

Demand Response for Peak Load Reduction in a Smart Distribution Network

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ABSTRACT

Electricity demand varies greatly through the day, rising to peaks that the network and generation must be sized to meet even though those peaks occur for only a few hours, which is costly and strains the system, and demand response, which encourages consumers to reduce or shift their use at peak times, offers a way to lower the peaks without building more capacity. This study examines demand response for peak load reduction in a smart distribution network and evaluates its effect on the peak demand and the use of the network. A demand-response scheme was applied in which controllable loads were reduced or shifted away from the peak hours in response to a signal, and the load profile was compared before and after, the peak demand, the load factor, and the consumption during the peak hours being assessed. The scheme substantially reduced the peak demand, clipping the highest part of the load and shifting some of it to off-peak hours, so that the daily peak fell while the total energy consumed was largely preserved, merely rearranged in time. The reduction in the peak improved the load factor, the ratio of average to peak demand, indicating more even use of the network, and it relieved the network and generation of the most stressful part of the load. The study shows that demand response effectively reduces peak load and flattens the demand profile in a smart distribution network, deferring the need for additional capacity and improving the use of the existing system, and it discusses the controllable loads and the signals on which the scheme depends.

KEYWORDS: *Demand response, Peak load reduction, Smart grid, Load factor, Peak shaving, Load shifting, Distribution network, Demand-side management, Load profile*

INTRODUCTION

The demand for electricity is not constant but varies through the day and the year, rising and falling with the activities of consumers. It typically reaches peaks at certain hours, such as the evening, when many demands coincide, and falls to low levels at others, such as the small hours of the night. This variation poses a problem for the electricity system, because the network and the generation must be sized to meet the highest peak demand, even though that peak occurs for only a few hours; the capacity needed for the peak sits largely idle the rest of the time, which is costly and inefficient.

Meeting ever-higher peaks by building more generation and network capacity is expensive and increasingly difficult, and it leaves that capacity underused outside the peak. An alternative is to reduce the peaks themselves, by influencing the demand rather than only supplying it. Demand response does this: it encourages or enables consumers to reduce their use at peak times, or to shift it to off-peak times, in response to a signal such as a price or a control command. By lowering the peak demand, demand response can defer or avoid the need for additional capacity and make better use of the existing system.

The smart distribution network, with its communication and control, makes demand response practical, allowing signals to reach consumers and controllable loads to respond. This paper examines demand response for peak load reduction in such a network and evaluates its effect. A demand-response scheme is applied in which controllable loads are reduced or shifted away from the peak hours, and the load profile is compared before and after, the peak demand, the load factor, and the peak-hour consumption being assessed. The aim is to quantify the reduction in peak load and the flattening of the demand profile and to discuss the controllable loads and signals on which the scheme depends.

LITERATURE REVIEW

Demand response and the broader practice of demand-side management have been studied extensively, and the literature establishes their principles and benefits. Demand response is described as the change in consumers' electricity use in response to signals, whether prices that vary with time or direct control of loads, with the aim of reducing or shifting demand. Its principal application is the reduction of peak demand, which relieves the system at its most stressed and defers the need for new capacity.

MECHANISMS AND BENEFITS

The literature identifies the mechanisms and benefits of demand response:

- Loads may be reduced at peak times, lowering the peak directly, or shifted to off-peak times, moving demand rather than removing it.
- Signals may be prices that vary with time, encouraging consumers to use less when power is expensive, or direct control of certain loads.
- Controllable loads, such as heating, cooling, and deferrable appliances, are those most amenable to response.
- The benefits include reduced peak demand, deferred capacity, improved load factor, and better use of the network and generation.

A recurring conclusion is that demand response reduces peak demand and flattens the demand profile, improving the use of the system, and that the smart grid's communication and control make it practical.

Studies of demand response report that it can substantially reduce peak demand by clipping and shifting load, that it improves the load factor by making demand more even, and that it defers the need for additional capacity, which is one of its chief economic benefits. The literature notes that the effectiveness depends on the amount of controllable load and the responsiveness of consumers, and that shifting load rearranges energy in time rather than reducing total consumption, so the benefit lies in the reduced peak rather than reduced energy.

RESEARCH GAP

Although demand response is well studied, a concise demonstration that applies a peak-reduction scheme to a load profile and shows the resulting reduction in peak demand and improvement in load factor remains useful as a clear illustration of the benefit. There is therefore value in a study that compares the load profile before and after demand response and relates the reduced peak and flattened profile to the clipping and shifting of controllable load.

OBJECTIVES

The objectives of this study are:

- To apply a demand-response scheme reducing or shifting controllable loads away from the peak hours in a smart distribution network.

- To compare the load profile before and after the scheme.
- To assess the peak demand, the load factor, and the consumption during the peak hours.
- To relate the effect to the clipping and shifting of controllable load and to discuss the loads and signals involved.

METHODOLOGY

Demand-Response Scheme

A smart distribution network supplying a daily load with a pronounced peak was considered. A demand-response scheme was applied in which controllable loads were reduced or shifted away from the peak hours in response to a signal, the reducible part of the load at the peak being curtailed and some of the shiftable load being moved to off-peak hours. The scheme is summarised in Table 1.

Table 1: Elements of the demand-response scheme

Element	Description
Objective	Reduce the peak demand of the network
Signal	Time-varying signal prompting response at peak
Controllable loads	Reducible and shiftable loads
Reduction	Curtailment of reducible load at the peak
Shifting	Movement of shiftable load to off-peak hours

Evaluation

The load profile over the day was compared before and after the application of the scheme. The peak demand, the highest point of the profile, was assessed to measure the reduction; the load factor, the ratio of the average to the peak demand, was computed to measure the flattening of the profile; and the consumption during the peak hours was examined, together with the total daily energy, to confirm that load was shifted rather than merely lost. The before and after profiles were thus compared on the reduction of the peak and the evenness of demand.

RESULTS AND FINDINGS

The demand-response scheme substantially reduced the peak demand, as shown in Figure 1. The highest part of the load, occurring in the evening peak, was clipped, the peak demand

falling markedly below its original value, and some of the curtailed load was shifted to the off-peak hours of the early morning, raising the demand there. The profile was thus both lowered at the peak and filled in the valley, becoming more even over the day, while the total energy consumed was largely preserved, the load having been rearranged in time rather than removed.

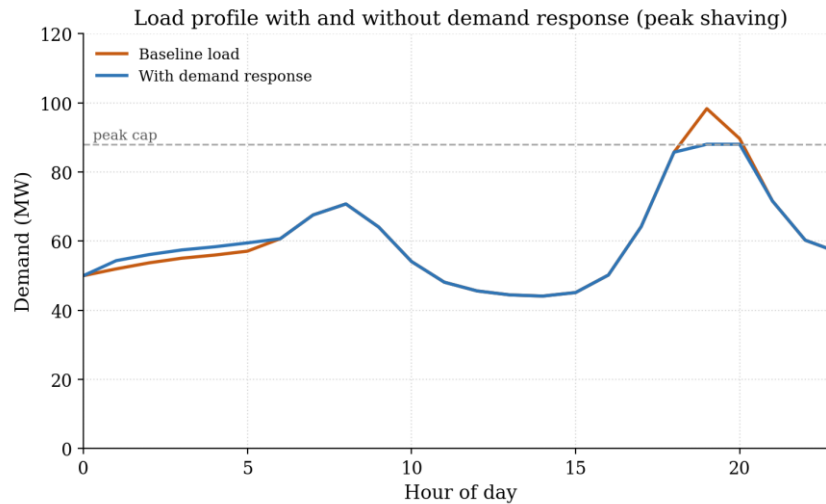


Figure 1: Load profile with and without demand response, showing peak shaving

The reduction in the peak improved the load factor, the ratio of the average to the peak demand, which rose as the peak fell while the average changed little. A higher load factor indicates more even use of the network and generation, which is beneficial because it means the capacity is used more fully and the most stressful part of the load is relieved. The peak-hour consumption fell, while the total daily energy was nearly unchanged, confirming that the scheme shifted load rather than reducing total demand. The effect of the scheme is summarised in Table 2.

Table 2: Network demand before and after demand response

Measure	Before	After
Peak demand	Higher	Reduced (peak clipped)
Load factor	Lower	Improved
Peak-hour consumption	Higher	Reduced
Total daily energy	Reference	Largely unchanged

DISCUSSION

The results show that demand response effectively reduces peak load and flattens the demand profile in a smart distribution network. The scheme acted on the peak in two ways: by curtailing reducible load at the peak, it lowered the highest demand directly; and by shifting some load to off-peak hours, it moved demand from the peak to the valley, both reducing the peak and filling the trough. The combined effect was a markedly lower and more even profile, which is precisely the outcome sought, since it is the peak that determines the capacity the system must provide.

The improvement in the load factor captures the benefit concisely. The load factor, the ratio of average to peak demand, is low when demand is peaky and high when it is even, and a higher load factor means the network and generation are used more fully and steadily rather than being sized for a peak that occurs briefly. By reducing the peak while preserving the average, demand response raised the load factor, indicating better use of the system. That the total daily energy was nearly unchanged, while the peak fell, confirms that the benefit comes from rearranging demand in time, not from reducing it, and so is achieved without requiring consumers to forgo their total consumption, only to move part of it.

The chief economic benefit of this peak reduction is the deferral of capacity. Because the system must be sized for the peak, reducing the peak defers or avoids the need to build additional generation and network capacity, which is costly, and makes better use of what exists. The effectiveness of demand response depends, however, on the amount of load that is controllable and on the responsiveness of consumers: only reducible and shiftable loads can be acted upon, and consumers must be willing to respond to the signals, whether prices or control. The smart grid's communication and control are what make the scheme practical, conveying the signals and enabling the response. The practical conclusion is that demand response is an effective and economical means of reducing peak load and improving the use of a distribution network, the main caveats being that the effect depends on the controllable load and consumer responsiveness and that the figures are for a representative profile.

CONCLUSION

Demand response for peak load reduction in a smart distribution network was examined, and

its effect on the peak demand and the use of the network evaluated. The scheme substantially reduced the peak demand by clipping the highest part of the load and shifting some of it to off-peak hours, so that the daily peak fell while the total energy was largely preserved, merely rearranged in time, and the load factor improved, indicating more even use of the network. The study shows that demand response effectively reduces peak load and flattens the demand profile, deferring the need for additional capacity and improving the use of the existing system, that the benefit comes from rearranging demand in time rather than reducing it, and that the scheme depends on the amount of controllable load and the responsiveness of consumers, made practical by the communication and control of the smart grid, with the figures here being for a representative profile.

LIMITATIONS

The following limitations apply to this study:

- The effect depends on the amount of controllable load and the responsiveness of consumers, which vary.
- The figures are for a representative load profile and would differ for other networks and patterns of demand.
- Shifting load to off-peak hours could create new peaks if applied at large scale without coordination, which was not examined.
- The study assessed peak reduction and load factor and not the detailed economics or the consumer response in depth.

FUTURE SCOPE

Future work could extend the present study as follows:

- Study of large-scale demand response and the coordination needed to avoid creating new peaks off-peak.
- Modelling of consumer responsiveness to different signals, including time-varying prices and direct control.
- Assessment of the economic benefit, including deferred capacity and reduced costs.
- Integration of demand response with renewable generation, shifting load to times of high renewable output.
- Evaluation across diverse networks and demand patterns to assess generality.

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