going up as we are talking about places where people do not use enough electricity which is important for their sustainable development. Therefore, building up the load is also part of load management.

Again, coming back to the term management, it does not simply imply the reduction. Management means how can you optimally use a scarce resource? This is again the optimum utilization of a scarce resource, a resource that you use in the best possible manner. It does not mean that you deprive somebody and you ask somebody to reduce the consumption to such an extent that sustainable development is hampered. Load building can also be a component of load management specially, in the context of developing countries or less developed countries.

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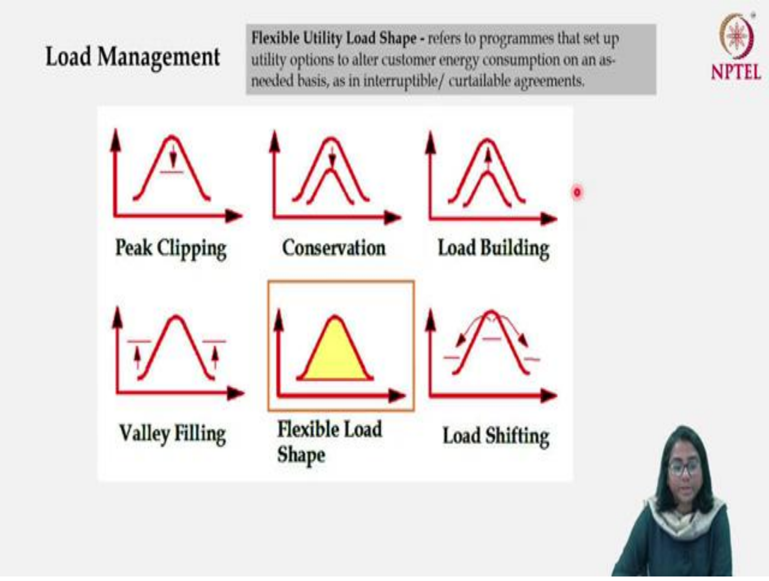


The last one that we are going to look at is called the flexible load shed. This is something which is not quite available in our country, this is actually based on a contract between the utility that is the power supplier and the consumer. They enter into a contract and the utilities actually install certain instruments or some equipment in order to alter customers' energy consumption on need basis. The utility itself will actually have control over different electrical equipment that has been installed at the customer’s place and if the utility thinks that there is some peak demand approaching then they may disconnect the use of those particular equipment.

This is especially useful for activities such as using a washing machine. The washing of clothes doesn’t have to happen in a particular time of the day and can be shifted at any point of the day. The customers register accordingly for the use of the equipment whose use is flexible during the time of the day. However, this is not there in our country, in many developed countries this is in place.

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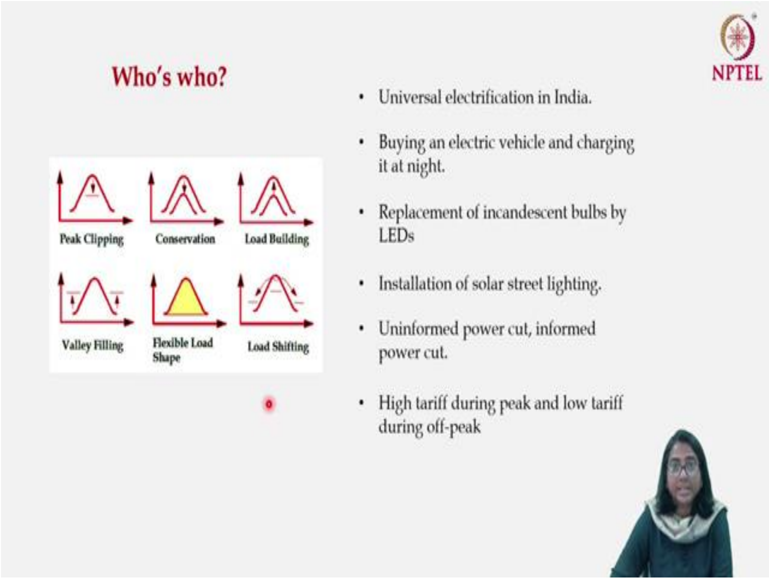


Let us have a quick look and this is the fun exercise that we are going to do. We will take a couple of examples and we will try to see which load management concept we can attach to this particular event. The first one is universal electrification in India. It's sort of simple when you have universal electrification in India, you are providing electricity to a lot more households and the load curve is going to go up. This is definitely a load building activity, again to emphasise this is also a very important part of load management and the demand side management.

The second one is buying an electric vehicle and charging it at night. The electric vehicles run on battery and to charge these batteries you have to have a charging infrastructure in place and it's up to you when you want to charge the battery. Before buying the electric car this activity was not present in the electricity consumption profile but now this is going to be added. If assuming that night time is the off-peak period and charging is done in the off-peak period then you are contributing to valley filling. The remaining load curve remains unchanged whereas you are actually increasing energy demand during the off-peak period.

Next is replacement of incandescent bulbs by LED; there are two options that you can choose; if you think about replacement of incandescent bulbs by LED in a particular commercial area where the lights are always switched on, this will actually lead to conservation. You are actually reducing the energy consumption at every point of time. However, if you think about a particular household or the residential sector, the demand for lighting service comes during late evening and night time. If that period is the peak demand period for the residential consumer then replacement of incandescent bulbs by LED will actually lead to peak clipping. During the peak period your demand is coming down nothing happens to the rest of the time of the day where you actually do not have any requirement for lighting services.

Next one is the installation of solar street lighting. If the solar street lights are installed then in one particular peak demand period which is the evening peak demand for the municipality corporation, the electricity demand from the grid will come down. This is another example when you have peak clipping and with the help of this example you can see is that if you have demand side management in place you are actually encouraging or you may encourage the consumers to install renewable energy systems on a scale that is feasible within their domain.

The next one is uninformed power cut and informed power cut. Let us take an example of an uninformed power cut. Suppose, the dinner time is 8:30 PM and there is a sudden power cut at 8 PM which continues till 9:30. Now you have no prior information about this power cut and are forced to eat cold food. If that happens during the peak demand period then you may suggest that this is an activity which is leading to peak clipping because your energy demand in the peak period has been forced to come down. However, it is better not to call it peak clipping because this kind of an event is not at all, sort of a load management.

The concept of management is highly related to informed decision making and you are optimizing based on that particular information. Here you had no information, you were forced to do something which you would not like to do. This should not come under load management at all. This is an unprecedented event which should not happen. However, if there is an informed power cut and it takes place during the peak period meaning there is an informed power cut during the same period of time that is from 8 to 9:30 and you know it beforehand. In this situation probably you will heat your food before 8 PM and keep it and have it at your dinner time. So, you can manage or alter your behaviour.

This means that when there is an informed power cut you are shifting some x amount of load from your peak period to the off-peak period as you are heating up your food before the peak period approaches. If this is an informed power cut then it is the case of load shifting.

The next one is high tariff during peak demand and low tariff during off-peak demand. This is sort of an incentive structure and this will lead to load shifting again because if the price is high then given the law of demand people will lower their demand and if the price is low people are going to increase their demand.

If you reduce the price during the off-peak period they will try to use more during the off-peak period and probably there will be a shift of load from peak period to off-peak period leading to load shifting.

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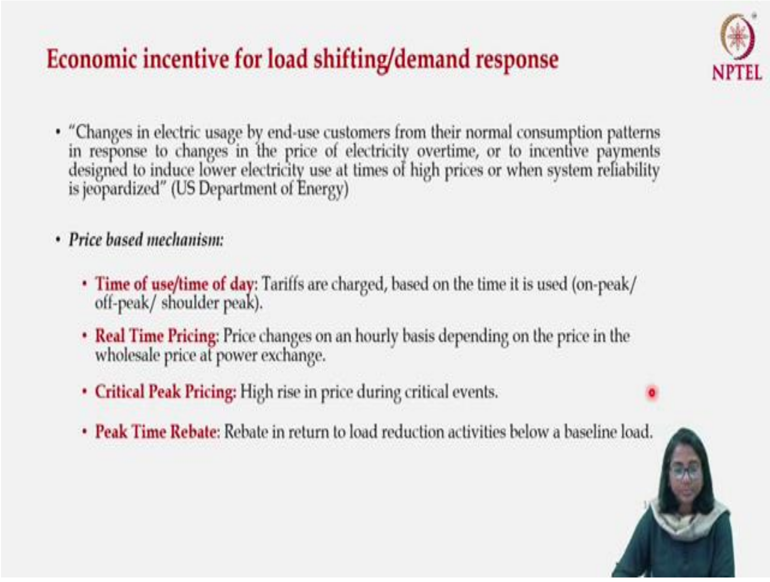


Next, we will discuss the economic incentive for load shifting or demand response. The definition from the US Department of Energy says that changes in electric usage by end use customers from their normal consumption pattern, (remember that red load curve) in response to changes in the price of electricity over time or to incentive payments designed to induce lower electricity use at times of high prices or when system reliability is jeopardized.

In a way this is talking about high tariff during the peak period and low tariff during the off-peak period or similar kind of incentive.  This statement is from the US Department of Energy and not from any other developing country because it's often discussed that the concept of load management or load shifting is more relevant and has been more researched in the context of developed countries because the load can be shifted to various times of the day.

In developing countries, the number of equipment using electricity is so low that the electricity demand at every point of time is kind of rigid and therefore it is difficult to implement the load management policies. However, there are results which contradict this. Most of the literature on load management are in the context of the developed countries or in the context of the industrial and high-tension users and the commercial buildings. There is in fact, very limited literature on load management in the household or residential sector in the developing countries.

However, coming back to discussing the economic incentive for load shifting. The incentive has to be built up in a particular manner so that people make informed decisions. People are not being forced to do something but just allowing them to take some informed decision which will flatten the load curve.

There are two types of economic incentive that you come across in the literature; the first one is price-based mechanism. Under this mechanism high tariff is charged during the peak period and low tariff during the off-peak period. There are various particular forms of price mechanisms that you can come across in various parts of the world, some of the common ones are as follows. One is time of the use or time of the day. Tariffs are charged based on the time of the use; off-peak period has lower tariff and peak period will have higher tariff to incentivize the load shifting.

The second one is called the real time pricing. The price changes on an hourly basis not depending on the peak or off-peak period. There is more disaggregation on an hourly basis depending on the price and the wholesale price at the power exchange where the electricity is being bought and sold. Now in both these cases the consumer can actually take an informed decision if the prices are communicated to them beforehand. Let the consumers know about the price, a few hours ahead of time or maybe one day ahead. That is very important otherwise even if you are changing the tariff and the consumers don't know about it you can expect no result out of it.

The third one is critical peak pricing. Let us take the example of Diwali, on the night of Diwali there is a sudden rise in the electricity demand. Every state, every city, every village requires a lot of electricity in order to lighten up the streets and buildings and so on. The critical peak pricing actually means high rise in price due to some critical events like Diwali. On the evening of Diwali there will be extreme hike or extreme increase in the price of electricity in order to make people take optimized decisions.

The final one that we are going to discuss is called the peak time rebate. These are not the only 4 types of price-based mechanism, there can be others as well. Instead of reducing the price during the off-peak hour, it says that if you reduce electricity consumption during the peak period there will be a rebate which will be realized in your electricity bill. These are the types of price incentives that you can observe.

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The second type is the incentive-based mechanism, here the price may not change at different points of time but the incentive structure may vary. Actually, in some of the literature you will find that this peak time rebate is considered not to be a price-based mechanism but more like an incentive-based mechanism.

What can be the incentive-based mechanism? The first one is called the direct load control. Here the utility installs a control device on electrical equipment of willing customers and through this device the utility is able to shut down or cycle the appliances. This is the same as flexible load management. The utility can control the use or usage pattern of some of the electrical equipment that are installed mainly in the residential sector or in the small commercial sector. This does not really happen in the case of the industrial sector.

The second is called the interruptible load, where the consumer will generate a part of demand on their own during the peak load with combined heat and power, through the solar panel or it may use the battery as well. This is a very-very interesting concept because here what you are doing is that you are asking the consumer to become a producer of electricity. This is done for the industrial sector.

In the peak period in the residential sector, one particular building might say that we are going to fix our peak load, we can actually support x percentage of our peak load by the amount of electricity that we are generating through solar power at our own place. In this way the consumer also becomes a producer and this particular category in the literature is called the prosumer and this is a very good example of how the behaviour of the consumer is integrated as a part of the whole electricity network. It becomes an integrated decision-making system. However, when you enter into an agreement with the utilities and say that you are going to support x amount of peak load through own generation then you will receive some financial benefit from the utilities.

The last one that we are going to discuss is called the capacity market programs. Here the consumers agree to reduce the load to a pre-specified level. There will be a threshold which will be set up and the consumer has to reduce the electricity consumption beyond that level and this threshold is, of course, more applicable when you are having your peak demand. If you become a part of this program then the utilities will make some guaranteed payment; however, if your obligations are not met and there is default then there can be some penalty which will be applied.

In a nutshell these are the various types of price-based and incentive-based mechanisms that are in place in order to promote load management techniques under demand side management.

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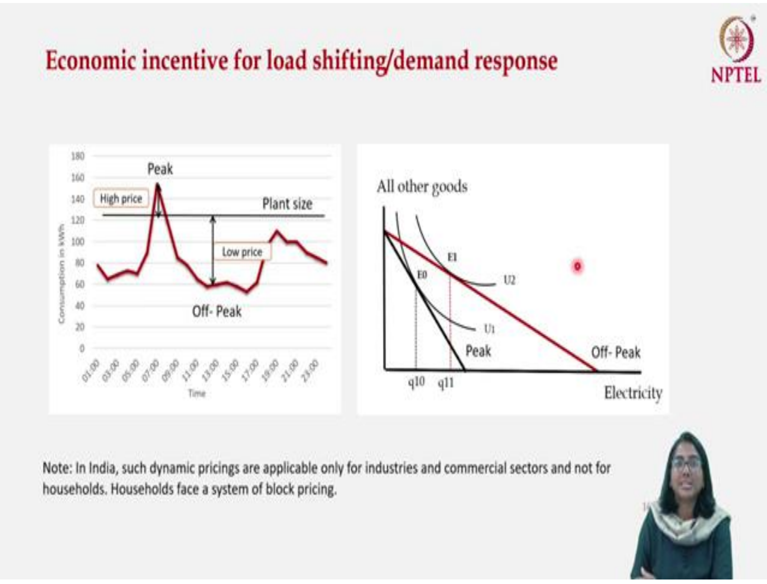

Here we are going to have a quick look at these two diagrams in order to understand how we use the economic framework of utility maximization for understanding the response to the price mechanism. Suppose given is the plant size, the black line represents the plant size and under the reference scenario the demand for electricity is higher than what the plant can produce during the peak period, that is there is an excess demand for electricity. If there is an excess demand for electricity and you want to discourage the demand then the utilities can increase the price. If the price is high then in a two-commodity framework where on the x-axis we are plotting electricity and, on the y-axis, we are plotting all other goods we can represent the budget line when the price is high.

This budget line represents the budget line for the consumer during the peak period resulting in equilibrium at $E_0$ and $Q_{10}$ is the quantity of electricity that is demanded. However, you can also see that during the off-peak period there is a kind of excess supply, not that the power producers are producing and supplying this particular amount of power. They may reduce their supply of power but in terms of capacity utilization there is of course excess supply which you want to reduce. If you want to reduce that we can actually reduce the price of electricity which will increase the demand during the off-peak period. If the price of electricity is reduced then the budget line for the consumer actually rotates.

If the black line represents the budget line for the consumer during the peak period and red line is the budget line for the consumer during the off-peak period and the equilibrium also shifts from $E_0$ to $E_1$ resulting in an increase in the electricity demand during the off-peak period. This is how the dynamic pricing system can actually reduce the consumption of electricity during the peak hour and increase demand for electricity during the off-peak hour.

One note is that this kind of dynamic pricing is not prevalent in India for the residential customers. This is there for the high-tension users, the industry sector, the commercial users but it is not there for the household sector. What we have in the household sector is more like a block pricing.

In block pricing, up to x unit of consumption you pay a particular price, if your consumption goes beyond that then you pay an increased price. As the consumption during the month increases in different blocks, you pay different amounts or your price per unit actually increases as your consumption increases but that is not really the dynamic pricing. You should be able to distinguish between the dynamic pricing where the price is changing in a day and the block pricing where the price that you pay for different levels of consumption of electricity are different.

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There are various things especially the policy makers need to keep in the mind while implementing the load management policies. I have taken this example from a paper that we will discuss in a while. This is basically the load curve for a particular locality and you see that there are two peaks which are observed for the residential sector.

The peak period starts from 6 AM in the morning and goes until 11 AM in the morning so 6 to 11 AM is one peak for the residential sector. This is the aggregate demand curve for the residential sector or aggregate load curve and the second peak that you observe is again from 6 to 10 PM in the evening. So, these are the peak demands.

Now the question is that is it the case that industrial peak hour also coincides with the peak hour for the residential consumer or not? This question is very-very important because if the peak demand for the industrial consumer does not match with the peak period of the residential consumer and if you incentivize the residential consumers to shift load from peak to off-peak period for residential sector then it may actually add to the total load of the peak period of the aggregate demand curve because the aggregate demand curve is a result of aggregation of the load curve for the residential sector as well as the non-residential sector.

For example, these shaded periods are the peak demand for the high-tension users that are the industry and the commercial sectors. Their peak period actually coincides with the peak period of the residential sector. If that is the case then this peak period that is morning 6 to 11 and evening 6 to 10 this is the period where the load coming from the residential sector as well as from the high-tension sector both are high and so the load in the peak period at an aggregate level is very high.

Another thing you have to keep in mind is that the load curve that you are having for the high-tension users, this is in response to the dynamic pricing. They are already facing the dynamic pricing. However, if there is overlapping of a peak load for the high-tension users and residential users and you sort of introduce the time of use or time of day so that the residential sector transfers some of this peak load to the off-peak period that will actually add to the off-peak period in an aggregate. This is not only the off-peak period for the residential, this is also the off-peak period for the high-tension users and therefore, this is the off-peak period in an aggregate. If the residential peak load and the industrial peak load more or less coincides or more or less look similar then only it makes sense to incentivize the household sector to shift their peak load to some off-peak period, otherwise it may create some other problem.

You can have a detailed discussion on this if you go through this paper published by Thakur and Chakraborty in the year 2016. It gives you a detailed understanding of different types of demand management policies that are applicable for developing countries, how the price mechanism is structured in India and what can be the responses?

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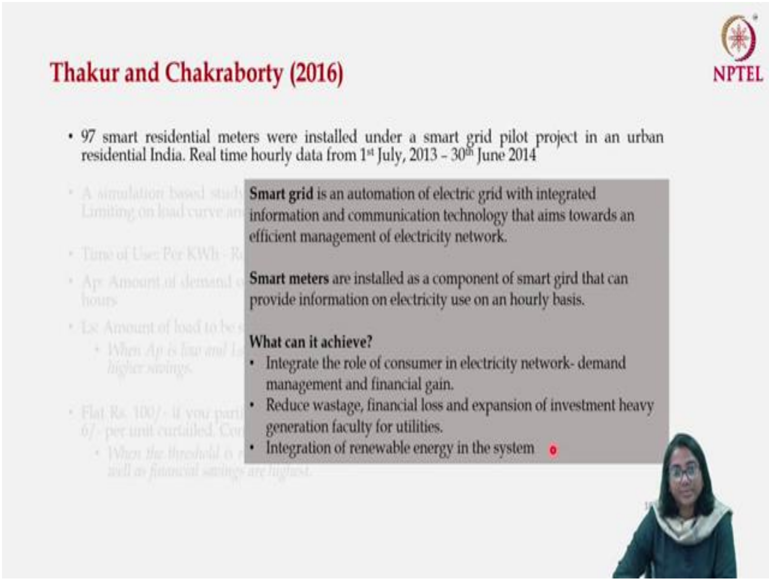


We are going to discuss this paper and some observations that have been found are important in the context of load management. This study was carried out and the data for this study was actually collected in the year 2013-2014 for a duration of 1 year in some urban locality in a union territory where 97 smart residential meters were installed. They generated data from 97 smart meters installed in the residential area.

We will take a short digression and look at what we mean by smart grid and smart meter and what are the roles of these things in the context of demand side management. Smart grid is basically an automation of electric grid with ICT that is Information and Communication Technology which aims towards the efficient management of the electricity network. This integration of the ICT is very-very important in the context of smart grid and smart meters. There are the components of smart grid which are installed in each and every household which are coming under the smart grid to generate a lot of data and to have a clear understanding of the load curve for each of the households. Now if you think about your home in most of the cases you will see that a person comes at the end of the month and notes down the difference between the units of the previous month and the current unit.

You get only one figure for the entire house where the electricity will be covered by one electricity bill and it doesn't tell you what is the load curve, you don't get detailed information. The smart meters are a component of a smart grid where you are getting information on electricity consumption at every hour of the day, that is you get the load curve. For this particular study they were getting 97 load curves per day for each day of the year. As it was run for 365 days for 97 residential units, they were getting 365 multiplied by 24 multiplied by

97 use points. It first of all generates a lot of data which is very important in order to understand what your demand side management can deliver and what should be the actual pattern of incentive.

Secondly, it integrates the role of the consumer in the whole system and it shows the way towards some kind of financial savings to the consumer. This leads to avoidance of the investment in additional power generation activities. This investment can go to certain other development activities and later we will see this can also integrate the renewable in the whole system.

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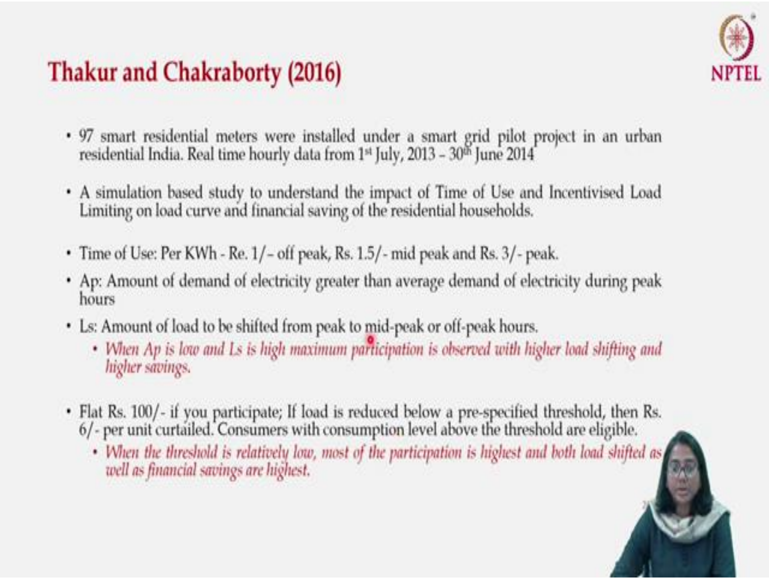


Coming back to the study based on this data collected from 97 smart meters, they have run a simulation to study what is the impact of two mechanisms; one is time of use and the other is incentivize load limiting. And they are trying to look at the impact on two things; one is the impact on the load curve and the second is the impact on the financial saving of the residential household.

As a consumer, I am not really interested in the load curve, what I am interested is, in the fact whether I am getting some financial savings by acting in a particular way or not. As per the time of use you can see that there is a higher tariff for peak period, a medium tariff for the mid-peak period and a very low tariff for off-peak period to encourage the consumers to go for load shifting. And what they have seen is that if you can include more and more customers to participate in this program then not only the shifted load will be higher but also the financial savings altogether will be higher and they are taking help of two parameters Ap and Ls. Ap is the amount of demand of electricity greater than average demand of electricity during peak hour and Ls is the amount of load to be shifted from peak to mid peak hour and then they show under different combinations of Ap and Ls how the load curve changes.

If you go through this paper, one interesting observation is that you have to really intelligently choose Ap and Ls because if you are not setting up your incentive in a right manner, there happens to be a lot of load shifting then instead of flattening the load curve you may end up having a new peak during the off-peak period, that is also possible.

This kind of simulation actually gives you an idea what should be the optimum tariff structure, what should be the optimum load that you want to transfer, what should be the optimum gain. The second one, the incentivized load limiting, here if somebody participates in the program then they are paying flat 100 rupees per month and if you reduce your peak load then for per unit reduction you are getting 6 rupees. And there they have shown that if you keep your threshold close to the average then most of the households will participate again resulting in greater incentive at higher savings rate.

I will encourage all of you to go through this paper published in Energy journal in 2016 and this is one of the rare simulation studies based in the context of a very detailed data from a developing country.

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We are going to stop with this paper which was published by Wolak in 2011 followed by another paper in 2010. The context of the study is a developed country but the findings are very important. They studied 1245 households in the district of Columbia and the data was collected almost 10 years back from 2008 to 2009 and they carried out a randomized controlled trial experiment where the control group and the treatment group received or were exposed to one of the instruments as early price, critical peak pricing or the critical peak pricing with rebate and it was observed that all these three dynamic pricing mechanism provided very stable, predictable and sizable demand reduction during the peak period. So, all the mechanisms worked.

What I find fascinating in the paper is the finding that we tend to believe that the response only comes from customers with high peak hour load, with a lot of equipment and with a lot of demand for electricity. Those who are small users of electricity are not likely to respond to this kind of price or incentive-based mechanisms but this study actually proved this kind of notion completely wrong.

In the district of Columbia they found that the response that they received to these kinds of instruments from the low income households were much higher than what they received from the high income households and the reason that they gave was quite fascinating because with all these instruments we always think about the shifting of the load, flattening of the load curve so that is not the only thing which is being achieved. At the same time as I mentioned the households are actually experiencing some of the financial gains. If your financial gain is 100 rupees that may be a very meagre amount for a very rich household but that's a very important amount for a very poor household. Therefore, the response that came from the poor households even if their electricity consumption was less was much greater as compared to the high-income households.

This actually tells you that often we have a discussion that load shifting may not be a very efficient way of load management in the context of developing countries but if this is the case then the story may go other way round and we may see a lot of response or this kind of instruments in terms of load shifting in the context of developing country as well. We are going to stop here; in the next lecture we are going to discuss energy efficiency which is our next tool that we are going to consider as a demand side management.

Thank you and see you later.