PEAK SHAVING THROUGH MULTI-MODE OPERATION OF HOUSEHOLD REFRIGERATORS

HYR Perera
University of Morauwa

1.0 Introduction

In view of the continuously increasing cost of electric energy as a commodity, its efficient utilization is becoming more and more important. An improvement in energy efficiency at its end-use or in the process of generation, transmission and distribution is necessarily synonymous with conservation of energy. An efficiency improvement in utilization means consumption of less energy and/or the most appropriate form of energy to maintain the same level of services to the end-user.

When comparing the cost of energy, it is appropriate to take the national cost or the global cost which is not always reflected in the price paid by the end-user. As an example, most of the Sri Lankan consumers pay same price per kWh they use irrespective of the time of day. However the cost incurred to the supply authority depends on whether the unit is generated during the peak-time or during off-peak. This is due to the fact that the supply authority, in general, has to start power plants operating at higher running costs and lower plant factors to supply the peak demand. In most of the systems such plants are less efficient and contribute more to the green house gas emissions making the environmental cost of each unit relatively high.

In case of the end-use equipment which has the capability of storing energy for some time, it is possible to improve the overall efficiency by programming the equipment for less energy usage during peak-time [1],[2],[3]. This paper introduces a new concept for operation of household/commercial refrigerators that leads to a reduction of energy cost at national and global levels.

2.0 Multi-Mode operation of household refrigerators

In order to reduce the energy consumption of household/commercial refrigerators during the peak-time it is suggested to operate them in three different modes 'high,' 'low' and 'normal' depending on the time of day. In 'high' mode the cooling level is higher than the average and the refrigerator operates in this mode for a time interval immediately prior to the peak time. During the interval corresponding to the system peak the refrigerator operates in 'low' mode, where the cooling level is lower than the average, causing a significant reduction in the power consumption. Outside both these intervals the refrigerator is to operate in the 'normal' mode, where the average cooling level is maintained.

3.0 Load Curve

To analyze the effects of multi-mode operation of household/commercial refrigerators it is necessary to develop a mathematical model for their load curve for which following observations are taken into consideration. A refrigerator is continuously connected to the power supply but it consumes power only during the period in which the compressor is on. Here the power consumed by auxiliaries such as interior lighting and defrosting is not taken into account. The compressor motor is normally a fractional horse power constant torque motor and draws a constant power after the completion of the acceleration. A typical load curve of a compressor is shown in figure 3.1.

Figure 3.1

The time intervals t_{on1}, t_{on2}, t_{on3} as well as t_{off1}, t_{off2} are stochastic values. The main task of the development of the mathematical model is obtaining the probability density functions of the continuous random variables t_{on} and t_{off}.

To get the type of distribution for the off-time the following behavior patterns are considered. During the periods when the users are not active the refrigerators are not opened and thus they do not experience a sudden input of heat. The off-time t_{off} during such periods will be a constant that depends on the type of refrigerator, how it is placed and the ambient temperature. In a large batch of refrigerators this value tends to be normally distributed with a mean μ_{off} and a standard deviation σ_{off}.

During the active period the off-time t_{off} will depend on sudden heat inputs originated by occupant's activities.

This heat input is caused due to exchange of warm air in place of cool air in the refrigerator with or without an addition of a warm item to the contents. Under such conditions distribution of t_{off} can be approximated through an exponential distribution having the mean value λ_{off}. The overall distribution of off-time is obtained by mixing these distributions to the ratio $p_{off}/(1-p_{off})$. The shape of the distribution resulting from these considerations is shown in figure 3.2.

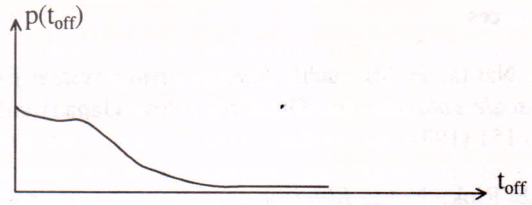

Figure 3.2

During the on-time the refrigeration action pumps out the excess heat in the refrigerator. As this amount of heat mainly depends on the load of items in the refrigerator, the on-time distribution can also be approximated through a normal distribution having the mean μ_{on} and the standard deviation σ_{on}. These distributions of off-time and on-time are described using four and two parameters respectively. Realistic estimates to these parameters are to be obtained through statistical measurements yet to be carried out.

4.0 Peak Shaving Potential

In order to asses the peak shaving potential, first an estimate for the upper limit for the saving of peak-MW is obtained. A survey conducted in 1994/95 in a sample of 600 households has revealed that 56% of the households have a domestic refrigerator [4]. As the sample selected in this study has been biased towards higher income groups, this figure of 56% represents an upper limit for the islandwide penetration level. Extending this result to 1,400,000 electrified households there are presently an estimated number of 784,000 refrigerators in operation. According to another study [5] conducted in 1995 the average energy consumption of a refrigerator used in Sri Lanka amount to 50 kWh/month. This corresponds to an average power consumption of 70W per refrigerator. Because the load curve of a stock of normal refrigerators can be approximated through a constant load the total consumption of the stock works out to 55 MW. This figure is continuously increasing with the economic development of the country. Around 55,000 refrigerators have been sold in the year 1995. This indicates an annual growth rate of 5% based on the assumption that one third of the new refrigerators replace old ones.

A total of 55 MW peak power can be saved if the refrigerators can be electrically disconnected during the peak time (say from 1900 to 2100). Such an action however will jeopardize the main purpose of the household refrigerator, namely conservation of food, and thus becomes unacceptable.

To find a compromise, it is suggested here to operate the refrigerators in low-power mode during the peak time. The parameters related to on- and off-times distributions are affected by the operation mode of the refrigerator leading to an overall power saving. Under low-power mode the parameters λ_{off} and μ_{off} tend to increase and the parameter μ_{on} tend to decrease. All these changes effect a reduction of the total power consumption of the stock of refrigerators operating in low-power mode.

A theoretical analysis done for the refrigerant R-12 has revealed that an increase of evaporation temperature by 5°C leads to an energy saving of 20%. By setting the evaporation temperature corresponding to 'low' mode 5°C higher than the normal evaporation temperature the average energy consumption is reduced by 20% during peak-time.

To enhance the saving it is suggested here to operate the refrigerators at high-power mode in a period immediately prior to the beginning of the peak-time. This brings the refrigerator temperature to the lowest desirable level and keeps it ready to overcome the peak-time with least possible energy consumption.

During the period of 'high' mode operation refrigerators consume in average 20% more than normal. This energy is effectively stored for later use during the peak-time. The proper selection of the 'high' mode operation period the peak energy consumption can be further cut down by 15% allowing 1/4 out of the 20% for losses. This is added to the earlier 20% leading to a total saving of 35%.

Based on this, each refrigerator of multi-mode type consumes in average 24.5W (=70W*0.35) less during the peak time. If all the new refrigerators sold (55000 annually) are equipped with multi-mode facility the growth of the system peak, due to above saving, is slowed down at the rate 1.35MW (24.5W*55000) per annum. This means that the supply authority avoids an investment worth of at least Rs. 30 million every year.

A more accurate estimate is possible once the parameters described in section 3.0 are obtained through field measurements.

5.0 Implementation

A simple control system timed by an internal clock can do the switching over from mode to mode. The cost of this control unit is added to the production cost of the refrigerator. The investments avoided by the electricity supply authorities will substantially override the above cost giving a net benefit to the national economy. The policy makers will have to intervene and motivate the refrigerator manufacturers to integrate this concept into their products.

Since only the new refrigerators can be practically equipped with multi-mode facility some time will be taken to achieve the desirable penetration level.
The other problem may be to motivate the households to buy this type of refrigerators and to persuade them to keep the refrigerator clock in tact. The manufacturers will have to use their design skills to place the refrigerator clock in such a way that it serves as a kitchen clock as well.

6.0 Concluding Remarks

This paper introduces a new operating concept for household refrigerators whose implementation leads to a reduction of the burden imposed by refrigerators on the power system during peak time. A potential peak shaving of 1.35MW is identified for every year based on the current sales of 55000 new refrigerators annually. In order to get a closer Estimate of this a mathematical model has been developed for the load curve of the refrigerators. The parameters of this model are to be obtained through field measurements planned.

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SLEMA NEWS.........

Changing today's consumption patterns —for tomorrow's human development

World consumption has expanded at an unprecedented pace over the 20th century, with private and public consumption expenditures reaching $24 trillion in 1998, twice the level of 1975 and six times that of 1950. In 1900 real consumption expenditure was barely $1.5 trillion.

The benefits of this consumption have spread far and wide. More people are better fed and housed than ever before. Living standards have risen to enable hundreds of millions to enjoy housing with hot water and cold, warmth and electricity, transport to and from work—with time for leisure and sports, vacations and other activities beyond anything imagined at the start of this century.

How do these achievements relate to human development? Consumption is clearly an essential means, but the links are not automatic. Consumption clearly contributes to human development when it enlarges the capabilities and enriches the lives of people without adversely affecting the well-being of others. It clearly contributes when it is as fair to future generations as it is to the present ones. And it clearly contributes when it encourages lively, creative individuals and communities.

Human life is ultimately nourished and sustained by consumption. Abundance of consumption is no crime. It has, in fact, been the life blood of much human advance. The real issue is not consumption itself but its patterns and effects. Consumption patterns today must be changed to advance human development tomorrow. Consumer choices must be turned into a reality for all. Human development paradigms, which aim at enlarging all human choices, must aim at extending and improving consumer choices too, but in ways that promote human life.

Source: United Nations Annual Report 1998 on Human Development