Design of home load management system for load rationing in Pakistan

Muhammad Bilal Butt¹ | Saad Dilshad² | Naeem Abas¹ | Shoaib Rauf¹ | Muhammad Shoaib Saleem³

¹Department of Electrical Engineering, University of Gujrat, Hafiz Hayat Campus, Gujrat, Pakistan
²Department of Electrical and Computer Engineering, COMSATS University, Islamabad, Pakistan
³Department of Electrical Engineering, University of Management and Technology Lahore, Sialkot Campus, Pakistan

Correspondence
Naeem Abas, Department of Electrical Engineering, University of Gujrat, Hafiz Hayat Campus, Gujrat, Pakistan.
Email: naeemkalair@uog.edu.pk

Abstract
The fast-growing electricity demand in Pakistan and other developing countries has posed a severe challenge to electricity distribution systems. Indeed, most of the utility companies have to follow a trend of load shedding to face this difficulty. Load shedding is the “art” of managing the load demand by shedding loads in critical situations where the demand is higher than the total generation to avoid system failure. Although electricity utilities are suggesting consumers reduce the load during peak hours in their monthly bills, the consumers are not willing or aware of this. It is clear how tedious and tiresome it is to remind the customers what the peak hours are, and manually switch off/on the heavy load during peak and off-peak hours. The estimated cost of the system is around 43$ and 28$ with and without Global System for Mobile Communications module for message notification. Moreover, the distribution feeder has a specific capacity to bear the load in peak hours after this is automatically shut down the whole feeder. In this paper, the simulation analysis of a single-family house is performed for automatic load reduction during peak hours in Proteus software. A hardware prototype is then designed and applied so as to validate the proposed control system. The results show that the proposed scheme allows for an efficient peak shaving during peak hours. For some typical domestic and commercial consumers, the financial benefits are also calculated. It is concluded that the payback period of this device is almost 1 month if it reduces 50% of load during the 4-hour peak time. The proposed system may be implemented as a single additional tool/span is already available energy meters and may quickly be adopted by electric utilities of developing countries to avoid the load shedding trend.

Keywords
demand side management, load shedding, peak hours, smart metering
1 | INTRODUCTION

Electrical Energy is invisible, a universal commodity that is immediately available in most of the world, and it has been recognized as an everyday consumer need. Renewable Energy (RE) is used to aid the primary energy demand in the form of solar PV, solar thermal, wind energy. The intermittent nature of RE, harmonics, and reactive power problems halts the performance of the power system by originating stability concerns in the power system. The use of Flexible AC transmission controllers and energy storage devices (batteries, fuel cells, pumped, hydrogen and compressed air storage) are widely used around the world.

Due to the increasing population and low economic growth, Pakistan is suffering from an electricity crisis from the past decade. On the other hand, the world is moving toward innovations in electronic appliances. Everyone wants comfort and ease in one’s life, and modern appliances are increasing rapidly. A load of an ordinary person’s home is doubled, at least due to modern appliances. The current electricity generation is unable to meet electricity demand. The gap between demand and supply was reported around 6000 MW, 5201 MW, and 7000 MW in 2012, 2015, and 2017, respectively, which have resulted in load shedding hours reaching to 10-12 and 16-18 hours reaching in urban and rural areas of Pakistan. The new induction of electricity resources was 7775 MW and 3673 MW in 2017 and 2018, and total capacity after these additions reached 37634 MW by the end of FY2018. There are two possible solutions to this problem; one is to increase the generation, and second is the load management in peak and off-peak hours. The electric utilities in Pakistan have different peak and off-peak timing in summer and winter with total peak hours duration of 4 hours. Pakistan’s Water and Power Development Authority (WAPDA) is generating electricity from different sources, for example, furnace oil, hydel, gas/Liquefied Natural Gas (LNG), coal, nuclear energy, and renewable energy and their share are demonstrated in Figure 1. It clearly shows that the contribution of furnace oil is more significant, which is not suitable for the environment due to the high emission of CO2. The considerable emissions in the world are mainly due to the burning of fossil fuels like coal, oil, and gases. First time in the Paris agreement, world representative decided to take some stern steps for the betterment of the climate, it was decided to control the maximum difference in the temperature of the earth below than 1.5 or 2°C until 2030.

Electric power distribution companies encourage their users to use the heavy load including, air conditioner, heater, electric motors, iron, and so on, in off-peak hours instead of peak hours. However, its impact can be reduced by controlling and optimizing the available resources. The load management system is essential in the scope of energy management as it relates to the economy and system efficiency. A considerable amount of research work is done on several demand-side load management (DSLM) techniques, such as load control, Global System for Mobile Communication (GSM)-based remote controlling system, smart load management, evolutionary priority algorithm, DC/AC hybrid Grid and demand-side management using PV system, and so on. Some other demand-side load management techniques are peak clipping, valley filling, and load shifting, which are the direct control methods of high-power consuming loads. The limitations of DSLM methods are that they can only be implemented for those loads which are versatile. Similarly, there are many systems based on different technologies, which provide automation for homes or offices. With time,
these systems demand some advancement in them. A more reliable and dependable system, with some amendments in infrastructure, replaces its precursor.

Sakthivel et al proposed to design a system to minimize the energy consumption for the specified customer in planned duration instead of load shedding. There will be a GSM-based remote controlling station from where we could send control information that will consist of maximum power consumption and restricted time-period. If the user uses more power than the permitted power, after a warning, his power supply will be disconnected automatically by the system. An evolutionary priority algorithm-based demand side management system is proposed in Reference 31, the system is based on time, and device-based priority for consumers that they can set the devices and as well as the timing of their use in the demand meter and the EPA enable control helps them to achieve the minimum load based on their use. Labib et al have presented a design of smart load management system (SLM) scheme which can be used efficiently to satisfy consumers during emergency demand (light and fan) when available power is not sufficient concerning its demand.

Rani et al have proposed the smart grid implementation in Pakistan to resolve stress situations in the electrical energy system by responding to demand. The primary aspect of their work was to manufacture an economical GMS-based smart energy meter that can send information of instant power usage on the customer’s side to the grid via GSM modem. Each user was permitted to use a specified load if the load exceeds the load limit, short message service (SMS) caster sent a notice to reduce the load within the specified limit to avoid power cut-off after 10 minutes. The limitations of their work are that the proposed system cut off the complete power of the individual user. A generic demand side management (GDSM) scheme is presented by in Reference 35. The GDSM is proposed to decrease peak-to-average ratio, electricity cost, and waiting time of appliances.

Review on information processing for a renewable energy system using two-way communication for demand side management (DSM) and demand response system. The use of DSM is gaining popularity due to the maturity in IT industry and meanwhile rising cost and demand for electricity. They have presented a review of different control strategies for DSM. A review of Internet of things (IOT) and cloud computing for accessible data collection, and communication for every engineering field is presented in Reference 36.

Some of them are needed continuously human interference, very costly, complex and challenging to implement on a large scale. Home load management is a very vast field, and many researchers are working on it to manage the demand and supply. The proposed, the designed control system is most suitable in term of performance and simple technique of control using an Arduino controller. Because the conversion of all the grids to a smart grid is not happening in a short time, this requires a large infrastructure, capital, and proper training of the utility workers. However, this system has an advantage like its hardware is less complicated and cost-efficient than other techniques and it can work standalone system without any monitoring.

The paper is organized as follows: Section 2 covers the proposed methodology and proposed a model of home load management and control system, estimation, and design of its parameters. Section 3 includes results and discussion. The conclusion and future outlook of this research are described in Section 4.

2 | PROPOSED HOME LOAD MANAGEMENT DESIGN

Electric power distribution company can install this system at the consumer end. It consists of a current sensor which can be used as a current sensing device that will detect the load current continuously. When the peak hours come and if the load current exceeds the calculated set range from the threshold level, then the microcontroller will send the trip signal to the attached relay to switch off the connected heavy loads. When the off-peak hours come, it will give the alarm/buzzer if a consumer wants to use any heavy load during this time. This system will help us to manage between the demand and supply to avoid load shedding during peak hours. It also gives the consumer to low-cost tariffs and encourages the use of heavy load in off-peak hours without shutting the load during high-cost tariff time and when this time of use meter control is connected. The key benefits of this system are summarized in Figure 2.

In this research, the main focus is maintaining the load current of a particular feeder of an electric utility in a permissible limit to avoid the load shedding during the summer season. This research project’s main objective is to manage the home’s heavy load appliances’ automatic control during peak and off-peak hours. The electric utility will control the bulky load devices, including AC, electric heater, electric iron, and motor, with calculated base load values as feed in the microcontroller. AC current value is measured by the current transformer/current sensor from the consumer’s home’s service mains. This AC current value is an analog signal that must be converted into a digital signal so that microcontroller can read this value and send the signal to the operational relay to switch on/off the load during peak and off-peak
hours. This will lead us to give the load control in peak hours and encourage the consumer to use the heavy loads in off-peak hours. This technique is different and easy to apply from the literature review techniques because no human intervention is required in this system. In a broader sense, if electric utility uses this technique to the whole town/city, then electric utility can overcome the problem of load shedding in that area because no peak hours will come.

The design system to manage the home load consists of the microcontroller (Arduino UNO) and current sensors, for example, Current Transformer (CT) and ACS712. This system will help to switch off the home appliances during peak hours automatically. This microcontroller system will help to switch on the loads during the off-peak hours and encourage the consumer to consume the electricity at a low-cost tariff. The design of this will be simple, cost-effective, and easy to understand by the consumer.

In Pakistan, people face unusual electricity shut down due to the high peak demand during the summer season. Furthermore, they are facing the issue of increasing the cost of electricity, global warming, and climate change. Research on RE applications like solar thermal, net-zero energy buildings, and climate-friendly substances and applications like natural refrigerant, and fuel cell-based micro-combine power systems are getting considerable attention in Pakistan. There is a need for electricity utility to analyze each home appliances’ electricity usage and manage its use in peak demand hours. Some devices are consuming unusually high power consumption, and it should be turned off at peak hours.

2.1 Home load calculation and management

First of all, the Home load is calculated for each home appliances so that electric utility can set a threshold value for tripping the load and the Diversity Factor and Demand Factor. Their diversity factor is defined as the ratio of the individual maximum demand of the system to the maximum demand of the whole system.

\[
\text{Diversity Factor (DF)} = \frac{\text{Sum of Individual Maximum Demand}}{\text{Maximum Demand of the System}}
\]

(Figure 2) Key benefits of the proposed load management system
The diversity factor and the load are very closely related to each other. The demand factor is the ratio of the sum of maximum demand of the system to the system’s whole connected load.

\[
\text{Demand Factor} = \frac{\text{Sum of Maximum Demand}}{\text{Total Connected Load}}
\]

Consider the example that a home has the total connected load of 100 A but has the maximum demand on a peak time is 60 A; hence the demand factor is 0.6 that is less than 1.

Now, separate loads of the low power appliances and loads of heavy/inductive appliances will be calculated by using the real-time example of a typical home in which all the appliances for example, fans, electric motors, AC, washing machine, Television (TV), energy savers, microwave oven, electric iron, refrigerators, electric heaters, and so on. A typical home load classification is given in Table 1, and the AC current rating of some appliances along with their power ratings is mentioned in Table 2.

From the above calculations, the home’s total connected load is 38 A, in which 33.25 A are of heavy loads. The use of these appliances can vary season to season. The base load of the above-mentioned home load is 9.9 A.

### 2.2 Design of control system

The block diagram of the load management and control system is shown in Figure 3. The main components of the proposed method are a current transformer, Analog to digital converter, Arduino UNO microcontroller, power supply, LCD,

| Load type              | Power \((P_{\text{max}})\) (W) | AC/DC | Appliance                                                                 | Urgency       | Usage time duration |
|------------------------|-------------------------------|-------|---------------------------------------------------------------------------|---------------|--------------------|
| Primary                | 150                           | Both  | AC/DC Fans AC/DC energy savor, LEDs Mobile/Laptop and small gadgets chargers, TV, Computer, AC lights, DSL adapter | First         | Full Day           |
| Regular (necessary)    | 400-1200                      | Both  | AC/DC Fridge AC/DC Deep Freezer Uninterruptable Power Supply (UPS)         | Second        | Full day           |
| Regular (luxury)       | 1200                          | DC    | DC inverter AC                                                            | Third         | On Demand          |
| Brust (luxury)         | 1000-2000                     | AC    | Pump motor, washing machine, juicer electric oven, Irons and electric gas heaters | Fourth       | Occasionally       |

| Appliances              | Quantity | Power (W) | Current (A) | Total current (A) |
|-------------------------|----------|-----------|-------------|-------------------|
| Energy saver            | 30       | 24        | 0.10        | 3.27              |
| Fans                    | 5        | 100       | 0.454       | 2.27              |
| Electric iron           | 1        | 1000      | 4.54        | 4.54              |
| TV                      | 1        | 100       | 0.454       | 0.454             |
| AC                      | 1        | 2400      | 10          | 10                |
| Refrigerator            | 1        | 200       | 0.909       | 0.909             |
| Heater                  | 1        | 2000      | 9.09        | 9.09              |
| Microwave oven          | 1        | 1500      | 6.81        | 6.81              |
| Washing machine         | 1        | 500       | 2.27        | 2.27              |
| Electric motor          | 1        | 1.5       | 5.08        | 5.08              |
| Total load              |          |           |             | 38                |
relay drivers, and relay according to the load current. ACS712 IC can also be used as a current sensor instead of the current transformer if the current value is less than or equal to 20 A. The controller is connected with the current sensor as a feedback loop. A real-time clock and time adjustable is also attached as the input of the controller. LCD will display the real-time and value of the load as the output of the controller. The current sensor’s output is associated with the heavy loads and depends upon the amount of the load current. A buzzer will indicate that off-peak hours are going on.

3 | RESULTS AND DISCUSSIONS

The Arduino sketch was made for the load management system design on Arduino compiler IDE, and a flow chart of the proposed control scheme is illustrated in Figure 4. The complete design, including Arduino UNO, current sensor, and connected devices, are made and simulated on Proteus Professional Software. The circuit diagram used for simulation in Proteus is shown in Figure 5. The current sensor ACS712 is used instead of CT to measure the current of active loads. A current sensor is continuously monitoring the load current of the home appliances to check the value of the load current. If the amount of the load current is higher than the set value, then Arduino will send the trip signal to the relay to switch off the heavy loads until the desired amount of the load is reached. A real-time clock is also attached to measure the peak and off-peak time. There are four electric lamps, and one motor is used as a heavy load in this simulation. Each electric lamp consumed 2.85 A, and the motor consumed 9.9 A. These loads are connected with Arduino UNO via a relay.

3.1 | Operation during peak hours

In this simulation, the set time for the peak hours is 6:00 PM to 10:00 PM, and the rest of the time is off-peak hours. The current threshold value should be less than 10 A. Arduino will only operate when both these conditions come true. The total load consumed by the four electric lamps (11.4 A) and one motor (9.9 A) is 21.3 A, as shown in Figure 6A. During peak hours, the current sensor ACS712 measures the value of the current that is 21.3 A. It means that all the attached loads in working condition then the Arduino controller immediately send the trip the signal to the first relay and shut down the first lamp. The value load decreased from 21.3 A to 18.45 A. But this value is still higher than 10 A, so after the delay of 2 seconds, Arduino again sends the trip signal to relay two and shut down the lamp 2. The value of load current
now decreased to 16 A, as shown in Figure 6B. Initially, the current value was 21.3 A, and when the peak hour came to the control system operates, it turned off the first two appliances, and the load current reached up-to 16 A, which is still higher than the set load current of 10 A for peak hours times. Then the control system again operates, and another appliance is off, and now the load current drawn by the appliances is less than the set limit. The current value is fluctuating between 21.3 A and 15.6 A. When the peak hours (6 PM to 10 PM) come, all the heavy loads have shut down, and load value decreased to the desired base value of 9.9 A. This system is very flexible in terms of peak hours because the peak hours of the electric utility varies from area to area and season to season. The Customer Support Representative (CSR) of an electrical power
company can easily change the value of peak hours by change the Arduino code in the system installed at the consumer end. After this, all the lamps will shut down, and the value of the load current reaches the desired value of 9.9 A. Now only one load is working and consuming the 9.9 A, as shown in Figure 6C.

3.2 | Operation during off-peak hours

During off-peak hours, Arduino sends the signal to the attached buzzer that will remind the consumer that peak hours are gone, and now they can operate their devices as per their choice. It also encourages the consumer to use their heavy appliances during these hours so that electric utility can maintain the balance between demand and supply during the summer season. The control scheme also does not turn off any device during off-peak hours. Hence, all the appliances run smoothly during that time, with this control system connected to their main electricity utility meter.

3.3 | Hardware implementation

A prototype of the load management system is made and evaluated using a project-based scenario with three current sensors to measure connected load currents of all different kinds of loads like lighting, necessary and general loads. For implementation, testing, and evaluation, the smaller current values are used to perform a safe, practical demonstration.
Three lamps of 100 W each are connected to depict the different load scenarios for the experiment. During off-peak times, these three lamps can be turned ON and OFF any time. But during peak hours, only a specified amount of the load can be used. In this case, a total limit of 0.55 A was set to check the proposed design’s implementation. These are the outputs that we got on the LCD screen during different situations.

Initially, the input is applied to the energy meter, but there was no load connected with it at that time. Figure 7A shows the different loads’ readings when there is no load on the system. Then all three lamps depicting lighting, necessary, and luxury loads. Readings of the various loads when 100 W of the lamp are connected representing each load are seen in Figure 7B. After 1 minute and 30 seconds, the energy meter sends a notification by SMS to the user stating to reduce the load within limits because peak time will start soon. After 30 seconds of this notification, the energy meter sends the other notification stating that peak time has been started, so keep your load within the limit to avoid power cut off.

When peak time starts, the energy meter checks the consumer total load current and compares it with the allowed load. In our case, it is 0.55 A. The energy meter automatically disconnects the luxury load, which can be seen in Figure 7C. Because the total current is more than the limit and sends the notification to the user about this, the energy meter again checks the total current. If the load current is still higher than the sanctioned load, it disconnects the necessary load, as shown in Figure 7D, and sends a notification about this. When the peak time finishes, the energy meter automatically connects all the disconnected load, as shown in Figure 7B, and sends the notification.

When the voltages are below 180 V, the energy meter cut off the power to save the appliances from damage, as shown in Figure 7E. The GSM also sends notification of these situations to the consumer’s mobile by GSM. All the notifications can be seen in Figure 8.

The GSM module is used to send a customer notification on the consumer mobile phone for informing about the current state of the decision taken by the meter. Figure 8 shows some messages/notifications received on mobile whenever some action is taken by the energy meter during different situations.

1. About 30 seconds before the peak time.
2. When peak time starts.

**Figure 7** (A). All load is off, (B) all load on during off-peak time, (C) during peak hour luxury load turned off, (D) necessary load turned off to meet the load requirement during peak time, (E) protection of electrical appliance against low voltage.
3. If the load is higher than the allowed load during peak time.
4. If the load is still greater than the permitted load during peak time.
5. When off-peak time starts.
6. If voltages are under 180 V.

### 3.4 Cost of load management device

The electric utilities in Pakistan decide to change the electric meter by themselves. However, the energy meter’s expense is charged from the costumers on installments in their electricity bill. It is not an issue for the utilities to decide if this benefits them in the long run and the Government in Pakistan also has a policy to give subsidy for domestic and agriculture consumers. The estimated cost of equipment for load management devices is presented in Table 3. This cost is almost identical to the cost of an energy meter installed at domestic consumer premises. The circuit diagram of the proposed system is illustrated in Figure 9.

### 3.5 Impact on consumers electricity bills

There are different types of meters applied for domestic, commercial, industrial, and agriculture users. The tariffs for TOU meters are almost similar for various applications with a slight difference. Electricity tariffs by electric utilities in Pakistan for different applications are presented in Table 4.

| Serial no. | Item name              | Quantity | Per unit cost (PKR) | Total (PKR) |
|------------|------------------------|----------|---------------------|-------------|
| 1          | Arduino Mega           | 1        | 1100                | 1100        |
| 2          | ACS712 Current sensors | 3        | 250                 | 750         |
| 3          | Transformer            | 1        | 300                 | 300         |
| 4          | Other Electronic Components | 1   | 200                 | 200         |
| 5          | LCD 20 x 4             | 1        | 570                 | 570         |
| 6          | Switch board           | 1        | 200                 | 200         |
| 7          | Power supply           | 2        | 250                 | 500         |
| 8          | Arduino cables         | 2        | 150                 | 300         |
| 9          | Relay                  | 5        | 150                 | 750         |
| 10         | GSM module             | 1        | 2500                | 2500        |

Total including GSM 7170 PKR \( \approx 43 \) $

Total (without GSM) 4670 PKR \( \approx 28 \) $
A cost analysis to check the financial saving with the proposed home load management system is applied to domestic and commercial applications. The peak and off-peak unit’s prices are 20.70-14.38 and 21.60-15.63 PKR per kWh (1 kWh = 1 Unit). Table 5 shows a calculation for estimated consumed units 800 off-peak and 400 peak hours, and the estimated bill is calculated. The peak and off-peak hours are 20 and 4 hours throughout the year and with different timings during summer and winter. The peak hours for December-February, March-May, June-August, and September-November are 5 PM-9 PM, 6 PM-11 PM, 7 PM-11 PM, and 6 PM to 10 PM, respectively. The typical bill without any load management system is around 26 609 PKR. A similar statement is also obtained from one of the utility websites. The utility’s electricity bill calculation results show a 26 604 PKR bill, and almost there is 34.5% of government taxes involved in the billing in Pakistan. They are then assuming only a 50% load reduction during the peak hours. The resulted electricity bill is calculating as 21 041.18 in Table 5 and similar in Figure 10B. This shows an around 5500 PKR ≈ 33 USD saving, the saving of 1 month is enough to pay back the cost incurred on these devices.

### Table 5 Estimate of energy saving with proposed load management system

| Meter type | Consumer and meter type | Peak per kWh (PKR) | Off-peak per kWh (PKR) |
|------------|-------------------------|--------------------|------------------------|
| A          | Residential (A1-03)     | 20.70              | 14.38                  |
|            | Commercial (A2)         | 21.60              | 15.63                  |
| B          | Industrial              |                    |                        |
| B1 (b)     | 1. Up-to 25 kW          | 18.84              | 13.28                  |
| B2 (2) B3  | 2. 25-500 kW at 400 V   | 18.78              | 12.98                  |
|            | 3. up to 5000 kW (at 11,33 kV) | 18.78          | 12.98                  |
| D1-(b)     | Agriculture >5 kW       | 18.60              | 11.35                  |

### Table 4 Electricity tariffs in used by electric utilities in Pakistan

| Meter type | Tariff per kWh (PKR) | Estimated unit consumed (1 Unit = 1 kWh) | Cost of electricity (without load management) [PKR] | Total cost of electricity (50% Peak load reduced to 50%) [PKR] | Saving in money (PKR) (50% Peak load reduction) |
|------------|----------------------|--------------------------------------|--------------------------------------------|------------------------------------------------|-----------------------------------------------|
| Residential (A1) | 20.7 | 14.38 | 800 | 400 | 11 504 | 8280 | 19 784 | 26 609.5 | 4140 | 21 041.18 | 5568.3 |
| Commercial (A2c) | 21.6 | 15.63 | 800 | 600 | 12 504 | 12 960 | 25 464 | 45 835.2 | 6480 | 34 171.2 | 11 664 |
FIGURE 10  Calculated bills for the estimated cost (A) domestic (without load management) (B) domestic (with load management) (C) commercial (without load management) (D) commercial (without load management). Source: Reference 45
Similarly, another commercial application scenario is checked and due to very high government taxes on the consumed electricity is around 80%, and almost double saving is achieved with this system. Around 11,664 PKR $\approx 70 USD saving can be archived by reducing only half of the peak load utilizing this load management system. The estimated bill calculated from the utility website shows that with and without a load management system gives around 45,544 PKR and 34,255 PKR bill for 1 month. This significant difference is also due to the very high government taxes on the used electricity amount.

This device’s short time benefit is to tackle the high energy demand efficiently without applying a forced load shedding on a whole feeder. The long term benefits of such devices are the amount of money it saves for the consumers as 4 hours of peak load, mostly in the evening time, and almost 60% increased tariff is applied during peak load time. After this increased tariff, there is a lump sum of 23% of government taxes applied to the amount of total electricity bill. Thus a slight increase in electricity kWh during peak hours may increase the electricity bill a lot. Therefore, such devices are very beneficial for the consumer to manage their electricity bill.

### 3.6 Research implementation on GEPCO subdivision for load shaving

The detailed research objectives to maintain the balance between demand and supply during peak and off-peak hours to overcome the problem of load shedding is explained by proposing this system for a Gujranwala Electric Power Company (GEPCO) feeder. The results of this simulation can be implemented on any GEPCO subdivision to get the desired output. Consider an 11 kV feeder of Wazirabad GEPCO sub division Wazirabad was chosen for the desired data collection. The data were collected from the Wazirabad GEPCO subdivision for a single feeder. It has the 9939 consumers on this feeder, and it can bear the maximum load of 400 A at 11 kV. All these consumers consume the 6.86 MW power of connected load of 12 MW of all the attached distribution transformers; If the current reaches the value of 400 A, the distribution feeder will get overload and trip. All the consumer will face the load shedding after tripping the feeder. On a typical day, the consumer may not use the maximum load of more than 10 A; however, many customers will use it. Different consumers may use different load in peak hours. The electric utility can have assumed their load consumption from consuming kWh, as mention in the bill. It is extracted the data from the monthly billing report of the Wazirabad Subdivision that most of the consumers are consuming the load value less than 10 A but still 3439 customers that are consumed the load greater than 10 A in peak hours, as shown in Table 6. However, not all consumers at a time are using the same load value in peak hours.

The home loads are running on a different current value higher than 10 during off-peak hours. When the peak hours (4 hours of peak time) come, all the heavy loads have shut down, and load value decreased to the desired base value of 9.9 A. This is how electric utility can run the home or commercial load during peak hours down to a base level to avoid unnecessary load shedding in the summer season. This system is very flexible in managing peak hours because the electric utility’s peak hours vary from area to area and season to season. The Customer Support Representative (CSR) of an electrical power company can easily change the value of peak hours by change the Arduino code as per the requirements.

These 3439 customers are increasing the load current on the feeder of 11 kV due to which feeder get overload and trip in peak hours, and unscheduled shedding will occur. There is a need to reduce the load of the consumer by applying the research results, and electric utility will get the reduction of load in peak hours. The designed control system will reduce the load in peak hours as set in the simulation. The value of load current can vary according to different environments and areas. The 3-day graph is made to explain the reduction on load during the peak hours after applying the home load management scheme. The segments of consumers are shown on the X-axis, and the value of load current (with and without control) is plotted in YZ-axis (see Figure 11).

#### Table 6 Load management in peak hours (4 h in evening)

| No. of consumers | Load current range (A) | Total load current without control system (A) | Total load current with control system (A) |
|------------------|------------------------|---------------------------------------------|------------------------------------------|
| 1-1500           | 1–2                    | 3000                                        | 3000                                     |
| 1501-3500        | 3–5                    | 5000                                        | 5000                                     |
| 3501-6500        | 7–10                   | 8000                                        | 8000                                     |
| 6501-9939        | 10–25                  | 25,000                                      | 14,000                                   |
| 9939             |                        | 41,000                                      | 30,000                                   |
CONCLUSIONS

Electric utilities want to reduce the load during the peak hours and encourage the user to use the appliance in off-peak hours to manage the load between supply and demand to avoid unscheduled load shedding. A home load management system for distribution utilities to prevent unnecessary load shedding during peak hours is proposed in this research. The Arduino-based smart load management system is simulated and tested using Proteus software. It can be a very cost-effective load management system. This system’s hardware is less complicated and can be applied easily on the heavy load consumer houses. The system design can switch off the heavy load during peak hours without any human interference and encourage the consumers to use these heavy loads during off-peak hours. The cost-effectiveness, easy implementation, SMS notification, and only a 1 month payback period are key features of the proposed home load management system. Such projects are necessary for both the consumers as well as a utility as both can benefit from this. Therefore, it is highly recommended to both consumer and electric utilities to control the use of heavy home load during peak and off-peak hours as well a considerable amount of saving for both domestic and commercial consumers is achieved by employing this. This will lead the electric utilities to avoid load shedding in peak hours due to an imbalance between demand and supply, and the consumer can avail the benefit in the form of less billing. Further research needs to be conducted to improve the control system’s designs by adding the real-time monitoring of load at the consumer end via DSL.

ACKNOWLEDGMENT

We are thankful to the XEN (Executive Engineer) Wazirabad, Subdivision Wazirabad, Gujranwala for providing their single feeder connected load data.

PEER REVIEW INFORMATION

Engineering Reports thanks Pengfei Liu and other anonymous reviewer(s) for their contribution to the peer review of this work.

CONFLICT OF INTEREST

The authors declare no potential conflict of interest.

AUTHOR CONTRIBUTIONS

Muhammad Butt: Conceptualization; data curation; formal analysis; writing-review and editing. Saad Dilshad: Formal analysis; visualization; writing-original draft. Naeem Abas: Conceptualization; data curation; investigation;
methodology; software; supervision. **Shoaib Rauf:** Investigation; methodology; resources; software; validation. **Muhammad Saleem:** Software; visualization.

**DATA AVAILABILITY STATEMENT**
The data that support the findings of this study are available from the corresponding author upon reasonable request.

**NOMENCLATURE**

| Abbreviation | Description |
|--------------|-------------|
| AC           | alternating current |
| CT           | current transformer |
| DSL          | digital subscriber line |
| DSM          | demand side management |
| DSTM         | demand-side load management |
| DTMF         | dual tone multi-frequency |
| GDSM         | generic demand side management |
| GEPCO        | Gujranwala Electric Power Company |
| GSM          | global system for mobile communications |
| IOT          | Internet of things |
| kWh          | kilo Watt hour |
| LCD          | liquid crystal display |
| LNG          | liquefied natural gas |
| RE           | renewable energy |
| SLM          | smart load management system |
| SMS          | short message system |
| TOU          | time of use |
| UPS          | uninterruptable power supply |
| WAPDA        | water and power development authority |
| Wi-Fi        | wireless fidelity |

**ORCID**

*Saad Dilshad* [https://orcid.org/0000-0001-7894-3509](https://orcid.org/0000-0001-7894-3509)

*Naeem Abas* [https://orcid.org/0000-0002-7214-2986](https://orcid.org/0000-0002-7214-2986)

**REFERENCES**

1. Khan N, Dilshad S, Khalid R, Kalair AR, Abas N. Review of energy storage and transportation of energy. *Energy Storage.* 2019;1:1-49. [https://doi.org/10.1002/est2.49](https://doi.org/10.1002/est2.49).
2. Kalair AR, Abas N, Hasan QU, Seyedmahmoudian M, Khan N. Demand side management in hybrid rooftop photovoltaic integrated smart nano grid. *J Clean Prod.* 2020;258:120747. [https://doi.org/10.1016/j.jclepro.2020.120747](https://doi.org/10.1016/j.jclepro.2020.120747).
3. Abas N, Khan N, Hussain I. A solar water heater for subzero temperature areas. *Prog. Sustain. Energy Technol. Gener. Renew. Energy.* Cham, Switzerland: Springer International Publishing; 2014:369-377. [https://doi.org/10.1007/978-3-319-07896-0_20](https://doi.org/10.1007/978-3-319-07896-0_20).
4. Pineda I, Pierre Tardieu W. Wind in power 2017. Annual combined onshore and offshore wind energy statistics; 2018. [https://windeurope.org/wp-content/uploads/files/about-wind/statistics/WindEurope-Annual-Statistics-2017.pdf](https://windeurope.org/wp-content/uploads/files/about-wind/statistics/WindEurope-Annual-Statistics-2017.pdf). Accessed May 29, 2019.
5. Basit MA, Dilshad S, Badar R, Sami ur Rehman SM. Limitations, challenges, and solution approaches in grid-connected renewable energy systems. *Int. J. Energy Res.* 2020;44(6):4132-4162. [https://doi.org/10.1002/er.5033](https://doi.org/10.1002/er.5033).
6. Kalair A, Abas N, Kalair AR, Saleem Z, Khan N. Review of harmonic analysis, modeling and mitigation techniques. *Renewable and Sustainable Energy Reviews.* 2017;78:1152-1187. [http://dx.doi.org/10.1016/j.rser.2017.04.121](http://dx.doi.org/10.1016/j.rser.2017.04.121).
7. Abas N, Dilshad S, Khalid A, Saleem MS, Khan N. Power quality improvement using dynamic voltage restorer. *IEEE Access.* 2020;8:164325-164339. [https://doi.org/10.1109/ACCESS.2020.3022477](https://doi.org/10.1109/ACCESS.2020.3022477).
8. Sarkar MNI, Meegahapola LG, Datta M. Reactive power management in renewable rich power grids: a review of grid-codes, renewable generators, support devices, control strategies and optimization algorithms. *IEEE Access.* 2018;6:41458-41489. [https://doi.org/10.1109/ACCESS.2018.2838563](https://doi.org/10.1109/ACCESS.2018.2838563).
9. Badar R, Dilshad S. Adaptive Type-2 NeuroFuzzy wavelet-based supplementary damping controls for STATCOM. *Int Trans Electr Energy Syst.* 2020;30:e12429. [https://doi.org/10.1002/2050-7038.12429](https://doi.org/10.1002/2050-7038.12429).
10. Abas N, Kalair E, Kalair A, Hasan QU, Khan N. Nature inspired artificial photosynthesis technologies for hydrogen production: barriers and challenges. *Int J Hydrogen Energy.* 2019;45:20787-20799. [https://doi.org/10.1016/j.ijhydene.2019.12.010](https://doi.org/10.1016/j.ijhydene.2019.12.010).
11. Khan N, Kalair E, Abas N, Kalair AR, Kalair A. Energy transition from molecules to atoms and photons. *Eng Sci Technol an Int J*. 2019;22:185-214. https://doi.org/10.1016/j.jestch.2018.05.002.

12. Abas N, Kalair A, Khan N. Review of fossil fuels and future energy technologies. *Futures*. 2015;69:31-49. https://doi.org/10.1016/j.futures.2015.03.003.

13. Rafique MM, Rehman S. National energy scenario of Pakistan – current status, future alternatives, and institutional infrastructure: an overview. *Renew Sustain Energy Rev*. 2017;69:156-167. https://doi.org/10.1016/j.rser.2016.11.057.

14. State of industry report 2014–15. National Electric Power Regulatory Authority (NEPRA), Pakistan. https://nepra.org.pk/industryreports.htm. Accessed September 3, 2019.

15. Dawn, power cuts return as shortfall touches 7,000 MW, 2018; 2017. https://www.dawn.com/news/1331738.(accessed November 6, 2018).

16. Gap between electricity demand and supply reaches 6,000 mega watts; n.d. https://nation.com.pk/27-May-2012/gap-between-electricity-demand-and-supply-reaches-6-000-mega-watts. Accessed September 3, 2019.

17. State of Industry Report 2017 National Electric Power Regulatory Authority. (NEPRA), Pakistan; n.d. https://nepra.org.pk/industryreports.htm Accessed September 3, 2019.

18. Abas N, Khan N. Carbon conundrum, climate change, CO2 capture and consumptions. *J CO2 Util*. 2014;8:39-48. https://doi.org/10.1016/j.jcou.2014.06.005.

19. Agreement P. *United Nations Framework Convention on Climate Change*. Paris, France: United Nations; 2015.

20. The Paris Agreement | UNFCCC; n.d. https://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement. Accessed September 20, 2019.

21. Kalair A, Abas N, Khan N. Comparative study of HVAC and HVDC transmission systems. *Renew Sustain Energy Rev*. 2016;59:1653-1675. https://doi.org/10.1016/j.rser.2015.12.288.

22. Khan N, Mariun N, Abas N. Photon fuelled electric power plants. *Lasers Eng*. 2008;18(5-6):383-401.

23. Khan N, Saleem Z, Abas N. Endorsement of new SI unit prefixes for space, time, energy and matter. *Lasers Eng*. 2008;18:107-118.

24. Abas N, Khan N, Haider A, Saleem MS, Kalair AR. CO2 utilization drivers, opportunities and conversion challenges. *Ref. Modul. Mater. Sci. Mater. Eng. Amsterdam: Elsevier*; 2018. https://doi.org/10.1016/B978-0-12-803881-8.10494-1.

25. Abas N, Kalair AR, Khan N, Haider A, Saleem Z, Saleem MS. Natural and synthetic refrigerants, global warming: a review. *Renew Sustain Energy Rev*. 2018;90:557-569. https://doi.org/10.1016/j.rser.2018.03.099.

26. Khalil HB, Abas N, Rauf S. Intelligent street light system in context of smart grid. Paper presented at: 8th Int. Conf Comput Commun NewTech ICCCNT 2017; 2017. https://doi.org/10.1109/ICCCNT.2017.8204158.

27. Khan N, Kalair A, Abas N, Haider A. Review of ocean tidal, wave and thermal energy technologies. *Renew Sustain Energy Rev*. 2017;72:590-604. https://doi.org/10.1016/j.rser.2017.01.079.

28. Aghaeiabrahimi MR, Tourani M, Amiri M. Power consumption management and control for peak load reduction in smart grids using UPFC. Paper presented at: IEEE Electr. Power Energy Conf.; 2011: IEEE: 327-333. https://doi.org/10.1109/EPEC.2011.6070220.

29. Sakhthivel P, Ganeshkumar S. Design of automatic power consumption control system using smart grid—a review. Paper presented at: 2016 World Conf Futur Trends Res Innov Soc Welf (Startup Conclave; 2016): IEEE: 1-4. https://doi.org/10.1109/STARTUP.2016.7583951.

30. Labib M Billah MR, Islam GMSM. Rana, design and construction of smart load management system: an effective approach to manage consumer loads during power shortage. Paper presented at: Int. Conf. Electr. Eng. Inf. Commun. Technol.; 2015: IEEE:1-4. https://doi.org/10.1109/ICEEICT.2015.7307346.

31. Khan A, Javaid N, Iqbal MN, Anwar N, Haq I, Ahmad F. Time and device based priority induced demand side load management in smart home with consumer budget limit. Paper presented at: IEEE 32nd Int. Conf. Adv. Inf. Netw. Appl.; 2018: IEEE:874-881. https://doi.org/10.1109/AINA.2018.00129.

32. Rauf S, Khan N. Application of DC-AC hybrid grid and solar photovoltaic generation with battery storage using smart grid. *Int J Photoenergy*. 2017;2017:1-16. https://doi.org/10.1155/2015/6736928.

33. Kalair AR, Rauf S, Kalair A, Abas N, Hasan QU, Khan N. DSM in hybrid AC/DC rooftop PV integrated smart nano grid. Paper presented at: 4th Int. Conf. Smart Sustain. Technol.; 2019: IEEE:1-7. https://doi.org/10.23919/SpliTech.2019.8783032.

34. Rani M, Ramzan F, Javed A, Farooq A, Malik TN. Smart grid implementation to overcome electric power system stress conditions through demand response in Pakistan. Paper presented at: Int. Conf. Intell. Syst. Eng.; 2016: IEEE:340-344. https://doi.org/10.1109/INTELSE.2016.7475146.

35. Khan MA, Javaid N, Mahmood A, Khan ZA, Alrajeh N. A generic demand-side management model for smart grid. *Int J Energy Res*. 2015;39:954-964. https://doi.org/10.1002/er.3304.

36. Hashem IAT, Yaqoob I, Anuar NB, Mohktar S, Gani A, Ullah Khan S. The rise of “big data” on cloud computing: review and open research issues. *Inf Syst*. 2015;47:98-115. https://doi.org/10.1016/j.is.2014.07.006.

37. Tamkitthikun N, Tantidham T, Intakot P. AC power meter design for home electrical appliances. Paper presented at: ECTI-CON 2015 – 2015 12th Int. Conf Electr Eng Comput Telecommun Inf Technol; 2015. https://doi.org/10.1109/ECTICon.2015.7207005.

38. Abas N, Kalair AR, Seyedmahmoudian M, Naqi V, Campana PE, Khan N. Dynamic simulation of solar water heating system using supercritical CO2 as mediating fluid under sub-zero temperature conditions. *Appl Therm Eng*. 2019;161:114-152. https://doi.org/10.1016/j.japthermeng.2019.114152.

39. Irfan M, Abas N, Saleem MS. Thermal performance analysis of net zero energy home for sub zero temperature areas. *Case Stud Therm Eng*. 2018;12:789-796. https://doi.org/10.1016/j.csite.2018.10.008.

40. Dilshad S, Kalair AR, Khan N. Review of carbon dioxide (CO2) based heating and cooling technologies: past, present, and future outlook. *Int J Energy Res*. 2020;44:1408-1463. https://doi.org/10.1002/er.5024.
41. Hussain F, Ashfaq Ahmad M, Badshah S, et al. A modeling approach for low-temperature SOFC-based micro-combined heat and power systems. *Int J Mod Phys B*. 2019;33:1950001. https://doi.org/10.1142/S0217979219500012.

42. Mehta VK. *Principles of Power System, S. Chand*. New Delhi, India: Chand (S.) & Co Ltd; 2004.

43. Glisson TH. *Introduction to Circuit Analysis and Design*. Springer, Netherlands: Springer Science & Business Media; 2011.

44. Tariff Guide; 2020. https://iesco.com.pk/index.php/customer-services/tariff-guide. Accessed July 31, 2020.

45. LESCO – Customer Services Bill Estimator; 2020. http://www.lesco.gov.pk/Modules/BillCalc/BillCalc.asp. Accessed July 31, 2020.

**How to cite this article:** Butt MB, Dilshad S, Abas N, Rauf S, Saleem MS. Design of home load management system for load rationing in Pakistan. *Engineering Reports*. 2021;3:e12312. https://doi.org/10.1002/eng2.12312