ELECTRICITY CONSERVATION IN DOMESTIC SECTOR OF PAKISTAN: A SYSTEM DYNAMICS APPROACH

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ABSTRACT

This paper describes the dynamics of supply and demand, price and pilferage, and resources and need of electricity conservation in the Domestic Sector of Pakistan. The dynamic hypothesis of the model is described. Then explanation of system behaviour, through model simulation, is given. The system dynamics treatment of the feedback loops is contrasted with the treatment found in most electric utilities[1] of the world in general and of Pakistan in particular. The flexibility of the technique was extensively utilized in policy analysis and 22 policies were studied, out of which 11 are discussed in this paper. It also shows that electricity conservation is a very complex socio-economic problem in Pakistan in the face of pilferage which in turn emerges from the socio-economic environment, a more complex issue than conservation itself, rather moral than economic, and is not very much in the control of utilities alone. The study provides many insights, e.g. pricing policies are not the cause of the problem, increase in income level may not alleviate pilferage of electricity, conservation may be possible with pilferage control and certain incentives, and resource allocation needs special attention.

BACKGROUND

One of the chronic problems faced by WAPDA[2] is the excessive loss of energy in its power system. There was little realization to improve the situation until the impact of sudden increase of oil prices was felt in the 70's. The country-wide scarcity of energy resources and the increasing costs of energy supply highlighted the importance of both the energy conservation as well as power system losses Beg (1985).

Electricity tariffs do not contribute to technical losses, but they cause distortions in economic patterns and social life style of consumers. Pricing will cause shifts in non technical losses, mainly theft of electricity Beg (1985).

Pilferage of electricity has no data available and is estimated through losses. The analysis of the losses and the interviews with the WAPDA's relevant officers indicate that it ranges from 6% to 12%. Further analysis showed that the 12.8% losses in Wapda's statistics in 1990-91 might be 18.6%, actually. Furthermore, pilferage is related with demand which is increasing, so, the same may be the case of pilferage.

NEED OF THE STUDY

A study was needed to probe the following questions:

1. Should the management concentrate on capacity expansion only?
2. Can electricity be conserved in domestic sector in the presence of pilferage or should the latter be alleviated, first ? or,
3. Only pilferage control will serve the purpose ?

The audience of the model is WAPDA, Pakistan.

SYSTEM BOUNDARY

The model under study consists of a number of sectors representing the major activities of the consumer and the utilities. It includes Electricity Demand, Capacity Expansion, Price Regulation, Pilferage, Cash, Cash Borrowing, Pilferage Control, and Conservation Sectors.

LIMITATIONS AND ASSUMPTIONS

Electricity conservation in domestic sector is a multi-faceted problem and its main character is the household consumer, who has different income groups, literacy levels, technical know-how, psychological structures, behavioral tendencies and, most important of all, moral character. It is observed that conservation is not so easy a task to be handled only by campaigns or codes of ethics. There are as many barriers as the people involved, which include more economic, informational, institutional, psychological, social and political barriers than technical ones.

Due to such complexity of the problem, the model, for simplification, is developed on the basis of assumptions, some of which are:

1. Social environmental, political and moral factors are not included in the model.
2. Elasticities of demand, price, income and substitution are assumed to be non-linear and implicitly modelled.
3. Effect of tariff slabs on pilferage and conservation are ignored and only average price is used.
4. Honest and dishonest households are not discriminated and average pilferage per household is used.

FEEDBACK LOOPS GENERATING THE DYSFUNCTIONAL BEHAVIOUR

The inner loop in Fig. 1 represents a racing competition between elect. bill and pilferage. Race is said to be between elect. bill and pilferage as the consumer assesses the elect. price through the bill. The price remained almost unchanged during the decade of 70s since the power supply was mainly hydel and the demand was not growing faster than supply. Furthermore, only twenty years ago, tariffs used to be lower on increased consumption to encourage greater usage of electricity and also the supply was given to the tribal agencies absolutely free of cost due to political reasons (who still don't believe in paying). So, in the early decades of the creation of WAPDA this loop was not so much active and also the impact of pilferage was not thought into seriously.

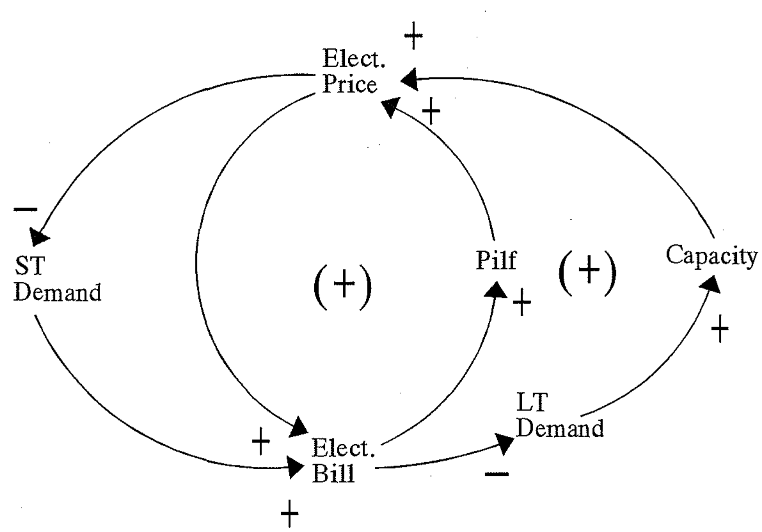

Figure 1: Positive loops creating the dysfunctional behaviour

Since electricity consumption/HH consumer is already below his desired level (due to shortage of supply, low income, etc.), he can not cut his demand below a certain level and so he fulfils his remaining demand through pilferage. Thus system losses are increased which result in reduction of units sold, and an increase in cost/unit. So the utilities have to increase the price to cover the cost of losses.

The outer loop in Fig. 1 is called the demand spiral which represents a peculiar behaviour and explains how, the elect. demand increases to become out of control. In the Spiral of Impossibility Ford and Youngblood (1983), demand decreases with an increase in price but the loop in this study differs in many respects. First, the demand, here, is split into two parts: short term demand (STD) and long term demand (LTD). Second, STD has some similarity in behaviour to the demand in the Spiral of Impossibility in response to change in price but has some difference as well that it is less elastic. So, actually STD does not decrease as it appears from the reduced billed consumption but it is fulfilled through pilferage. Third, the behaviour of LTD is contrasted with that of the Spiral of Impossibility i.e. it increases with an increase in price, of course after some delay. This is due to a decrease in bill by pilfering electricity and giving a relief to the household income which may result in some saving and a higher utility level. Thus it will shift LTD higher with the same income level and after the conservation programmes, if any, it will includes their saving effects too. But it is thought, in this study, that it would not let the demand reduce in the long run inspite of any conservation program in the residential sector, as is obvious from Fig. 2. There is a perception and decision making delay in the link between EP and STD. But the delay between BILL and LTD must be longer than the former one.

As demand grows, more capacity is needed to provide the power. As a result, fixed costs and cost/kWh increase (Lyneis 1983), this, in turn, increases the company's allowed revenues and increases the price of electricity that must be charged under the rules of commission. After a regulatory delay, electricity price increases (Ford and Youngblood 1983).

Fig. 2 shows the mechanism of adjustment between pilferage and billed consumption with the yardstick of monthly bill. Whenever billed consumption rises the consumer is slapped with a higher elect. bill. So, he reduces his billed consumption and fulfils his remaining energy needs through pilferage. But he can not reduce his billed consumption to zero and even below a certain level lest he may be exposed. Similarly he can not steel the energy infinitely, the constraint being his income level due to which he can not buy or replace the appliances promptly and frequently.

The demand spiral is not left free to operate dangerously but is controlled by a demand control loop (Fig. 2). As billed consumption rises, elect. bill also rises. With this the consumer has to decide whether to keep this new expenditure pattern or to reduce his demand (LTD). He may reduce the demand by curtailing the consumption or indirectly by adopting some conservation measures. Since the consumption

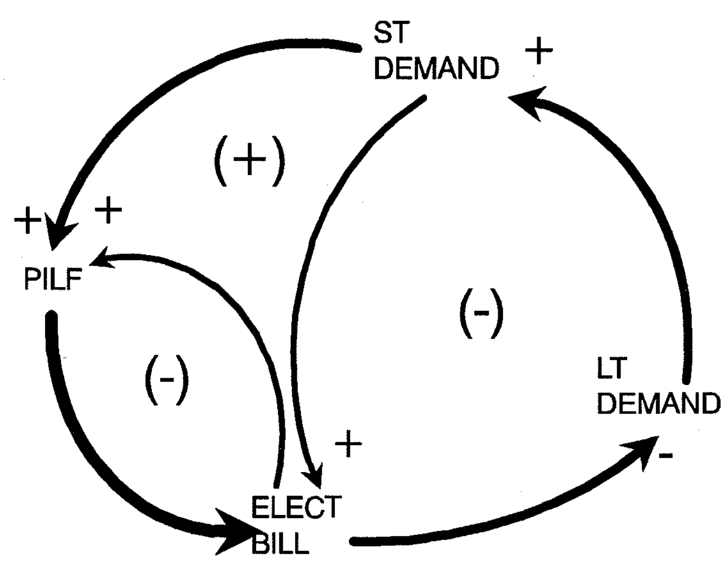

***Figure 2:** The Pilferage Spiral and control loops.*

level/HH customer is already very low, he adjusts his demand at the maximum possible level. But the adjacent loop shows that actually the demand is controlled by the reduction of bill through pilferage. This explains why and how pilferage is increasing over time. When LTD decreases, STD in turn reduces. This is because LTD and STD control each other to seek and maintain a maximum utility level, so that there should be no discrepancy between the STD and the desired utility level.

The outer loop is the monster, the heart of the problem, i.e. the Pilferage Spiral (shown in bold). With this process not only the pilferage spirals high in the sky but also the demand. So, it is observed that the consumers who have only lighting and fan-cooling load, one air conditioner or many, if they are stealing electricity their bill amounts to be almost equal showing that pilferage increases with the income level.

POLICY ANALYSIS

Its purpose was to find out ways to increase the end-use efficiency, alleviate pilferage and increase the capacity of the system. Basically three types of policies were experimented:

i. Pricing Policies:
   a. Existing pricing policy
   b. Cost plus pricing policy
   c. Shortage premium policy
ii. Availability Improvement Policies:
   a. Price rise policy
   b. Capacity expansion policy
iii. Energy management policies:
   a. Pilferage control policy
   b. Elect. conservation policy

Comparison of Pricing Policies

Simulation experiments of different pricing policies reveal an interesting result. The demand is so strongly intertwined in the system structure that demand spiral is never left too free to operate to become a vicious cycle of exponentially rising demand.

In each case, price also tries to stabilize near the initial value after some oscillations, inspite of 20% step rise to demand (Fig. 3). Strangely enough, pilferage, after some disturbance gains approximately the initial steady state value. This is not because pilferage/HH does not increase with demand but because generation is also increased. So, percentage of pilferage remains almost at the same level. Another coincidence can also be noticed that even the behaviour mode of pilferage is different in each case, each one strictly follows the behaviour mode of the corresponding price. Availability[3], also tries to gain steady state level after some depression.

It can be noticed from Fig. 3 that the behaviour modes of all the pricing policies converge at the end. So, it can be safely deduced that the system is nearly insensitive to pricing policies or in other words the system might not be improved with the change of the pricing policy. This shows that the pricing mechanism is not the cause of price rise in itself. In other words, problem aggravates with the price level and not with the pricing mechanism, since with all pricing mechanisms the corresponding prices keep on converging to the same price level. Behaviour of the price is the result of system structure and not the pricing structure only. Pricing system do have some effect on the behaviour mode as these shift the behaviour modes in different directions but these don't have significant effect or control. It is due to the fact that all these pricing mechanisms depend on the supply and demand conditions. And after every disturbance the gap between supply and demand tend to reduce, in the model, till both meet.

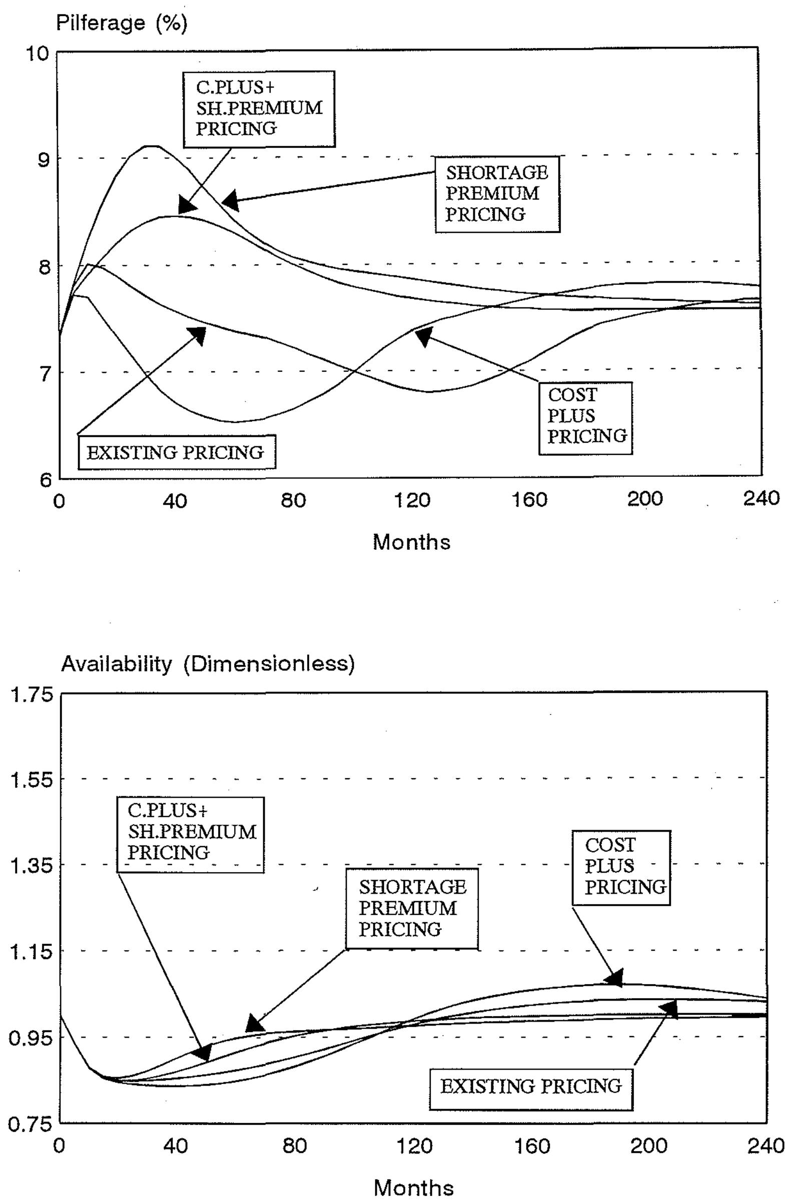

Figure 3: Comparison of pricing policies

Comparison of availability improvement and energy management policies

The objective of the Price-rise policy was to generate more revenue to facilitate capacity expansion. However, this objective seems not to be achieved since, with the price rise, pilferage rises and demand falls. This fall of demand is not the result of conservation, rather it is suppressed artificially by its shift between billed consumption and pilferage. Thus revenue can not be increased to allow the capacity to expand (Fig. 4) which declines with the demand and the capital.

The objective of capacity expansion policy is to keep excess capacity to reduce the pressure of demand. But 20% increase in capacity orders resulted in only 2.75% increase in the installed capacity in the end of the simulation period. It means the system does not allow to expand capacity exogenously without overcoming the constraints and allowing the demand to flourish. This is because with the increase in capacity, capacity costs, rate base and then the price increase decreasing the demand. It is quite understandable because this policy might be important from reliability's point of view, but here it adversely affects the demand which it is proposed to follow. This also explains how the reserve margin is dragged towards minimum possible level (which , of course, is not the case of Pakistan being referred to).

It is observed that the pilferage control policy is problem alleviating one, which relieves some capacity, increases cash ratio, and demand is controlled. This shows to be a promising situation and this policy has the potential of being a fundamental change agent[4].

The conservation policy is another option to solve the problem. The incentives supposedly given to the consumers, in this study, are two complete sets of fluorescent lamps including installation at the premises. This is taken with the assumption that customers

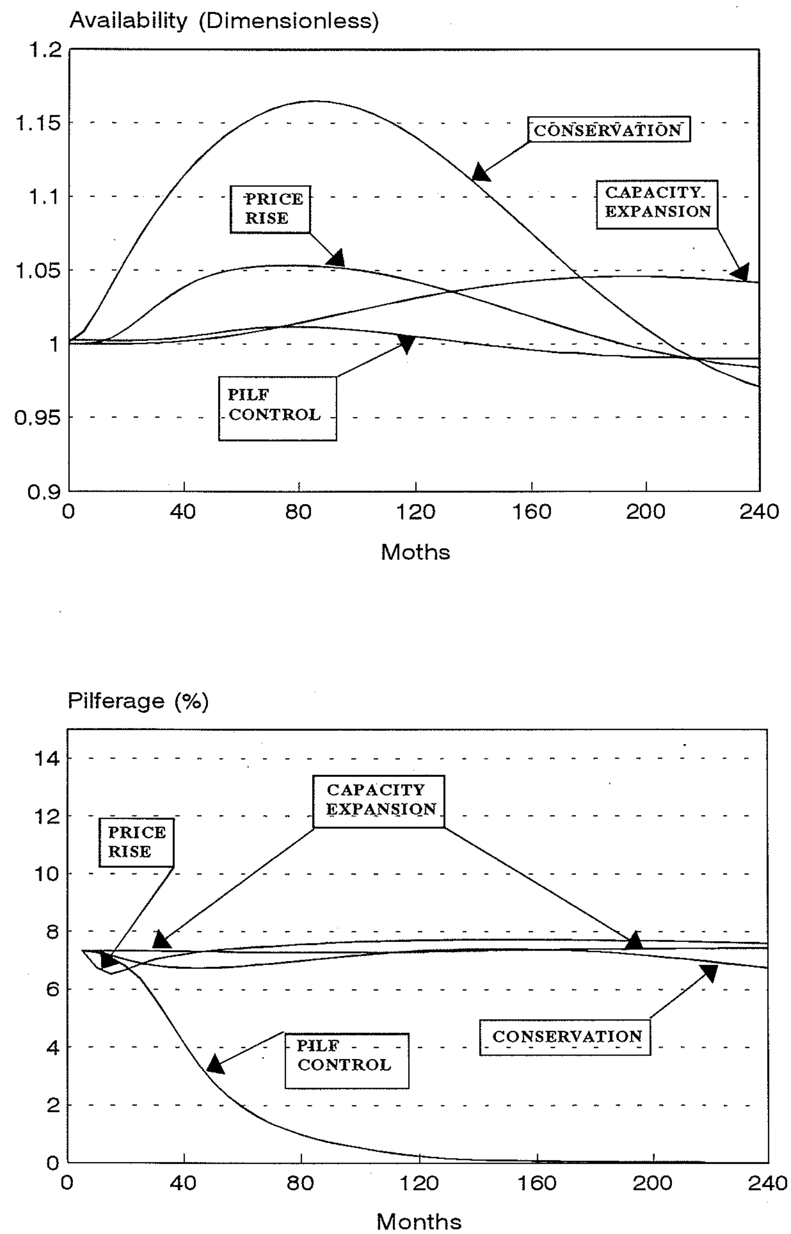

Figure 4: Comparison of availability improvement and energy management policies

are reluctant to buy them due to the above mentioned reasons but once they own them, and become used to its lighting and economic benefits, they will be ready to replace them themselves. This should be a soft loan which can be collected in small instalments over a period of 5 years. This policy reduces the demand, since it reduces both the consumption/HH, and pilferage whereas pilferage control policy reduces only the pilferage. Cash ratio increases even better than that of pilferage control policy. Inspite of the investments in conservation incentives debt remains zero.

Thus, conservation is another good policy to control pilferage through demand management which raises the availability and also improves cash conditions. The maximum increase in availability with this option should not lead to wrong conclusions. With this policy price increases and the demand decreases. The capacity also declines sharply and rise of availability means that demand decreases faster than the capacity. Besides this, the pilferage remains at almost the same percentage level. If rise in price is acceptable then the price rise policy has an edge over it: capacity decreases with less rate, pilferage is comparable and availability also increases. Above all, there is no headache of finding suitable incentives and investing for them.

It is not being stated , here, that there is no conservation potential but that it in itself is not the only criteria to be followed. So, this may be another fundamental change agent but before corroborating it, elasticity of demand, effect on economic development, and the implications of incentives and prospects of public participation must be extensively explored.

Comparison of combinations of policies

Out of many policy combinations which were analysed in the study, after careful analysis, three are chosen and mentioned here and their results are shown in Fig. 5. In this case, the best option seems to be the combination of four policies i.e. pilferage control, conservation, capacity expansion and price-rise. Pilferage control is necessary to alleviate the problem and conservation further improves the condition. Now if demand is assumed to be rising with the development, capacity should allow that, but in order to keep the demand from exponential rise, price can play an important role. A combination of all these policies should not be considered too big a package to be financed, as it can be implemented only with proper resource allocation and without extra borrowing.

Secondly, price rise is combined with capacity expansion and pilferage control. Instead of pilferage control, conservation could also be opted and both combinations seem to be logical and rational as with price rise indicated conservation is more pronounced. In the first glance, it appears that with conservation availability increases more than that with pilferage control, but

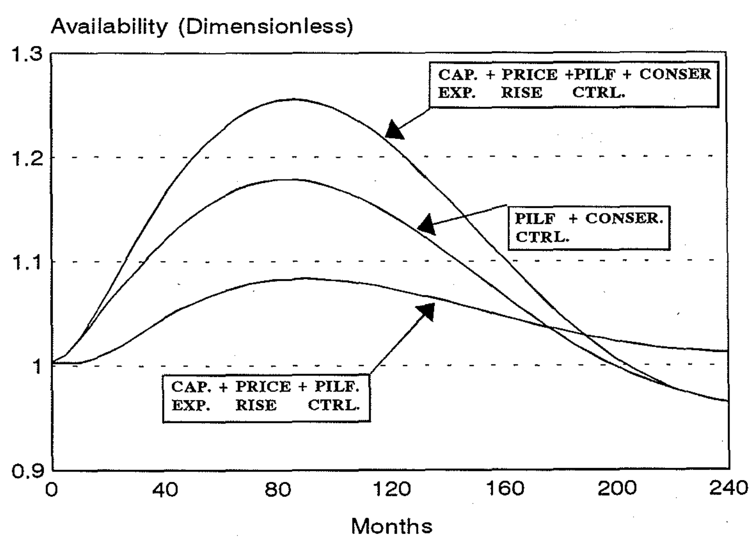

Figure 5: Comparison of the combinations of policies

further analysis reveals the actual picture. In fact, with conservation the decline in demand is partly due to the rise in price and but the pilferage does not decrease. It is also felt that in the case under study the energy saved by pilferage would be more than the conservation potential itself. Note that price rise combined with capacity expansion and conservation seems to be logical but sole price rise would be a cruel decision, because it means punishment to those who do not steal and also to suppress the demand/HH where it is already too low i.e. 305kWh/capita/year which was 296kWh/capita/year in 1992.

When pilferage control and conservation policies both are implemented together, pilferage is reduced to zero due to pilferage control. Demand also declines through conservation measures. Thus some power is avoided and capacity is relieved. The policy seems to be very promising, since it requires no borrowing and inspite of all these investments and the price fall, the cash ratio increases and debt remains zero.

SUMMARY

Resources are the major constraint to capacity expansion in the power sector. One of its remedies is the demand side management, through electricity conservation. A tedious obstacle found in the way to it which would not let it succeed and make the process very slow too, is pilferage. A study was needed to solve this problem which could also handle its multi-dimensioness consisting of demand control, capacity expansion, resource allocation and pricing policies. A tool was required to provide the opportunity of conducting a multi-scenario analysis rather than a traditional single scenario approach with no option, to help understand the dynamics of the system and their relationships so that better options could be found.

It was found that the system had dynamic, feedback relationships between the system factors that change over time. A system dynamics model was build, tested and verified. Several simulation experiments were carried out. Results were analyzed and compared.

Mainly three types of policies were analyzed: pricing, availability improvement and energy management policies. Energy management options were combined with the pricing policy and were experimented. The results were compared and conclusions are synthesized below:

CONCLUSIONS

1. In the outset of the study it was thought that poverty was the major cause of pilferage and it should decrease with better economic conditions but experimentation showed the opposite case i.e. pilferage/HH increases with income.
2. Price rise may be a facilitator in general but in the case under study is not suitable. Sole price rise may even aggravate the problem.
3. Capacity costs and energy generation costs directly influence the price so a least cost plan should be selected for capacity expansion.
4. Any of the four selected pricing policies does not change the problem behaviour, which means that the pricing system is not the cause of the problem behaviour, and it might not be solved through it either.
5. It was also thought that any conservation program may not be effective in the presence of pilferage, which may be true in other programs. The situation still is not much bright and no clear verdict can be given in favour of conservation in the case under study.
6. It is found that pilferage control policy, no doubt, is the fundamental change agent and capacity expansion with cost plus pricing may be the facilitator[5].

ENDNOTES

1. Bull, M. et. al.(1985).
2. Water and Power Development Authority of Pakistan
3. Availability = (Capacity/Demand)
4. A fundamental change agent is the one without implementing which, other policies have little effect.
5. A facilitator is a policy that has no significant effect alone, but improves the behaviour of a system in combination with a fundamental change agent.

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