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LOAD MANAGEMENT IN MUNICIPAL ELECTRICITY SYSTEMS

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SUMMARY

Load management is one means of reducing maximum electricity load, and hence also the cost of electricity. In Sweden, the amount charged during the maximum load hour might be about 200 times higher than the standard charge for one kilowatt-hour. If the load could be reduced by certain equipment in factories and buildings, the need for new power stations and higher capacity in the grid would also be decreased. Using electricity load data for one full year and a short computer program, this paper shows by how much the load could be reduced by postponing demand. If part of the load could be postponed by only one hour, this part may need to be only very small for maximum benefit. If longer time segments were practicable, larger chunks could be transferred. The main result of the study is, however, that load management in practice is a very subtle task if an optimal solution is to be achieved.

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1. INTRODUCTION

At the moment of writing, December 1995, Sweden plans to phase out its nuclear power stations before the year 2010 in accordance with a parliamentary decision. If this comes about, new generating capacity must be built or there will be a substantial shortage of electricity. The cost of electricity will therefore increase, especially for periods when such a shortage is more likely to occur. Marginal cost theory also implies that the cost of electricity should reflect the cost of producing one extra kilowatt-hour, or the money that would be saved if one kilowatt-hour were not produced at all. When there is a risk of a shortage, this cost will be very high, i.e. it reflects the cost of building new power stations. Studies of electricity use patterns reveal that buildings and factories produce peaks that are expensive both for the proprietors and for the utilities serving them. In one paper dealing with industrial buildings (Björk and Karlsson, 1988), the authors discuss how to reduce the expensive peak charge and at the same time use cheap off-peak electricity for heating the premises. McDonald *et al.* (1994a; b) examine how end-use consumers react to spot-price tariffs for electricity and what measures they could take in order to avoid the highest costs. They also stress the necessity for consumers to be aware of the prices in effect, and further they discuss in more detail how a tariff should be designed when based on these spot prices. In the work of Renar and Tomsic (1992), methods of avoiding costs by the utility are stressed and what measures should be taken if the utility is to act in an optimal way. However, they use long-range marginal costs for finding such measures, which can only be accurate if a number of investments are considered. For more details about marginal cost theory see, for example, the work of Schramm (1991) and Weismann (1991). Unfortunately, none of the papers examines in detail how a load management system should be designed in order to achieve an optimal result, i.e. to find out how much, and for how long, parts of the peaks should be transferred to later hours. However, to some extent this has been dealt with by Gustafsson (1996) who examined a small carpentry factory. The main conclusion of that study was that only

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a very small part of the peak, about 3% of the total peak load, should be moved, and then only for a few hours. This result created interest in a further study: the electricity load of a municipality with a much higher electricity demand.

2. CASE STUDY

The electricity load data for this case study comes from the municipality of Kalmar, which is about 300 km south of Stockholm, Sweden. The values were monitored in 1990 and they have also been the subject of earlier studies (Gustafsson, 1992; 1993). In Figure 1, a duration graph is shown, in which the hourly demands have been arranged in descending order. From Figure 1 it is obvious that the peak is not very accentuated. None the less, a reduction by say 5 MW would be very profitable because each MW costs about 300 000 SEK in demand charges (one US$ equals about 7 SEK). The question is now if this could be achieved with a load management system.

2.1. Load management

The demand charges in Sweden are based on the maximum demand during one month. The average of four or five of these values is then multiplied by the demand charge which is expressed in SEK per kilowatt. In the case of Kalmar, the maximum load during the monitored year emerged on 17 January 1990 at 11:00. However, the load management system must always start to operate on the first hour of the month, i.e. if no default lowest value is set into the apparatus. In Table 1, the values monitored on 1 January are shown. In the first hour of the year, the monitored load was 40·379 MW. Suppose for a start that 100·0 kW h could be transferred to the next hour. The load will reduce to 40·279 MW and the next hour will receive the moved energy amount, resulting in a demand for 39·117 MW at 02:00 this first day of the year. So far, the system works well. Seven hours later the load is 41·468 MW and the system once again moves 100 kW h to the next hour, which also works well. At 11:00 the monitored load is 42·380 MW and again 100 kW h are moved, but now the load at 12:00 is 43·672 MW and the added energy aggravates the situation resulting in 43·762 MW. In fact, the system operates six times on 1 January but makes the situation worse for three of

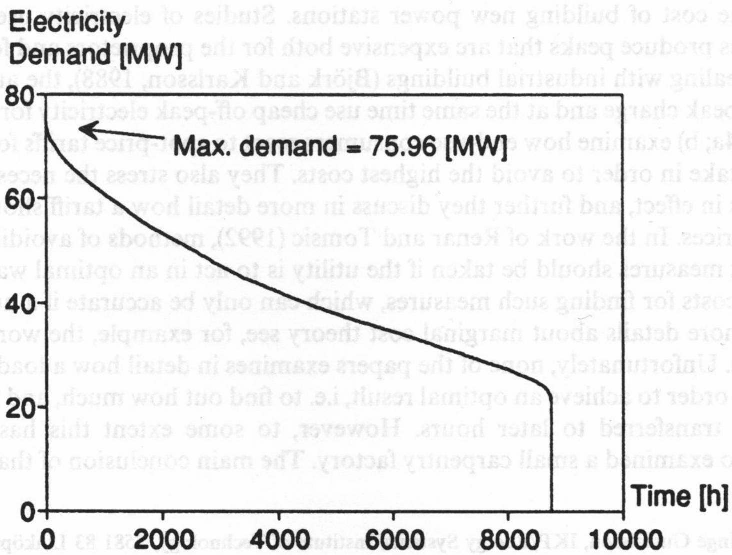

Figure 1. Duration graph for electricity load during 1990 in Kalmar, Sweden [*Source*: Gustafsson, 1993]

Table 1. Electricity demand monitored 1 January 1990 in Kalmar, Sweden

Hour	Demand (MW)	Hour	Demand (MW)	Hour	Demand (MW)
01:00	40·379	09:00	40·911	17:00	49·222
02:00	39·017	10:00	41·067	18:00	48·144
03:00	37·923	11:00	42·380	19:00	47·188
04:00	36·198	12:00	43·672	20:00	46·073
05:00	39·931	13:00	44·678	21:00	44·384
06:00	39·015	14:00	45·120	22:00	42·492
07:00	40·143	15:00	45·969	23:00	40·626
08:00	41·468	16:00	47·808	24:00	37·987

Table 2. Load management operation in January 1990. Level: 100 kW; transfer: 1 h

Date	Number of 'hits'	Original maximum load (MW)	New maximum load (MW)
1	6	49·222	49·122
2	4	67·205	67·305
4	1	67·635	67·535
7	2	70·221	70·121
8	1	70·240	70·140
9	1	70·403	70·303
14	2	75·225	75·325
15	1	75·665	75·565
17	1	75·955	76·055

the adjacent hours. For 2 January, four hours are subject to load management and in all cases the loads are made higher in later hours. It is also interesting to note that the system operates more frequently at the beginning of each month than at its end. This is because the lowest peak level increases when higher and higher loads emerge. This is shown in more detail in Table 2. After 17 January, no new peaks emerged and thus the system would have operated 19 times. Suppose, instead, a level of 1000 kW was used for the system. The first hour in January would of course still be subject to load management resulting in a new load of 39·379 MW. The second hour would then hold a load of 40·017 kW h, so this later hour will now be of interest which was not the case above. Table 3 shows this new situation.

This time 13 load management 'hits' were registered compared to 19 above. If the level were increased, the system would operate less frequently. It is also interesting to note that in spite of a higher level, the resulting peak increased. The situation therefore became worse than it was without load management.

One means to improve the system would be to allow just a part of the transferred load to be added the next hour and let the rest move to the second next one. Consider once again Table 1 and a level of 1 000 kW. The first hour will be reduced to 39·379 MW. Now, only 362 kW h is allowed to be added to the second hour, which results in 39·379 MW again, while 638 kW h are added to the third hour on 1 January which in turn will have a demand for 38·561 MW. The situation therefore improved. The next time the system will operate is at 07:00. If 764 kW h are transferred, the previous peak will not be exceeded. The next hour will therefore achieve a load of 42·232 kW h and the system must operate once again, now with a full 1000 kW h resulting in 41·232 MW at 08:00 and 41·911 MW at 09:00. Further, the procedure must be repeated at 11:00 leaving a load of 45·678 MW at 13:00. This somewhat tedious discussion shows that the load management system

Table 3. Load management operation, January 1990. Level: 1 000 kW; transfer: 1 h

Date	Number of 'hits'	Original maximum load (MW)	New maximum load (MW)
1	5	49·222	49·144
2	2	67·205	67·248
4	1	67·635	67·525
7	2	70·221	70·813
14	2	75·225	75·023
15	1	75·665	76·665

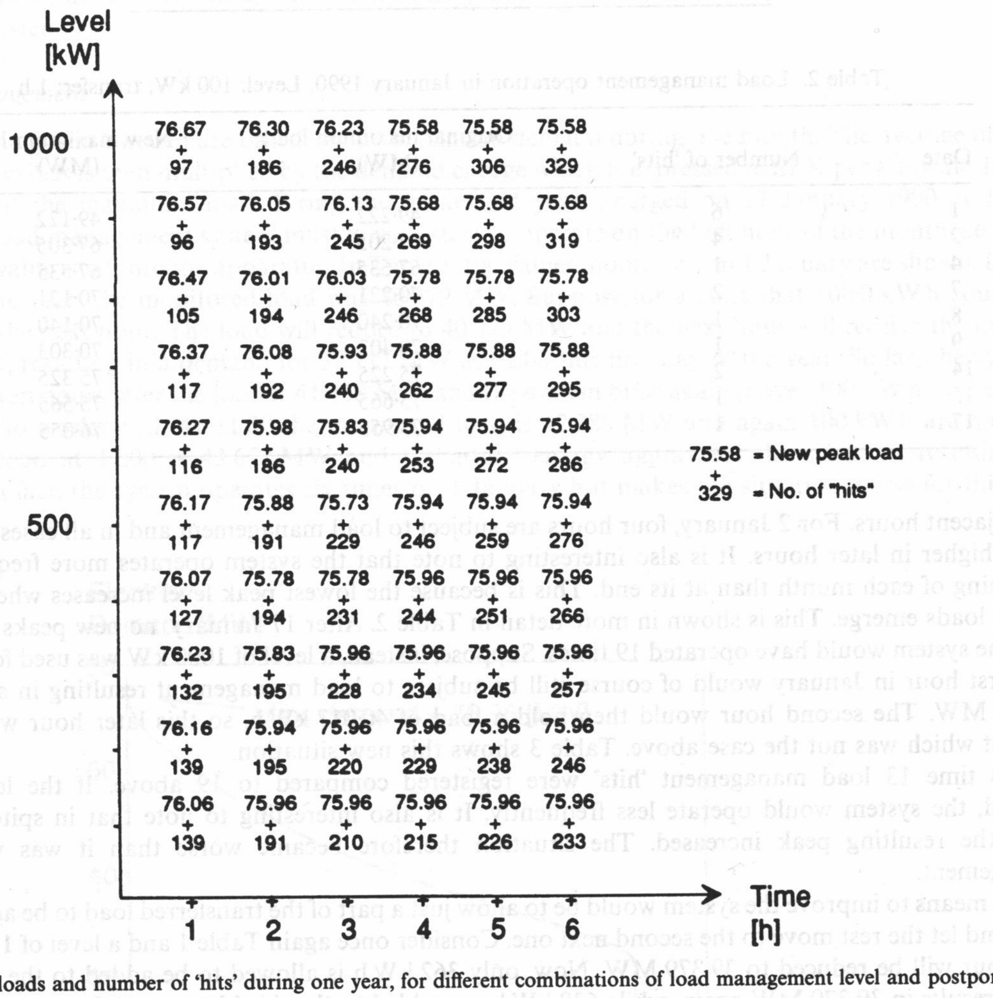

Figure 2. Peak loads and number of 'hits' during one year, for different combinations of load management level and postponements

operates more frequently if a longer transfer time is allowed, but also that the resulting peak load might be reduced. However, a closer study revealed that the peak for January now became 76·295 MW. Longer transfer times and higher levels will hence not always lead to a lower peak. In Figure 2 the situation is presented for all combinations of levels between 100 to 1000 kW and transfer periods from 1 to 6 h.

From Figure 2, it is obvious that a load management system will reduce the peak load. The original maximum load was 75 955 kW while the lowest value found in the figure is 75 580 kW, a reduction of 380 kW. The number of times the system operates increases with the allowed number of hours for postponement, but this will not always lead to a lower peak. For low levels about two hours seems to be optimal, while four hours seems to be sufficient for a 1000 kW level, for example. Because of the fast increase of the 'hits', which could be a drawback for industrial processes and so forth, one must not choose longer postponements than necessary. The fact is that the lowest value found in this study emanates from a level of 1500 kW and a postponement time of five hours resulting in a new peak of 75 225 kW. Even when the level was increased to 4000 kW, the situation did not improve. The optimal level for load management was therefore about 2% of the original peak load. If there are problems in finding processes that can be postponed for such long periods, the level of load management should be decreased. For example, the lowest value found for a two hour postponement is about 400 kW, i.e. only about 0·5% of the original peak. However, the economic benefits might be substantial. A decrease of 400 kW will reduce the electricity cost by 120 000 SEK each year, and therefore profitable load management measures must be possible to find. It is also important to note that the electricity tariff for the municipality might not always reflect the real marginal cost. In certain areas the grid, or other equipment, may be used to its maximum limit. If the cost of replacement by more powerful equipment could be avoided, or at least reduced, the economic benefits would increase.

3. CONCLUSIONS

The optimum level of load management in the municipality of Kalmar was found to be 1500 kW which is about 2% of the original peak load. However, this level implied that a five hour postponement must be introduced which might be hard to achieve without severe drawbacks for industrual process for example. If shorter postponements must be used, the level of load management must also decrease. A two hour postponement will result in an optimal level of about 400 kW, i.e. about 0·5% of the original peak. Even if the optimum level is very low compared to the original peak load, substantial economic benefits might arise because of high demand charges. If there are capacity problems in, for example, the electricity grid, these economic benefits will substantially increase.

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