Available online at www.sciencedirect.com

ScienceDirect

Energy Procedia 134 (2017) 555–566

Procedia Engineering

www.elsevier.com/locate/procedia

9th International Conference on Sustainability in Energy and Buildings, SEB-17, 5-7 July 2017, Chania, Crete, Greece

A Strategy to Reduce Grid Stress through Priority-based Inverter Charging

Ali Ahmad[a], Muhammad Junaid Subhani[a], Naveed Arshad[a,*]

[a]*Department of Computer Science, Lahore University of Management Sciences, Sector U, DHA, Lahore, Pakistan*

Abstract

Many developing countries face electricity supply shortfall. Utility operators induce scheduled power cuts to keep the demand under the available electricity supply. To deal with power cuts many consumers use inverters and fossil fuel generators. Inverters charge from the same electricity distribution system and provide energy to essential loads during power cut hours. However, uncontrolled use of inverters has created a cyclic load problem for an already stressed grid. In this paper, we propose a scheduling strategy that charge the inverters according to time of use pricing and consumer specified criteria of retaining minimum and maximum levels of charge in the battery. This strategy not only is able to lower the grid stress to a level specified by the grid operator but is also able to reduce the cost of ownership of inverters by as much as 30%. Additionally, this strategy has also shown to reduce the usage of fossil fuel generators due to availability of extra electricity in the system.

Peer-review under responsibility of KES International.

Keywords: Uninterpretable Power Supply System, Inverter, Grid load

---

1. Introduction

Electricity Deficits are prevalent in many developing countries. For instance in Pakistan the electricity shortage has been a major issue since the last decade. The Peak Demand is around 23 GW, while the power generation capability is 18 GW [1]. Thus the power deficit in 2015-16 is around 5 GW. To meet this gap the utility companies are forced to induce power cuts ranging from 3 hours to 12 hours in a day with an average of 5.3 hours load shedding per day. Typically these power cut hours are announced in advance in hourly slots spread throughout the day.

Most power cuts are scheduled in the peak hours to meet the electricity deficit. To reduce the effects of power cuts on everyday lives, a large number of consumers use back-up power to run their essential electrical loads. According to estimates around 28% of the people use battery based inverter backups while a good number also use fossil fuel generators [2]. The exhaust from fossil fuel generators contain more than forty air pollutants[3]. Fossil fuel generators have no direct impact on utility companies as they consume fossil fuels as a source of energy. Although the focus of this paper is reducing the inverter load on the grid but at a later stage in the paper we will show how reducing the stress on the grid may also help in reducing fossil fuel generators usage.

---

[*] Corresponding author
E-mail address: naveedarshad@lums.edu.pk (Naveed Arshad).

1876-6102 © 2017 The Authors. Published by Elsevier Ltd.
Peer-review under responsibility of KES International.
10.1016/j.egypro.2017.09.563

Inverters are designed such that they charge their batteries when the electricity is available from the utility companies. During the power cut hour, the charge in the batteries provide electricity for essential loads. Following a power cut hour inverters start charging their batteries. There are two major problems with this approach. The first one being the sudden peak load caused when all the inverters start charging their batteries together. Assuming the penetration level of 28% there would be hundreds of thousands of inverters charging at any given moment, causing significant peak load on the grid. The demand puts considerable stress on the grid, thus increasing the risk of further blackouts and increasing the cost of generation of electricity. The second major problem is the effect on the consumers which include variation in cost of charging the inverter battery, life of the backup battery and the inconvenience caused to the consumer due to unconstrained charging.

Furthermore, inverters are big time electricity wasters as well; the inversion, storage and rectification losses of charging a typical inverter sum up to be around 75% percent [4] [5]. These losses add to increase the electricity cost for the consumer as well as more stress for the grid.

The rest of the paper is structured as follows: Section 2 provides the Related Work. Section 3 analyzes the impact of unscheduled inverter charging. Section 4 discusses our proposed Inverter Charging Strategy. Section 5 shows the evaluation of our approach and finally Section 6 concludes with a discussion and future directions.

2. Background and Related Work

Alonso et al. discussed the hidden cost of inverters and battery backups [4]. In their paper they calculated energy losses incurred due to inverters and the impact of inverters on grid stability. Our work is different from them because we are more focused on the cost based analysis and effective scheduling to reduce the peak loads on the grid.

Another related work in EV (Electric Vehicles) charging is the heuristics based algorithm for charging of electric vehicles [6]. In this paper the authors have discussed the dumb charging strategy and their strategy based on genetic algorithm which produces significantly better results. However, inverters and EV differ fundamentally based on the availability factor and the fact that EVs are used as supplementary sources of storing additional electricity. But inverters are being used as primary backups of essential loads and they have to be charged at user defined minimum level before a power cut. The concept has been introduced in EV [7] where a minimum SOC has to be maintained in the EV for the daily operational readiness which is also implemented in our work, but unlike EV the inverters have a fixed schedule and they are always connected to the power sources which is different work from EV which is mobile and may be disconnected at random from the power sources.

A cost based approach to measure the effects and cost of power cuts was presented in which a methodology for the quantification of the power outages has been developed in another paper [2]. The work is focused over the total outage cost to residential consumers and they have made policy recommendations to end power cuts for better. It is the only survey of it's kind and differs from our work significantly as we are focusing over optimal charging schedules so that the benefits could be reaped by the electricity supplier as well as the consumers. For electric vehicle charging one purposed solution was off peak domestic charging, in which a simple timed controller is added to the charging circuit which schedules charging to start at 1:00 a.m. and remains on until 7:00 a.m. It will improve the load curve but there will be no significant impact on the distribution network capacity [8]. Although the overall profile is improved, there is still a peak after midnight and a dip at around 7:00 a.m. Our work is different as we schedule the charging hours according to the demand and cost of electricity per hour. Jain et. al worked on collaborative energy conservation in micro grid [9] and have worked with diesel generators scheduling to reduce diesel cost, but our work is different from them as we are only considering the inverter load on a grid and how to efficiently distribute it for benefiting both the consumers and the producers of electricity.

A Time of Use (TOU) and State of Charge (SOC) strategy discussed for EV [10] also used the approach of shifting the load to an area where the pricing is low and have taken the max battery charge which is user specified but our approach is different because we are utilizing the charging windows to provide the user defined SOC in two categories with different priorities A & B. EV charging strategies based on the distribution level capacities are discussed in another paper by Ahmet Dogan et al.[11] where they have worked on three EV charging strategies based on the load on distribution and with normal and quick charging modes. They have used fixed time based strategies which is different from our strategy, our algorithm optimizes the charging for various charging windows and tries to provide cost based and peak based optimization. Another related work done on PEV charging was done in a published paper by Sara Deilami et al[12]. They proposed sensitivities-based RT-SLM and allocated PEVs for charging as soon as possible based on real-time, cost minimization and improve voltage profile while considering designated charging time zone priorities specified by PEV owners.

The concept of customer engagement is not new and a lot of work has been done in this regard [13] our work too makes the inverter charging based on the requirements of the customers but unlike the Demand Response systems our work is focused on inverters scheduling to ensure a certain minimum state of charge and reducing the over burdening of the grid at the peak hours. Our work is different from the aforementioned efforts as in our approach the consumer can specify minimum and maximum charging levels of batteries and the supplier has the charging control subservient to user preferences but without putting load on the grid under usual circumstances.

3. IMPACT ANALYSIS

To develop a charging strategy for inverters it is important to know the penetration of inverters and their load on the grid. To calculate this we have measured power consumption of each kind of inverters available in Pakistan. We have taken the city of Karachi as an example. The city of Karachi is the most populous city of Pakistan with around 23 million residents. There are estimated 2 million grid connections in the city. According to an estimate around 28% of customers use inverters. Most of these inverters typically use Lead Acid batteries because of their low cost.

We developed an energy meter to measure the load inverter put on the grid while charging the batteries. Using this energy meter we analyzed the amount of current consumed by inverters. Our experiments included different inverters of different wattage and battery sizes. Most of them were locally made 1 KW inverters with single or double lead acid battery while some of them are 2-3 KW inverters which are used in bigger households and commercial settings. The batteries also vary in capacity from 100 Ah to 230 Ah. Bigger batteries take more time and more current to charge. In our experiments with different inverters we analyzed that 1000 watts inverters take on average 1.5 amperes of current and 2000 watts inverters draws on average 2.4 amperes of current.

The main lesson that we got after testing various inverters is that all the inverters take a single level of current until the battery is fully charged. We did not find any change in the level of current the inverters draw during charging Lead-acid batteries. Therefore, there is constant load on the grid until the inverter completely charges the battery.

Before delving into the details of the paper we would like to quantify the effects of inverters in the overall electricity system including the electricity supply system and the consumers.

3.1. Impact on Peak Generation

With 2 million customers and penetration level of 28% Karachi has around 0.6 million inverters [1]. These inverters are drawing electricity continuously from the grid even in the peak hours.

In our survey we have came across various type of inverters having power rating of 0.7 KW to 2KW and above. Majority of the households had 0.7-2 KW inverters which takes on average $I = 1.5 Amperes$ of current to charge. Inverters having wattage in range of 1.4-2 KW take $I = 2.3 Amperes$ current on average to charge. The voltage $V = 220$ is constant throughout Pakistan. Assuming inverters penetration with wattage upto 1.4KW watts is 70% the rest 30% we calculated an approximate load of inverters on the grid.

By Ohms Law,

$$Power(P) = Voltage(V) * Current(I)$$

$$P^1 = 330 Watts$$
$$P^2 = 506 Watts$$

We can get the average usage of power by multiplying the number of inverters with the above power consumption per inverter. Following the simple calculation we calculated the total power used by inverters to be,

$$P^T = 230 MW$$

This 230 MW is the load of inverters at anytime on the grid. Here it is pertinent to mention that the electricity deficit of K-electric a major electricity supplier of Karachi, Pakistan was 433 MW in 2012. Thus the inverters add a significant cyclic load after the power cut hour.

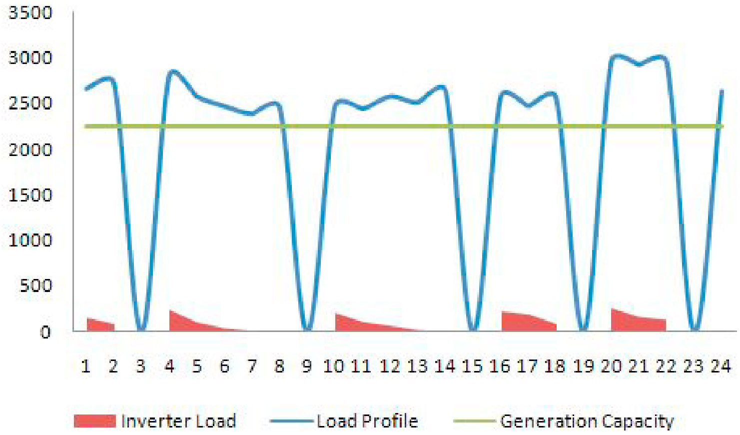

Fig. 1. Peak load and inverter charging load for K-Electric on a typical day. Where the red blocks are the load on the grid from inverters, blue line shows the total load including the inverter load and the green line is assumed total generation capacity.

Figure1 shows the load on the grid on a typical summer day and the respective load due to the inverters on the peak load. As shown, there are five hours of power cuts on this particular day. As soon as the power is restored all the inverters load is immediately put on the grid. This cyclic load of the inverters is greater than half of the peak power deficit. Thus exacerbating the problems of an already stressed grid. The generation capacity is taken as constant here at 2246 MW which is a fair estimate of generation, however the generation capacity fluctuates every hour.

3.2. *Impact on Consumer Costs*

The unscheduled charging may increase the cost for the customers. For example, the inverter charges the battery in the hours with peak pricing the cost of consumers is increased by around 50%. Moreover, without a minimum charge settings on the inverter the inverter may use cycles from the battery life. Finally since the inverters waste around 75% of the energy in charging discharging cycle, the inverters may end up costing more to the consumers if the charging is kept at the maximum level all the times. These three factors significantly increase the cost of owning an inverter for the consumer.

4. Smart Charging Strategy

In the previous section we have discussed the impact of inverters on the utility companies and on the consumers. In this section we would discuss our approach to efficiently minimize the effects of inverters on the grid. In our approach we assume that the power cut schedule for the next 24 hours is already available and we also know the hourly pricing for the electricity.

Furthermore, in our approach we let the consumer decide the minimum I_{umin} and maximum I_{umax} level of charge they would like to maintain in their inverter batteries. Depending on their load the consumers may define a minimum charge and a maximum charge they would like to maintain. The present level of charge and the minimum and maximum set by the user are available to the grid operator for all inverters.

Finally, in order to reduce the stress on the grid we divide the load capacity of the grid into two zones set by the electricity supplier. The first is the **Recommended Load Zone** L_{opt} in which the load on the grid is at the recommended level and there is no strain on the grid i.e the grid is working with close to optimal load. The second zone is the **Maximum Load Zone** L_{max} which is the zone where we can have above optimal level load on the grid which the grid can withstand but maybe at a higher cost of generation. Our strategy is to keep the load on the grid in the Recommended Load Zone as much as possible.

The number of hours before the next scheduled power cut are called the **Charging Window** W. This charging window is the amount of time that we have before there is a power cut and the inverters must be charged by that time. A sample charging window could be calculated as follows: if the first power cut hour is at 1PM and the next power cut is scheduled for 5PM then between 2PM and 5PM we have a charging window of 3 hours for changing an inverter. Our strategy would try to charge the inverters in this charging window to the user specified minimum level I_{umin} and if there is still enough excess electricity available, the batteries would be charged to the user defined maximum level I_{umax}.

Algorithm 1 Charging Windows Calculation

```
total_hours = 24
for $x$ = 1 to total_hours do
    if Hourly_cost[x]!= 0 and flag = 0 then
        window_start = x
        flag = 1
    else if Hourly_cost[x]== 0 and flag = 1 or Hourly_cost[x]!= 0 and x == 24 then
        window_end = x
        flag = 0
        $window\_count + +$
        add_Window(window_count,window_start, window_end)
    end if
end for
```

Algorithm 1 is used to calculate the Charging Windows given the power cut schedule of the day. Currently we are only taking the scheduled power cut hours as input in our algorithm. Here the cost of electricity of each hour is stored in the Hourly_cost array. The Hourly_cost for the power cut hour is set to 0, while the cost for other hours could be any positive integer. The Charging Window starts with a non-zero Hourly_cost which sets the flag true (meaning the current window is calculated) and ends when the cost of an hour is 0 where the flag is set to false, which marks the next power cut hour and end of current window. After the end of each subsequent window the next window is calculated, except for the 24th hour of the day which itself is the end of the day and the end of the window since we are calculating the window in 24 hours.

The inverters are divided into categories based on the current level of charge. There are three types of categories and each category has a priority associated with it. The categories are assigned by Algorithm 2 given below,

Algorithm 2 Priority Assignment

```
Input: total_Inverters ← Number of Inverters ,
Inv_data[total_Inverters]← Inverters Information List
for $x$ = 1 to total_Inverters do
    if Inv_data[x].SOC_Curr<Inv_data[x].SOC_Min then
        Inv_data[x].Priority ← A
    else if Inv_data[x].SOC_Curr>Inv_data[x].SOC_Min and Inv_data[x].SOC_Curr<Inv_data[x].SOC_Max then
        Inv_data[x].Priority ← B
    else if Inv_data[x].SOC_Curr>Inv_data[x].SOC_Max then
        Inv_data[x].Priority ← C
    end if
end for
```

Inverters are assigned with priorities based on the current State of Charge(SOC), the priority is set based on the following criteria,

Priority A Inverters: *Inverters which have the State of Charge(SOC) below the user specified minimum level.*

$P_A = I_{curr} < I_{u\_min}$

Prioirty B Inverters: *Inverters which have the State of Charge(SOC) above the user specified minimum but below user specified maximum.*

$P_B = I_{u\_min} \leq I_{curr} < I_{u\_max}$

Priority C Inverters: *Inverters which have the State of Charge(SOC) above or equal to the user specified maximum.*

$P_C = I_{curr} \geq I_{u\_max}$

The minimum level of charge is defined by the user keeping in view the current usage of the inverter and the essential loads connected to the inverter. The maximum level of charge again helps to know the user requirements and save additional charging of the inverter's battery to avoid overcharging. The thresholds could vary with the time of days. In the day ahead scheduling the P_A inverters are charged at first, followed by P_B inverters but the P_C inverters don't take any electricity as they have already achieved their maximum charge and there is no need to charge them immediate.

The required charge time R for each category of inverters is calculated as,

$$R_A = \frac{I_{umin} - I_{curr}}{I_{CR}}; I_{umin} > I_{curr} \tag{1}$$

$$R_B = \frac{I_{umax} - I_{curr}}{I_{CR}}; I_{umax} > I_{curr} \tag{2}$$

$$R_C = 0 \tag{3}$$

Algorithm 3 Optimizing Cost using Smart Charging

```
Input: Inverter ← Inverter for charging ,
Window_Info ← Window Information ,
Electricity_Supplier_Cost ← Electricity Supplier provided costs and load information
Output: Charging Cost
if Inverter.Priority == A then
    req_charge_time=(Inverter.SOC_Min-Inverter.SOC_Curr)/Inverter.Charge_rate
    limit=Electricity_Supplier_Cost.Maximum_Capacity
else if Inverter.Priority == B then
    req_charge_time=(Inverter.SOC_Max-Inverter.SOC_Curr)/Inverter.Charge_rate
    limit = Electricity_Supplier_Cost.Optimal_Capacity
else if Inverter.Priority == C then
    req_charge_time=0
end if
Sorted_Cost=Electricity_Supplier_Cost.sort()
for $x$ = 1 to req_charge_time∗granularity do
    if Electricity_Supplier_Cost.curr_load<limit then Electricity_Supplier_Cost.curr_load+ = Inverter.load
        cost = cost + Sorted_Cost[x]
        if Inverter.SOC_Curr>Inverter.SOC_Min and Inverter.Priority==A then
            Inverter.Priority==B
            break
        else if Inverter.SOC_Curr>Inverter.SOC_Max then
            Inverter.Priority==C
            break
        end if
    end if
end for
return cost
```

Smart charging strategy is shown in Algorithm 3. In this algorithm the maximum limit of grid usage is defined by the priority level. Priority A inverters will use the Maximum Load Zone while the Priority B inverters will use Recommended Load Zone. The req_charge_time is calculated by dividing the difference of charge percentage and dividing it by the Charge_rate of the inverter. Next we sort the Charging window hours in ascending order of the cost of the hour to always start charging from the minimum cost possible where the load doesn't exceed the set level. If the load on the grid is not exceeding the said limit than we start charging the inverter and increase the load on grid by the cost of inverter's charging. After this charging, if the current level of charge of the inverter is increased enough to meet the user defined minimum or maximum SOC then we change the priority of the inverter. The charging and testing could be done on various granularity level i.e. hourly, bi-hourly etc.

For the sake of simplicity we have assumed that the granularity level is hourly based.

W = Hours with Electricity Available = $\{H_1 \ldots H_{24-T_p}\}$
W_1 = Charging Window before the first power cut

The charging window hours are sorted in ascending order based on the electricity cost of that hour.

$$W_s = \sum_{j=1}^{T_w} Sort(W_j) \tag{4}$$

When $L_{TA} < L_{max}$ and I_p = A

$$P_A Charging = \sum_{i=1}^{n} \sum_{k=1}^{T_j} L_{TA} = L_f^k + I_\theta^i; \tag{5}$$

When $L_{TB} < L_{opt}$ and I_p = B

$$P_B Charging = \sum_{i=1}^{n} \sum_{k=1}^{T_j} L_{TB} = L_{TA} + I_\theta^i; \tag{6}$$

In the above equations we sort the Charging Window based on the cost of electricity and after that we at first start charging the inverters. P_A inverters are charged at first, followed by the P_B inverters whereas, P_C inverters don't require any charge. The L_f^k symbolizes the load without any inverter charging and our assumption is that this load is always less than the maximum capacity of the Grid L_{max}. L_{TA} is the total Load on the grid after we start charging the P_A inverters, whereas L_{TB} is the total load after charging both the P_A and P_B inverters. It could be seen that since the P_B charging occurs after we accommodate the P_A charging, the L_{TB} is calculated based on the L_{TA} Load.

Here the objective function is defined as,

$$Obj_1 = min \sum_{h=1}^{24} GridLoad_h; \tag{7}$$

The $GridLoad_h$ is minimum when the inverter charging load is lesser than the Maximum Capacity of the Grid and is preferably in the (Recommended Load Zone) Optimal state. The constraints on the charging ensure both of these constructs as in case of P_A charging we have to maximally charge the inverters, in order to reduce the inconvenience to the customer but in case of P_B charging we limit the grid load to the optimal level by ensuring that the inverter charging is well under the specified limit.

5. Evaluation

In this section we would show the result of applying our smart charging strategy on inverter charging. For the simulation purpose we took the real data of Karachi which has 2.1 million connections and keeping the 28% inverter penetration with an average 5 hours of Load Shedding. We simulated the data for the inverters, the inverters charge were randomly assigned between 0 and 100% and the user specified minimum and maximum is populated randomly where the minimum could be anywhere from 50% to 70% and maximum could be anywhere between 70% to 100% with charge rate according to the three stage charging of the lead-acid battery[14]. For the charging window of 5 hours we had 1.52% Priority A inverters which were not charged sufficiently as 5 hours were not sufficient for them to achieve the minimum charge, rest of the inverters were successfully charged. The cost saving was around 55% of the total cost incurred which is a really good number as for the said window we are reducing the cost to almost half.

Figure2 shows the charging pattern of the current charging approach and how our smart charging changes the course of charging of an inverter in each window. The x-axis shows the hours of the charging window and the y-axis shows the state of charge at each hour and the hours where charging is being done in the original (dumb) charging approach and the smart charging approach. We could see that the original charging charges in the hour 1, 2 and 3 of the window with prices 16, 4, 12 respectively. While the smart charging charges in hour 2,4 and 5 with prices 4,9 and 11 respectively which is saving 33% of charging cost in a 5 hour window.

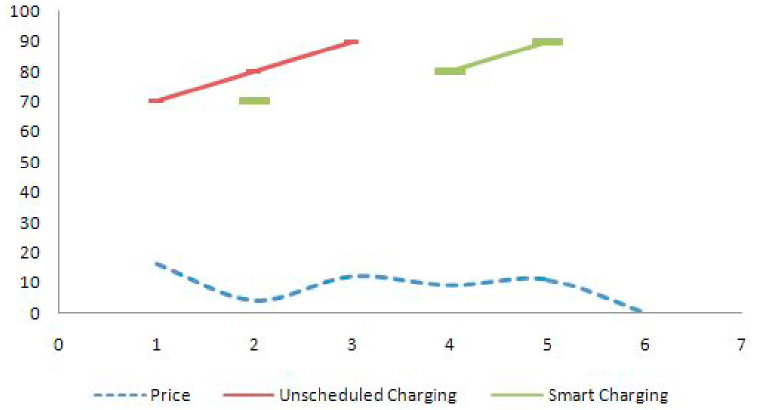

Fig. 2. Comparison of charging patterns of the unscheduled charging vs the intelligent charging. The blue line shows the per hour cost of electricity, intelligent charging picks the charging hours intelligently in the lowest cost hours.

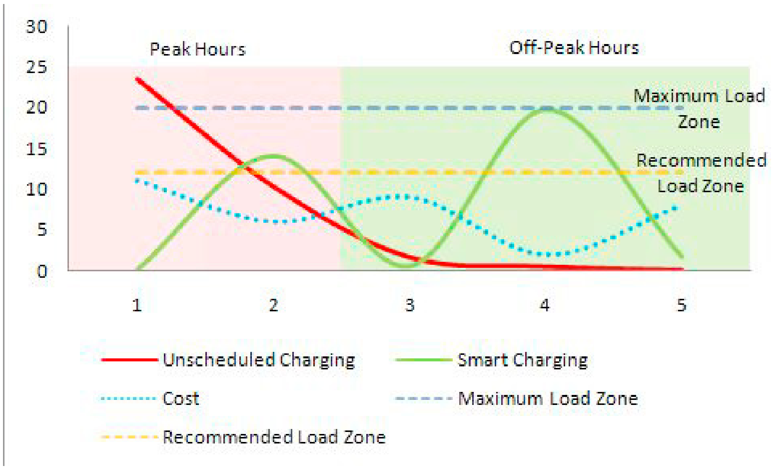

Fig. 3. Intelligent charging vs unscheduled(dumb) charging in a constrained grid where the maximum and recommended load zones are defined. Intelligent charging limits charging in the peak hours, and utilizes the off-peak low cost hours for inverter charging while keeping in regard the grid constraints.

Figure 3 shows the load per hour by charging the inverters using the unscheduled charging scheme and the cost based smart charging scheme. The charging window is kept at 5 hours and the load profile per hour is shown. The red region of the figure show the peak hours whereas the green region show the off-peak hours. For unscheduled charging it could be seen that the charging load exceeds the defined threshold and doesn't efficiently utilize the charging window. On the other hand smart charging approach reduced the cost by more than 55% without exceeding the maximum load zone threshold.

5.1. Peak Load Reduction on the Grid

The peak load on the grid is due to all the inverters starting their battery charging at once. In our strategy we suggest that a charging start/stop switch would be installed in the inverters by which the electricity provider can control the charging of the inverters. The electricity supplier can curtail the load to save the grid from working beyond maximum limit by switching the inverter battery charging off. In case there is peak forming up, the supplier can switch off the Priority B inverters which could reduce the peak load on the grid. Priority A inverters charging load could also be shifted if there is room in the charging window, if there is still load on the grid then charging could be disconnected for the customer who have agreed to the curtailment strategy in lieu of having lesser electricity cost. In Figure 3 we could see that smart charging is shifting more than 20 MW of peak load in various off peak hours.

5.2. Economical Charging of Inverter Batteries

Cost of electricity keep changing based on the hours of day and so does the charging cost of the inverter's battery. In a charging window we could have various hours and different prices associated with them. Currently, the unscheduled charging approach starts charging as soon as the electricity is available after a power cut hour. But this approach does not guarantee the best charging cost because it doesn't look for the best possible rates first. For example if an inverter needs 2 hours charge time in a charging window of 4 hours then it has to pick the 2 hours in which the load is minimum. The unscheduled charging approach is only effective when the cost of electricity is the lowest at the start of the charging window and increases by each hour. If we sort the charging window hours in ascending order of cost and start charging from that order we will always get the lowest charging cost. In case of a curtailment by the supplier the absolute minimum charging cost could not be guaranteed, to ensure the grid stability.

5.3. Inverter's Battery Life Improvement

The battery life is directly dependent on the level of charge of the inverter. If the battery charge level is constantly below a certain threshold or is overcharged the battery health (charging cycles) decrease significantly. Our strategy ensures that the inverters at each power cut hour has enough charge so that it doesn't get drained and loses the charge cycles. The user defined minimum and maximum allows us to provide the ample amount of charge to battery hence increasing the battery life.

5.4. Impact of Charging Window Size on Cost Saving

Charging window size is the number of hours that we have to charge our inverter's batteries before the next power cut hour. The saving is greatly dependent on the variability of the electricity prices in various hours and size of the charging windows. We have assumed that most of the inverters have charging requirements well within the charging window size and the grid load is below the maximum capacity, so to give us enough flexibility to run the scheduling.

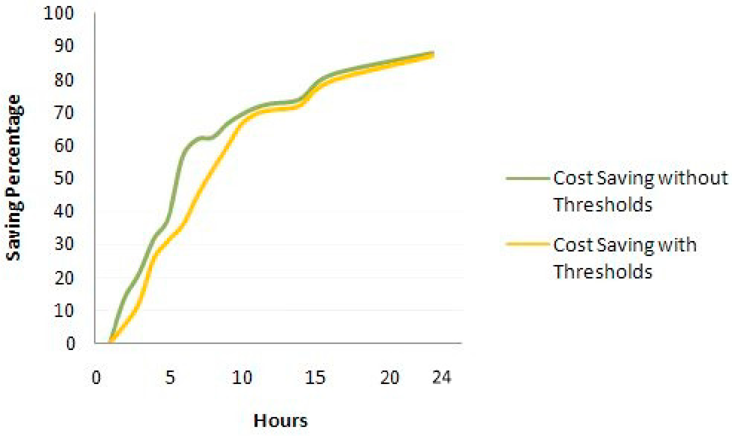

Fig. 4. Saving in cost is directly proportional to the size of charging window. The graph shows the saving in cost with and without thresholds, where the variability in cost of electricity per hour is high which provides ample opportunity for cost saving.

In Figure 4 we have assigned unique value to each hour in order to introduce variability in hourly cost. After which the simulations were run multiple times in order to have the average cost saving for different charging window sizes, we could see that for 1 hour window there is 0 cost saving. For a 2 hour window the saving is little over 10%, and the cost saving increases gradually with the size of the window. In realistic scenarios of 4 to 5 hours of power cuts we have charging windows ranging in size from 3 to 6 hour, and a cost saving of about 30% to 60%. Even with lesser variability we have around 30% saving in the cost, while ensuring that the Grid load never exceeds the specified level. The figure shows the graphs for both the charging with thresholds and without thresholds, we could see that there is significant difference here for smaller charging windows, but not much impact on the larger charging windows. The saving is lesser for the smaller charging windows because the curtailments hampers the charging after a certain limit and inverters have to be shifted in the costlier hours for charging, as the window increases the choice of hours increases and hence the cost saving is approximately the same. Even by inducing the Maximum Load Zone and Recommended Load Zone for curtailing the load on the grid, we still get ample saving while charging the inverters, hence benefiting the customers.

Another major aspect is the effect of variability of prices on the cost saving to the customers, the variability in price is the rate at which the prices of electricity change at each hour of the day. More variability and larger charging windows mean there is more room for the algorithm for scheduling and hence better cost saving.

Cost Saving Parameters		
Window Size	Cost Variation	Cost Saving
5	Low	10%
5	Medium	20%
5	High	28%
9	Low	22%
9	Medium	34%
9	High	58%
12	Low	30%
12	Medium	41%
12	High	67%

Table 1. Effects of Variation in cost and window size on Cost Saving

In Table 1 the cost of saving is shown with the low, medium and high variability of electricity cost per hour. In case of a uniform rate the only deciding criteria for the algorithm is the grid load at a certain period of time. We took the three most common window sizes to compare the savings and it could be seen that the worst results are for smaller windows with low variability of prices in the window. It could be seen that the savings increase significantly with the increased variability of electricity cost and the size of the charging windows.

5.5. Reduction in Inconvenience to the Customer

In any scheduled charging approach there is always the danger of inverter's battery being under charged and hence not being able to power the essential loads in power cut hours. Also the number of unscheduled power cut hours may increase due to the peak loads on the grid, using our strategy we could significantly reduce peaks and hence the unscheduled power cuts and the inconvenience associated with these hours. The customer defined minimum state of charge is achieved by assigning the inverters to Priority A and these inverters are charged even in the Maximum Load Zone. This priority charging enables the user to have the inverter in working state in every power cut hour which reduces the inconvenience to the customer.

5.6. Reduction in Power Consumption by Inverters

The smart charging strategy discussed has a prime feature which uses the user defined maximum SOC (State of charge) I_{umax} and minimum SOC I_{umin} of the inverters. These charging parameters are helpful in alleviating the load on the grid significantly, as the customers adhere to the minimum and maximum charging of inverters there will be a veritable saving in the electricity the inverters consume. As we computed in Section 3 the total load on the inverters is 230 MW, this is assuming that all the inverters charge to 100% and there is no maximum SOC threshold.

The maximum SOC threshold could be implemented by reviewing the demands in the power cut hours for a particular customer, if a user consumes only 10% of his inverter charge in a power cut hour, there is no need to set the maximum SOC level at 100%. The maximum SOC could be set at 80% to give a window of 30% to the customer (considering minimum SOC to 50%) in which he could power his essential loads conveniently. Hence by setting the I_{umax} at 80% we have saved the 20% of electricity which the inverter uses to charge but never discharges it. This electricity is just sitting there, and the load on the grid is increased significantly due to that steady load.

6. DISCUSSIONS AND FUTURE WORK

There has been a lot of work on getting the optimal solutions for the battery charging for EVs but not a lot of research in the scheduling of inverter's charging. And while EV is the closest thing to the battery backups, the context is essentially different for both based on the usage. EV is a detachable load and has additional information to cater like the availability and parking space. However, inverters are always available and switched in the charging dock in households. But there is no concept of V2G in case of battery backup of an inverter as of yet. In future V2G approach could also be tried to work with inverter's batteries but it is a big leap forward and a step which could be very rewarding but challenging at the same time.

Our major contribution remains the smart charging strategy that we have proposed which is flexible enough to favor the consumers and the suppliers at the same time or could tilt in the favor of one or the other if need be. The decision of low cost hours and peak shaving yet remains an open decision in some cases where there are scenarios in which the minimum demands of the inverters have to be fulfilled even when there is peak or a costly hour. Whichever optimization technique we opt for, there could always be a scenario in which the problem is designed to fail; in our case there could be a small enough window of let say 2 hours in which we have to charge significant amount of Priority A inverters requiring more than 2 hours of charging to reach the required minimum. In these kind of scenarios there isn't much room for optimization and our algorithm acknowledges that and shows the percentage of batteries it has successfully been able to charge and the cost reduction it has achieved. To promote the user level maximum minimum charge percentages, economical and environmental advantages of smart pricing methods can be beneficial[15], so that there is ample room for optimization.

We would like to mention here that the load on the grid in peak hours is reduced. Due to this more power is available for the consumers who otherwise would use fossil fuel generators. Therefore, there is an indirect impact on the reduction of emissions by using the smart charging strategy. This reduction has a significant impact on the environment as for generating a single KWH from fossil fuel generators upto 2 pounds of CO_2 is produced [16]. So, the cost saved is also having a healthy impact on the environment by supplying the surplus energy to the commercial areas where the customers rely on fossil fuel generators in the power cut hours.

Future area of interest is the scheduling of power cuts and the windows between the power cuts which greatly impact the scheduling potential. It has been noticed that the lesser the number of power cut hours are and the greater the charging windows are, the more is the cost effectiveness of the proposed strategy. Also the windows of pricing per hour and how well the prices are distributed also effect the yield of our strategy, so if we go one step deeper we could synchronize the power cuts and pricing in such a way that the benefits for the supplier and the consumers can be maximized.

References

[1] State of Industry Report 2014. 2014.

[2] Pasha, H.A., Saleem, W.. The Impact and Cost of Power Load shedding to Domestic Consumers. 2012.

[3] Awofeso, N.. Generator diesel exhaust: a major hazard to health and the environment in nigeria. American journal of respiratory and critical care medicine 2011;183(10):1437–1437.

[4] Seetharam, D.P., Agrawal, A., Ganu, T., Hazra, J., Rajaraman, V., Kunnath, R.. Hidden costs of power cuts and battery backups. In: Proceedings of the fourth international conference on Future energy systems. ACM; 2013, p. 39–50.

[5] Moura, P., Nuttall, C., Harrison, B., Jehle, C., de Almeida, A.. Energy savings potential of uninterruptible power supplies in european union. Energy Efficiency 2015;:1–21.

[6] Alonso, M., Amaris, H., Germain, J.G., Galan, J.M.. Optimal charging scheduling of electric vehicles in smart grids by heuristic algorithms. Energies 2014;7(4):2449–2475.

[7] Yu, J.J., Lin, J., Lam, A., Li, V.O.. Coordinated electric vehicle charging control with aggregator power trading and indirect load control. arXiv preprint arXiv:150800663 2015;.

[8] Putrus, G., Suwanapingkarl, P., Johnston, D., Bentley, E., Narayana, M.. Impact of electric vehicles on power distribution networks. In: 2009 IEEE Vehicle Power and Propulsion Conference. IEEE; 2009, p. 827–831.

[9] Jain, M., Khadilkar, H., Sengupta, N., Charbiwala, Z., Tennakoon, K.U., Wahab, R.b.H.A., et al. Collaborative energy conservation in a microgrid. In: Proceedings of the 1st ACM Conference on Embedded Systems for Energy-Efficient Buildings. ACM; 2014, p. 130–139.

[10] Cao, Y., Tang, S., Li, C., Zhang, P., Tan, Y., Zhang, Z., et al. An optimized ev charging model considering tou price and soc curve. IEEE Transactions on Smart Grid 2012;3(1):388–393.

[11] Dogan, A., Kuzlu, M., Pipattanasomporn, M., Rahman, S., Yalcinoz, T.. Impact of ev charging strategies on peak demand reduction and load factor improvement. In: 2015 9th International Conference on Electrical and Electronics Engineering (ELECO). IEEE; 2015, p. 374–378.

[12] Deilami, S., Masoum, A.S., Moses, P.S., Masoum, M.A.S.. Real-time coordination of plug-in electric vehicle charging in smart grids to minimize power losses and improve voltage profile. IEEE Transactions on Smart Grid 2011;2(3):456–467. doi:10.1109/TSG.2011.2159816.

[13] Hassan, N.U., Khalid, Y.I., Yuen, C., Tushar, W.. Customer engagement plans for peak load reduction in residential smart grids. IEEE Transactions on Smart Grid 2015;6(6):3029–3041.

[14] Hua, C.C., Lin, M.Y.. A study of charging control of lead-acid battery for electric vehicles. In: Industrial Electronics, 2000. ISIE 2000. Proceedings of the 2000 IEEE International Symposium on; vol. 1. IEEE; 2000, p. 135–140.

[15] Samadi, P., Mohsenian-Rad, H., Schober, R., Wong, V.W.. Advanced demand side management for the future smart grid using mechanism design. IEEE Transactions on Smart Grid 2012;3(3):1170–1180.

[16] DeLuchi, M.A.. Emissions of greenhouse gases from the use of transportation fuels and electricity. volume 1, main text. Tech. Rep.; Argonne National Lab., IL (United States). Energy Systems Div.; 1991.