

Consumer Co-operation in Demand Side Load Management; an assessment

Shailendra Baraniya

Department of EXTC Engineering, Mukesh Patel School of
Technology Management, and engineering,
NMIMS
ShirpurIndia
e-mail:shailendra.b@nmims.edu

Dr. Manoj Sankhe

Department of EXTC Engineering, Mukesh Patel School of
Technology Management, and engineering,
NMIMS
Mumbai, India
e-mail:manoj.sankhe@nmims.edu

Abstract- Power systems today are networked, and intelligent; thanks to the emergence of smart-grid infrastructure. This has opened up new frontiers in energy management paradigm. The transmission, distribution and dispatch systems have become smart and informed, leading to better services. A major concern in power systems operation is demand side load management; an issue affecting quality of service, and profitability simultaneously. This paper discusses a concept demand side load management (DSLMM) system, which invokes consumer participation in DSLMM, keeping consumer comfort intact. This system looks for change in time of use (TOU) of various appliances in the consumer premises, in agreement with consumer, and aims to attain peak shaving. The system limits the intervention, to peak hour and hence tries to keep consumer preferences least interfered. The performance assessment of the efficacy of system is done through simulation.

Keywords- Demand Side Load Management, Consumer Load Profile Management, Peak shaving, Boot-strap re-sampling.

I. INTRODUCTION

Demand Side Load Management is class of activities done by utilities/ consumers aimed at efficient utilization of energy, and improvement in productivity of the system.

Demand-Side Management (DSM) or Demand-Side Load Management (DSLMM) is defined as the selection, planning, and implementation of measures intended to have an influence on the demand on customer-side of the electric meter, either caused directly or stimulated indirectly by the utility.

The scope of DSLMM include utilization efficiency, load profile engineering, and QOS improvement [1]. DSLMM ultimately affects the Quality of Service (QOS), and profitability of generation and utilities, in addition to improving stability of the system.

One needs to look at deliberations at generation/ grid to realize impact of DSLMM on profitability. The transactions at grid are adequately understood by studying, Load Demand Profile (LP) at Generation/ Grid (LP-G); a plot of load delivered v/s time, on a given day.

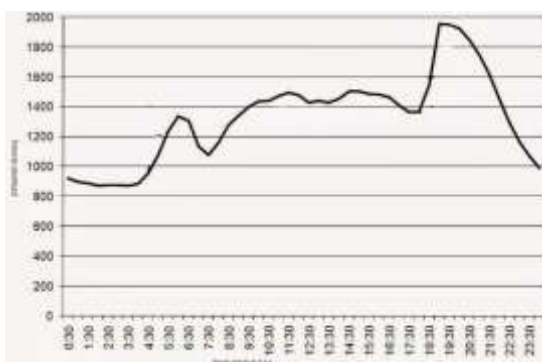


Figure-1 Typical Load Profile at Grid (LP-G)

The LP-G at any moment is plot for aggregate demand serviced by the grid v/s time, for the day. Figure-1

shows typical load profile at Grid. The fluctuations in LP-G originate from consumer preferences in utilization; their chosen time of utilization of energy. Hence, it is worthwhile to study the consumer behaviour. Similar to the LP-G, we have load profile at consumer (LP-C); a plot of connected load v/s time, on a given day. Delivery of fluctuating demand is challenging, technically (for dynamic concerns) and financially. At times of moderate and low demand (troughs) the marginal cost of generation goes up significantly, and at times of higher demand (peaks), near capacity, leads to frequency issues/ load shading/ capacity management. Thus, either way leads to a loss of profit or quality of service. Additionally the peaks and troughs of LP-G leads to problems relating frequency and voltage stability. As far as peaks of LP-G are concerned these can cause loss of frequency, and if not attended to may lead to generation falling out of step. This certainly risk the complete system and hence, the LP-G management has been and will ever remain an important issue demanding real-time intervention. The LP-G management in peak region is an exercise of bringing up additional capacities, to be able to cater to the peak load, or bringing down the peak demand by curtailing, partially the connected loads by load shedding. The second option is obviously not worth recommending. The DSLMM is accepted as a viable tool for LP-G management through modifications in LP-C of consumers.

There are opportunities of intervention at valley and peak, of the LP-G. We try to engineer the LP-G so as to flatten peak (peak shaving), and push up trough (valley filling), to smoothen the LP-G. Smoothing of LP-G leads to improved efficiency of generation and bring down marginal costs of energy. Higher efficiency means lower CO₂ emissions. The fluctuations in LP-G originate in consumer premises; hence, the solution should be seen there too. The work [C] establishes bearing of DSLMM on LP-C, and its role in creating additional capacity. The present work proposes to a DSLMM scheme in the consumer premises to improve LP-C with minimal or no loss of QOS to the consumer.

A. Related Work:

Since inception of power systems, the load profile management has been an omnipresent concern among power professionals, and researchers. The peaks of the LP-G may throw generation capacities to margins, and risk stability of the system. This calls for inventing additional capacities, to be able to maintain frequency and voltage stability, without resorting to load shedding. Evolution of grid infrastructure, distributed energy resources (DER), and advanced metering infrastructure (AMI) is leading to numerous innovations, in power system management. Typically, micro generation, in solar, wind and hydel, shows some way forward, by creation of microgrids. The works like [2], which brings to fore the possibility of optimizing distributed generation for better LP-C management. This utilizes the DERs like solar photovoltaics, wind units for creating floating capacity.

Engineering of LP at distribution is being effected, through load dispatch strategies, with success. DSLM can create adequate capacity, through altering time of use (TOU) of appliances, effecting load profile engineering [3]. Evolution of AMI, and a grid coordinated DSLM implemented inside consumer premises, promise to provide an enduring solution. There are good number of attempts available in this area of DSLM.

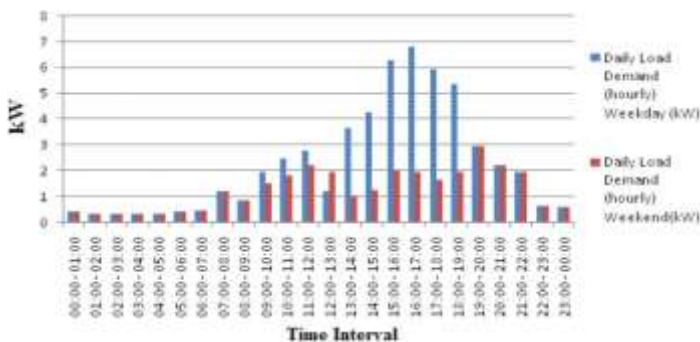


Figure-2 Typical LP-C

Coordinated scheduling of services is explored in [4]. The work [5] revoke interruptible loads to effect drop in peak demand at consumer premises. This proposal calls for identification of interruptible loads in the consumer premises, whose controls are surrendered to the central module. The capacity likely to be generated through this scheme depends on availability of interruptible loads, in the consumer premises. In addition to this, there is a thinking in industry supporting a real time pricing of electrical energy [6], [7]. The real time pricing tries to incentivise consumers, in grid off peak-hour utilization, and penalize consumers, in grid off peak-hour utilization. This approach has seen limited success. A work [8] on similar lines, has proposed an LP-C management via real time pricing (RTP) for residential consumers. This considers a zero sum game between the utility and the consumer. This is good for deferrable loads (DLs) like plugged-in electrical vehicles, storage batteries, etc. The mechanism is of help in valley filling. As far as the other utilization is concerned interaction between consumer and utility is not zero sum affair. Reason being; energy cost as part of total cost of a productive activity, is usually a minor consideration, and its TOU is governed by the underlying

processes, rather than cost of energy. Change in TOU for any appliance is linked to consumer comfort directly. Hence, the gain in PAR expected is difficult to realize.

Another work [9] talks about direct digital load scheduling (DDLs), and cooperation between different consumers, and classifies loads in consumer premises, as DLs, and non DLs. The DLs are surrendered to the grid, and used for creating floating capacity, for valley filling. Every consumer premises has a controller which schedules the DLs, and communicates with other consumers, and the grid. The DLs of different consumers create bigger capacity, as against an in house implementation, hence tries to address LP management better. This scheme freezes consumer preferences in operation, somehow affects quality of service. Also, scheduler being on network invokes security concerns.

B. Load Profile Management :

The objective of load profile management at grid is to smoothen the LP-G. The variations in LP-G originate from the energy usage patterns of individual consumers. The usage pattern of a consumer, i.e. his LP-C, is reflection of his TOU for different appliances. Theoretically, ignoring consumer preferences, the LP-G can always be smoothened to the optimal by rescheduling the appliances as per best available optimization algorithms, but, it is easier proposed than implemented.

The most important issue in design of a DSLM, inside a consumer's premises, is the acknowledgement of the consumer preference in TOU. TOU for any appliance, at consumer premises is defined by the need of energy consumption, in processes necessary for accomplishment of productive tasks. These preferences are stringent and difficult to negotiate, except in some cases of deferrable loads. These deferrable loads (D-loads) certainly bring some succour, and can be surrendered to an autonomous scheduler. Their rescheduling helps valley filling, and create reserve in peak hours. Except for these D-loads, any rescheduling of loads, his preferences are dynamic, and consent, every instant is essential. The consumer comfort is the major factor, in acceptability and success of a direct DSLM. The consumer comfort can be seen as a function of number of interventions made in scheduling of loads. Hence, a scheme which invokes lower number of rescheduling would mean better consumer comfort.

C. Contribution:

This paper studies a DSLM scheme. This scheme seeks implementation through a conceptual framework, acting as the vehicle of transaction between grid and consumer. The framework is thought of comprising of a hub communicating with grid to receive grid directives, and processing advice for various loads (nodes), to effect the desired. The system remains in a non-interference, advisory mode. It advises the consumer through flags and not controls the loads, thereby strictly not interfering with operation of the appliances, keeps consumer comfort intact.

II. THE PROBLEM

A. The Environment:

The distribution system is transaction place for energy between the consumer and generation/ grid. The transmission/ distribution have been made intelligent by smart-grid infrastructure, which carries real-time information pertaining to system status, energy dispatch vectors etc. These data can be used for better management of load dispatch, and improving productivity, and efficiency of the system. The smart grid infrastructure is extended to the consumer premises, till the advanced metering infrastructure (AMI). Since, the vital real-time data pertaining to the grid is available in the consumer premises; it will be worthwhile to utilize it for energy management inside the premises.

The LP-G can be smoothed through shift in TOU of loads, in consumer's premises. This shift in TOU needs to be synchronized with LP-G peaks, (or troughs). This requires the consumer to alter start time of individual appliances, so as to avoid loading of the grid, during grid peaks. And, to increase loading during grid troughs, the consumer need to shift the utilization of energy to trough hours of LP-G.

B. Issues:

The shifts in TOU of loads modify LP-C of individual consumer. When many such consumers effect shift in TOU, for their respective loads, synchronous with the grid peak hour, results in peak shaving or valley filling, of LP-G. An over-correction of this type may shift grid peak, or trough hour.

C. Assumptions:

The consumer premises electrical installation is an electrical power network, comprising of power taps with associated switchgear (nodes), where loads can be connected in the consumer premises, connected to the utility supply through advanced metering infrastructure (AMI), aka smart meter.

i. The scheme assumes that the consumer in whose premises the DSLM framework is installed is willing to co-operate in LP management initiative of the utility.

The motivation behind co-operation can be one or many of the factors including differed pricing, consumer education etc.

ii. An appliance is tied to a node in the power network. The appliance doesn't change nodes, this makes it convenient to associate load specific parameters, named node vectors (NVs) with the appliances.

iii. The AMI is willing to share the grid loading data with the consumer premises DSLM infrastructure.

iv. For sake of objectivity, the valley filling is assumed to be taken care by the autonomous scheduling of D-loads.

v. The start time of different appliances exhibit normal distribution about mean start time, with earliest start time, and latest start time as extremes.

vi. Any change in TOU of an appliance, when done by consumer, in response to a request by the grid, doesn't

deteriorate consumer comfort. The change of TOU happens within limits given in (v) above.

vii. The AMI, is available with the information of day's peak time(PT) at the grid, based on the utility's load forecasting systems, sufficiently, in advance, say 12 hours, on any given day.

III. THE DESIGN

a. *Scope of the study:* Scope of this study is to investigate effect of DSLM implementation on "real power" connected to the grid during grid peak hours. The DSLM communications effected through the framework are restricted to the consumer premises. The framework is supposed to remains in observation mode, at other times.

b. *Architecture:* The work [10], and [11] provides basic concept for architecture of the framework. The work [10] has been stripped down for this proposal. The architecture of conceptual framework takes care of adaptability in the existing infrastructure. In fact it is envisioned to seek no alteration in existing installation, switchgear, or appliances. It is seen as a strap-on system on existing installation.

The electrical power distribution installation inside the consumer's premises, is primarily a dumb network, i.e. it lacks information exchange, and decision making. These tasks are primarily done by the consumer himself.

In order to respond to requirements of the grid, a real-time information communication and processing setup is needed. The proposed solution, make appliance' nodes communicate to a processing centre, and implement algorithms for DSLM.

i. *Hardware:* The scheme involves installation of a simple DSLM system inside the consumer premises, without interfering with the existing electrical installation. The DSLM system comprises of two components, leaf; a transducer-transceiver mounted at load end of conductor, feeding the load, near switchgear (node), and a command centre (CC), having communication link with smart meter on grid side, and with various leafs, on the other side.



Figure-3 conceptual DSLM framework

The communication links can be seen established via any mode, wireless, wired, or power-line communication, using a suitable protocol. The leaf monitors current, voltage and phase at the node. These parameters of the node along with the node ID; are continuously transmitted to the CC, by the leaf. The leaf has two LEDs (flags), a green, and a red, mounted visible near the respective switchgear. Flags act as

communication to the consumer, from CC. One leaf is installed at each node.

ii. *Working:* The CC receiving data from various nodes, maintains a database of mean power drawn, power factor, start time (ST) of operation, operation time (OT) at all nodes. The system is made to run in training mode for a long period (usually a few months), enabling creation of a large database of start times, power consumption, p. f. etc. at various nodes. The CC derives earliest start time(EST) latest start time (LST), and mean operation time (OT); jointly named as node vectors, for each node from the database. Once the initial database is created, the system is ready for routine operation. The system, upon entering into operation mode, CC talks to the AMI, and requests the peak time (PT), and duration of peak hour, the peak span (PS), and registers the same upon receiving. The CC receiving feeds from various nodes keep updating the corresponding NVs. The communication from CC to leaf is, stimulus to red and green flags. A red flag at any node is an advice to the consumer to avoid powering the load, and a green flag an advice to powering the load. An absence of a flag means the CC has no advice for the node. The system aims at reducing average loading in the consumer premises, during PS. The CC identifies nodes, likely to go active during PS, their impact is assessed and decided as to whether the ST of the appliance be delayed, or advanced, so as to have reduce loading on the grid during PS.

iii. *Algorithm:* The nodes likely to go active during PS are categorized in different classes, as listed in table-1. Decision for flags, to be released for respective nodes is arrived at as per contribution of the node and its impact on the loading of the grid. The nodes who do not contribute to loading of the grid during PS, are not released any flags, and hence are unaffected by DSLM. The nodes contributing to the PS, are identified and categorised. Out of these, the loads, which have their typical start time before start of PS and its operation ends before end of PS, termed type-I. The type-I nodes are released green flag at their respective EST for advancing their start. The other types are defined accordingly. The scheme releases flags only for types I, II, IV, AND V loads, and all other nodes remain unaffected. The flags are withdrawn once the node goes operational.

Peak time of the grid: PT
Start time of PS: PT-PS/2
End time of PS: PT+PS/2

Table-1 Classification of Loads
(Flags: G- Green; to advance, R-Red to postpone)

S No.	Node Type	Start time (ST)	End time (ET)	Contributing to PS loading	Flag
1.	I	$ST < (PT - PS/2)$	$(PT - PS/2) < ET \leq (PT + PS/2)$	Y	G
2.	II	$(PT - PS/2) < ST \leq (PT + PS/2)$	$ET \geq (PT + PS/2)$	Y	R

3.	III	$ST < (PT - PS/2)$	$ET > (PT + PS/2)$	Y	-
4.	IV	$(PT - PS/2) \leq ST < (PT + PS/2)/2$	$(PT - PS/2) < ET \leq (PT + PS/2)/2$	Y	G
5.	V	$(PT + PS/2)/2 \leq ST < (PT + PS/2)$	$(PT + PS/2)/2 < ET \leq (PT + PS/2)$	Y	R
6.	VI	$ST < (PT - PS/2)$	$ET \leq (PT - PS/2)$	N	-
7.	VII	$ST \geq (PT + PS/2)$	$ET > (PT + PS/2)$	N	-



Figure-4 Algorithm

IV. PERFORMANCE ASSESSMENT

The efficacy of proposed scheme is seen as a drop in average power being drawn by the consumer during PS. A performance index is defined in [12], as ‘Demand Side Management Quality Index’ (DSMQI) as ratio of KVA input without DSM to KVA input with DSM. We define performance parameter of this scheme as Load Quotient (LQ), measured as a ratio (in percentage) of connected load of the consumer averaged over PS, on adaptation of the scheme, to the connected load, in absence of any interference, averaged over the PS. Since, the proposed DSLM system works in an advisory mode, the consumer response to flags, defines performance of the scheme. The LQ is largely influenced by the extent of consumer compliance to the flags. The consumer compliance is meant by number of flags, respected, and how early the flags are respected in case of green flags, or how late in case of red flags. Higher the compliance, lower the LQ would be. LQ Performance would be a function of a. Number of flags respected, for advancing or retarding of start of appliances, and b. The load, LD connected at the flagged nodes.

V. MODELLING

The consumer is modelled as an electrical network consisting of finite number (n), of nodes facilitating operation of appliances. The network is assumed to be connected to the grid through AMI. For sake of simplicity, the network is assumed to be transferring real power, to the nodes. This assumption is sufficiently valid, as we are aiming at load profile management through change in TOU, results of which can easily be extrapolated on apparent power.

Parameters of the model:

Number of nodes:	n
Node under consideration:	j
Load at j th node (in pu):	LD _j
Earliest Start Time of j th node:	EST _j
Latest Start Time of j th node:	LST _j
Typical operation time at j th node:	OT _j
Start time for j th node prior to DSLM intervention:	ST _j
Start time for j th node after DSLM intervention:	STC _j
Average load during PS in absence of DSLM intervention in i th iteration:	AV[i]
Contribution of type-I loads of i th iteration in absence of correction, to AV[i]:	Ci(I)
Contribution of type-II loads of i th iteration in absence of correction, to AV[i]:	Ci(II)
Contribution of type-III loads of i th iteration in absence of correction, to AV[i]:	Ci(III)
Contribution of type-IV loads of i th iteration in absence of correction, to AV[i]:	Ci(IV)
Average load during PS post DSLM intervention in i th iteration:	AVC[i]
Contribution of type-I loads of i th iteration post DSLM intervention, to AV[i]:	Di(I)
Contribution of type-II loads of i th iteration post DSLM intervention, to AV[i]:	Di(II)
Contribution of type-III loads of i th iteration post DSLM intervention, to AV[i]:	Di(III)
Contribution of type-IV loads of i th iteration post DSLM intervention, to AV[i]:	Di(IV)

$$Ci(I) = \sum_{\text{type-I}}^{\text{nodes}} (ST_j + OT_j - PT + SL) * LD_j \quad (1)$$

$$Ci(II) = \sum_{\text{type-II}}^{\text{nodes}} (PT - SL - ST_j) * LD_j \quad (2)$$

$$Ci(III) = \sum_{\text{type-III}}^{\text{nodes}} 2 * SL * LD_j \quad (3)$$

$$Ci(IV) = \sum_{\text{type-IV}}^{\text{nodes}} OT_j * LD_j \quad (4)$$

$$Di(I) = \sum_{\text{type-I}}^{\text{nodes}} (STC_j + OT_j - PT + SL) * LD_j \quad (5)$$

$$Di(II) = \sum_{\text{type-II}}^{\text{nodes}} (PT - SL - STC_j) * LD_j \quad (6)$$

$$Di(III) = \sum_{\text{type-III}}^{\text{nodes}} 2 * LD_j * SL \quad (7)$$

$$Di(IV) = \sum_{\text{type-IV}}^{\text{nodes}} OT_j * LD_j \quad (8)$$

$$AV[i] = \frac{Ci(I) + Ci(II) + Ci(III) + Ci(IV)}{2 * SL} \quad (9)$$

$$AVC[i] = \frac{Di(I) + Di(II) + Di(III) + Di(IV)}{2 * SL} \quad (10)$$

$$LQ[i] = \frac{AVI[i] - AVC[i]}{AVI[i]} \quad (11)$$

VI. SIMULATION

An LP (LP-G or LP-C) can be seen as comprising of four distinct regions, peak, trough, positive-gradient, and negative-gradient (figure-5). Peaks are global or local maxima, troughs are global or local minima, and shoulders are regions where demand trends-up to a peak; an uphill-shoulder, or rolls-down from a peak; a downhill-shoulder. We use simulation to assess performance of the scheme. We used VBA-Excel[®] for coding the model and simulation. This scheme seeks DSLM intervention so as to have implications in the peak hour of LP-G. The individual consumer, during LP-G peak hour, might be traversing through, in either of the four regions; peak, trough, uphill-shoulder or downhill-shoulder of his LP-C. This requires assessment of LQ for a chosen PS, at various points of LP-C, to establish performance of the scheme. Since the distribution of LQ for the population is not known, statistical means for making estimates is quite obvious. Median is chosen for as measure of central tendency, as the distribution of population is not known. We choose to estimate confidence interval, for LQ as median over the population. The consumer under study has 150 to 200 nodes, with swing in ST; (LST-EST), follow normal distribution with mean as 60 minutes, and s. d. as 15 minutes. The connected loads at various nodes are normal distributed with a mean of 1KW, and s. d. of 0.3KW.



Figure-5 Consumer load profile under study

For estimation of confidence interval, we utilize, Boot-Strap (BS) re-sampling procedure [13]. It calls for creating a small population of samples, for which the objective parameter is evaluated. This population is resampled large number of times (preferable in thousands) with replacement to create the BS population. BS population, so created is seen to represent the underlying population.

The median of the objective parameter (LQ here) is evaluated for all these BS re-samples. This median LQ for the BS population, is ranked to estimate median, and confidence interval (CI) for the mean LQ, for underlying population. Median of the population is seen 50 percentile of median LQ of the BS population. Assuming that we are interested in 'x%' Confidence Interval, the (100+x)/2 and (100-x)/2 percentile of BS mean LQ population marks the upper and lower limits of CI, respectively. For example if we are interested in a 90% CI,

then the 95 percentile member and 5 percentile member of the BS population, mark the confidence interval.

A typical consumer is defined by connected loads, and respective EST, LST, OT. The ST of the load is assumed to be following normal distribution about a mean $(EST+LST)/2$, with a standard deviation $(LST-EST)/6$. Using the load data of a consumer, we generate an LP-C. This LP-C is the LP-C prior to the DSLM intervention. The PT and PS are selected. This LP-C is then analysed, so as to identify the nodes, contributing, to the PS. The EST and LST of any node define maximum shift in TOU of any load. The contribution of any node to the PS can attain a minimum for $ST = EST$, for node type I, IV or $ST = LST$ for node type II, V. In implementation, the flags are accordingly released for the concerned nodes at their respective ESTs.

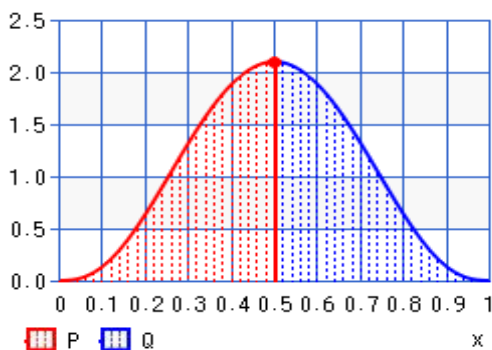


Figure-6 Beta Distribution Symmetric
(percentile $x=0.5$, $\alpha=\beta=3.7$)

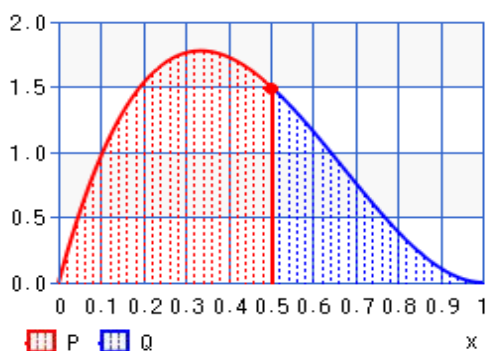


Figure-7 Beta distribution left-skewed
(percentile $x=0.5$, $\alpha=2$, $\beta=3$)

For simulation of advancing or retarding, of start of a contributing node, as consumer response to flags, we redefine the start time with a skewed distribution, Beta distribution [14], instead of normal distribution. The consumer compliance is simulated by level of skewedness of the distribution. For beta distribution parameters α , and β define shape of the distribution. Vital parameters of beta distribution are: mean as $\{\alpha/(\alpha+\beta)\}$, and variance $\sigma^2=\alpha\beta/\{(\alpha+\beta)^2(\alpha+\beta+1)\}$. Parameters α , and β when selected equal, and greater than one, the distribution is seen to be symmetrical about the centre. We select $\alpha=\beta=3.7$ (figure-6), for start times without DSLM intervention, a bell shaped distribution. The degree of compliance, for advancing the operation, is seen as fraction of nodes shifting their starting times from right half of the original bell curve to its left half. This can be effected by selecting values of α , and β such that the area under 50 percentile of the curve is made greater than the remaining. For example $\alpha=2$, $\beta=3$ makes left half area of the bell, 37.5%

bigger than its right half. This means that half of the 37.5% of the nodes have shifted from right half of the bell to its left half, an 18.75% compliance, for advancing the operation. Similarly, making $\alpha=3$, $\beta=2$ skews the curve to right, with right half area of the bell 37.5% bigger than its left half, an 18.75% compliance, for differing the operation.

i. *Objectives of simulation:* Objectives of simulation are:

a. Assess efficacy of the scheme for various levels of consumer participation.

b. Establish a 90% confidence interval for median LQ, for various levels of consumer participation.

ii. *Simulation settings:* The sample size chosen for this study is 100, for 11 values of PS, from 60 minutes to 165 minutes, in increment of 15 minutes. The instant of peak time is varied from 0200 hrs to 2200 hrs, in steps of 1 hr., this covers down-hill region from 0200 to 0600, trough form 0600 to 1100, Up-Hill from 1100 to 1800, and peak from 1800 to 2200. The PT is seen at the centre of PS. Selecting a PT, and a PS, LP-C is defined without DSLM intervention, and AVI(i), the average loading of the consumer over PS, is calculated. The correction on start time of loads is applied through redefining of the start time, using beta distribution.

Table-II shaping parameters for Beta Distribution

Compliance	" α "	" β "
5%	2	2.234
10%	2	2.488
15%	2	2.768
20%	2	3.082

The values of shape parameters (α , and β) of beta distribution used, for different compliances are given in table-II. This correction in start time leads to change in average loading of the consumer during the PS, calculated as AVC(i). The LQ(i) is evaluated as $\{AV(i)-AVC(i)\} \times 100 / AV(i)$. This exercise is done for various ST, and PS values keeping load, start time, operation time (identifying a consumer) intact. This computation, for 8 PS values for all 21 PTs, lead to 168 simulations per consumer. The LP-C data is generated with appropriate distributions, for the next simulation run leading to new node vectors. These simulation runs are done 100 times. LQs so computed for each simulation create the base sample population. The boot strap re-sampling for 100 members, is done with replacement to create a member of BS population. The size of BS population is taken as 10000. Each of these resamples is ranked and median of LQ is recorded. These 10000 BS members are ranked to arrive at median LQ, and 90% CI of LQ for the underlying population.

iii. *Results:* The simulation results are summarised as 90 percent confidence intervals, for median LQ. One of these results (compliance: 10%, Peak Span: 90 min), of various compliances, and peak spans, for regions Negative-slope, trough, positive-slope, and peak, are defined is shown in figure-8a to figure-8d, respectively.

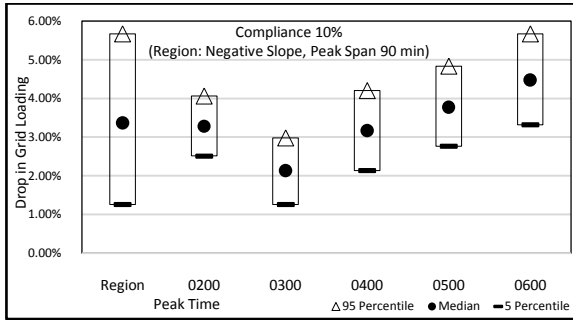


Figure-8a DSLM Performance in Negative slope region (PS = 90min)

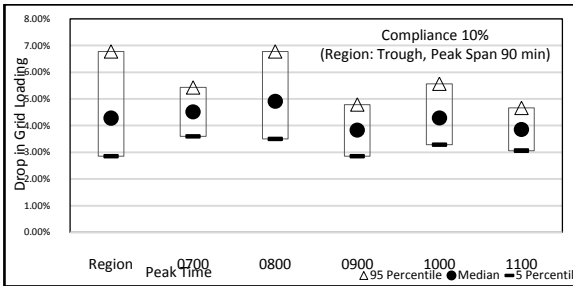


Figure-8b DSLM Performance in Trough region (PS = 90min)

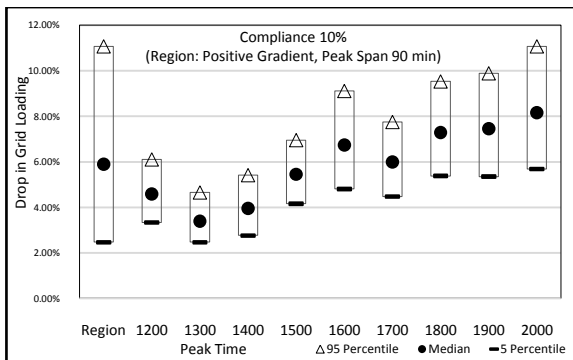


Figure-8c DSLM Performance in Positive slope region (PS = 90min)

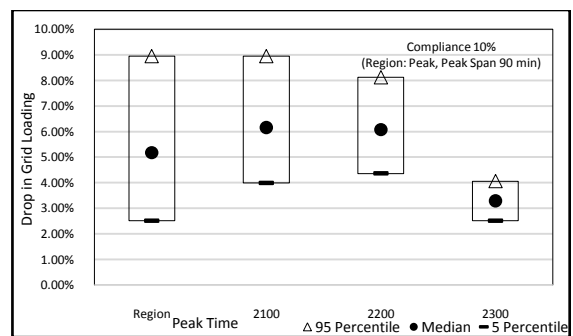


Figure-8d DSLM Performance in peak region (PS = 90min)

The overall DSLM performance is summed-up as 90% confidence interval for drop in grid loading for the regions over all peak spans(15 minutes to 165 min), for different compliances. These results for regions: negative gradient, trough, positive gradient, and peak are shown in Figure-9a to Figure-9d in that order.

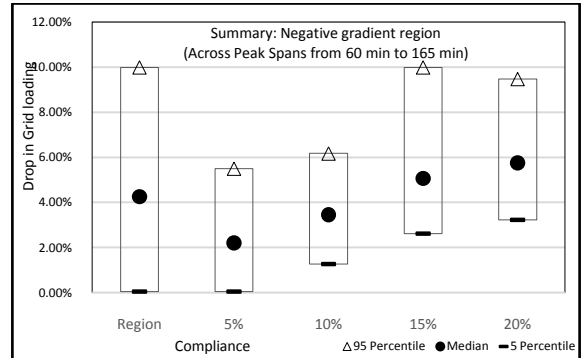


Figure-9a Overall DSLM Performance in Negative slope region

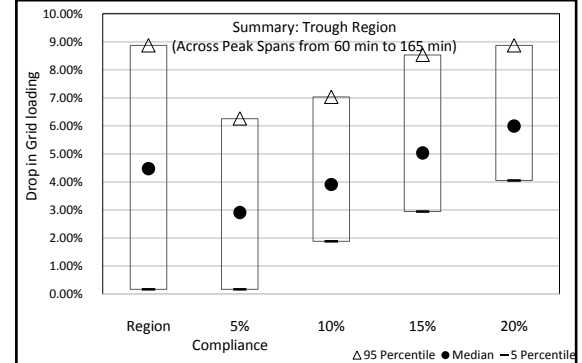


Figure-9b Overall DSLM Performance in trough region

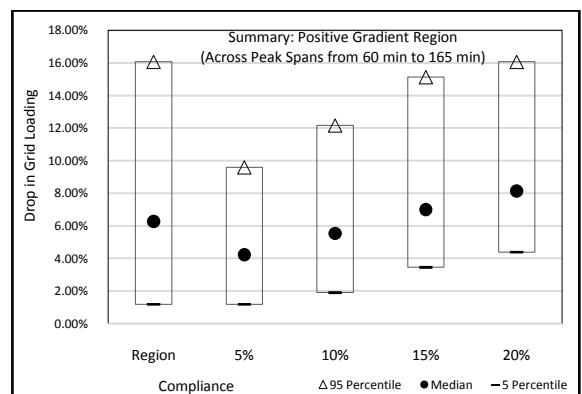


Figure-9c Overall DSLM Performance in Positive slope region

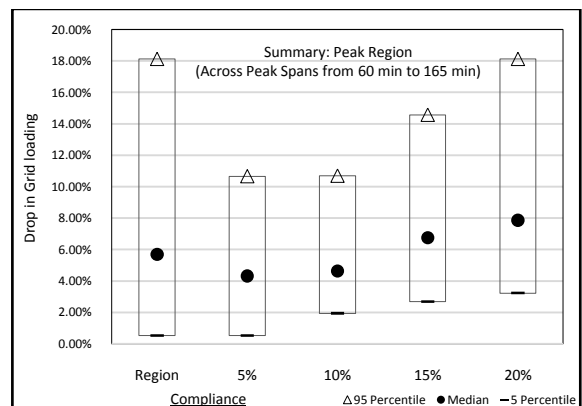


Figure-9d Overall DSLM Performance in peak region

The median for performance “drop in the grid loading” is seen in positive gradient region with a value of 4.23% to 8.15%, negative gradient region, at 2.20% to 5.76%, trough region across compliances. The positive gradient region is characterised by start of operation of newer appliances, and

the negative gradient region is characterised by end of operation of appliances. The scheme works on altering the start time of appliances, and in positive gradient region it is more assertive then in negative gradient region where it is unable to influence the end time of an appliance operation.

VII. DISCUSSION

The DSLM is seen leading to significant drop in grid loading, in all four regions. The scheme when adopted by numerous consumers connected to the grid, will create a capacity buffer, sufficient to influence grid performance. The important takeaways of the study are:

1. The consumer comfort, accorded priority in study, hence the study results are conservative.
2. The study envisages involvement of bigger population of nodes into peak load management, compared to interruptible loads, being invoked in [5].
3. The grid peak hour keeps changing with consumer behaviour, and other constraints. The DSLM framework keeps adapting to grid peak hour.
4. The DSLM performances are dependent on consumer responses, which are defined by willingness, load type and other constraints. The performances defined here are indicative ones.

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