Power-saving smart energy grid meter for blackout management

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Power generation and transmission effectiveness of energy systems have always been impacted around the globe. An imbalanced load of different devices on whole grids have factually conceived disastrous events across history. Traditionally, to resolve imbalances, blackouts are conducted to stabilize the supply to the remainder of the grid network. This paper presents the development of a remote energy measurement system using Arduino and sensors (C.T. & P.T.), to measure and protect user-end components from potential failure. Arduino records individual sensor data and transmits the relative data through Wi-Fi via a local internet connection to the base station. The unit also displays all related data such as energy consumption (Power), current, and voltage on an integrated display panel. This paper also proposes an improved energy meter design, capable of monitoring load prioritized electrical circuits for load management to avoid complete blackouts. The model is simulated, and energy meter hardware is developed, assessing the load shedding scheme using the proposed prioritization of load circuits.

Keywords: Energy meter, Potential transformer (P.T.), Current transformer (C.T.), Wi-Fi Module, Arduino, High priority load circuit board, Low priority load circuit board.

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1. Introduction

The main elements of power systems are generation, transmission, and distribution from powerhouse to the user [1–4]. Due to the low generation of power in 3rd world countries, indiscriminate blackouts are carried out to stabilize and ensure a reliable power supply to the remaining part of the system [5]. A power system must remain stable for reliable services and should be capable of withstanding a broader range of load uncertainty. First of all, one should know the main reason why blackouts are to be carried out. The answer is simple; the generation of power is low in the 3rd world and developing countries in comparison to the load consumed by the user side; therefore, to balance and manage the equal distribution of this resource, blackouts are carried out in a scheduled pattern. The whole city may be divided into sectoral areas to execute the said pattern. Each sector may have its own subset of DC-micro-grids with components protected by employing recloser-switches and fuses [6]. Each micro-grid takes on its share of a blackout for its load protection on specific times and days. Such a practice is not favorable and safe and can cause component failures due to the bidirectional flow of current during switching [7], especially to places like schools, universities, hospitals, and offices.

Less power generation at powerhouses like dams (restricted to the terrain and hurt local community), burning of fossil fuels (global-warming), and by other means are impacted by the availability of said sources [8, 9]. Conventional energy meters, even in a three-phase configuration, do not provide any control to the supplied power. Designing and implementing commercial as well as industrial systems based on Wireless communication has always been a prominent field of interest among many researchers and developers [10]. Recent developments of smart grids have further increased the flexibility of the power system along with the incorporation of distributed generators for islanded modes [11].

Smart meters can become surveillance devices that monitor the behavior of the customers [12]. Human interaction, like monthly meter reading and bill deliverance, which has, is quite known to have been entirely erroneous, is also mitigated by the induction of IoT [13]. The smart meters concept has also been laid in [14], which idealizes smart cities with IoT integration. With the replacement of electromechanical meters with electronic meters, reading wirelessly accuracy has also become more reliable [15]. The setup is not limited to locally installed meters. Still, it requires an entire structuring of the grid—novel communication parameters needed to be defined for monitoring and controlling of every unit. The user end can also make use of this full-duplex communication by accessing and monitoring their daily consumption online [16]. Consumption behaviors of every organization can also be recorded, noting any unusual anomalies and protection against power cyber-attacks [16]. By keeping low consuming equipment operational in such events, home-based patients can retain small-medical equipment functional, minimizing odds of life-threatening situations. The company can ensure maximum supply to its users. An estimated calculation for setting limits is required by a micro-grid at the time of blackout to supply the stored power out to select several consumers or the island itself. As a result, the information from a smart meter will ensure to limit the power set by the electric supply company [17]. Table 1 shows the pros and cons of the published articles with smart meter technology.

The energy meter proposed here is capable of load priority-based selective blackout scheme via IoT. The energy meter divides the house (or other units) into two output circuits of the proposed energy meter, the low priority load circuit board and the high priority load circuit board. This nullifies a complete shutoff of all devices in the system in case of imbalance and blackouts. Low consumption devices with low wattage can remain active. The architecture can be incorporated in IEEE RTS-79 system to aid in the evaluation of failures of cyber system based grids [21]. The power to minimum essential loads can be supplied while disconnecting the low priority load circuit or when any load circuits exceed the predefined limits by a utility. The energy meter will trip that overloading circuit; as a result, load management and energy conservation will be achieved.

2. Methodology

The Arduino collects these sensors (C.T. & P.T.) data for energy calculation, visualization, and analysis. The Arduino is equipped with an LCD to display power consumption, current, and voltage of low priority circuit board and high priority circuit board. The Wi-Fi module is responsible for sending power to the base station. We can also extend a wireless Wi-Fi network between the energy meter unit and a base station using a wireless repeater. The Arduino mega microcontroller is used here in the developed board due to its reliability, availability, and the maximum number of I/Os' measure current and voltages and send them to Arduino where power is calculated.

2.1. A.C. current measurement

The sensitivity of the current transformer (C.T.) is crucial for accurate measurement and differentiation of high and low power consumption per unit house. The principle function of C.T. is to measure high voltage A.C. power, as well as to reduce the high current to a lower level, which can be measured by sensitive devices like Arduino, ADC, Raspberry pi, and other microcontrollers. C.T.s are mostly in short-circuited condition, in-pair with a burden resistor. A current transformer must obey the amp-turn ratio formula mentioned in equation 1, like every other transformer.

$$TR = \frac{N_p}{N_s} = \frac{I_p}{I_s} \tag{1}$$

Where,
TR= turns ratio
Np= primary number of turns
Ns= the secondary number of turn
Ip= primary current winding
Is= secondary current winding.
To find secondary current, rearrange equation 1 to:

$$Is = Ip \times (\frac{Np}{Ns}) \tag{2}$$

When calculating and designing the final circuit, one must take the transformer error into account, which is usually caused by; the number of turns' ratio not being equal in primary to secondary and phase angle error. These can be reduced by using a high permeability core, lowered internal impedance, having the burden resistor value as close to operating mode as possible. One can match the C.T. with the burden resistor by calculating the turns ratio set inside the C.T. using ohms law. With this evaluation, one can easily find the best burden resistor by using the formula:

$$BR(ohms) = \frac{AREF \times CTTurns}{{}^{2}\sqrt{2} \times primary \quad max \quad current} \tag{3}$$

Here, AERF represents the analog reference voltage of the ADS1115 module, having a preset value of 4.096V. Finally, after evaluation and confirmation of the right transformer,

Table 1. Published smart meter analysis.

Published articles	Pros.	Cons.	Ref.
Smart City-based-meter	Highly integrated, multi-capable	Battery-powered meters, limited range of communication.	[14]
Smart IoT meter for efficient energy utilization	Energy theft detection	Architecture is limited to consumption. Not suitable for grid contribution to avoid blackouts.	[15]
GSM based SMS communication	Data delivery without internet	Limited data based on a cellular plan. Registration of Sim card	[18]
Prepaid-Energy Meter	Recharge via Smart card, RFID cards.	Sudden power cut-off in case of a cellular message not received. Constant manual recharge of cards.	[19]
Wireless IoT based metering system	Prepaid, user-oriented, with customer services.	Requires additional Bluetooth module for essential communication.	[20]
Unbundled Smart Meter	Multilayered protocols, architecture, data privacy, and data association.	Complex for simple augmentation, expensive implementation.	[20]

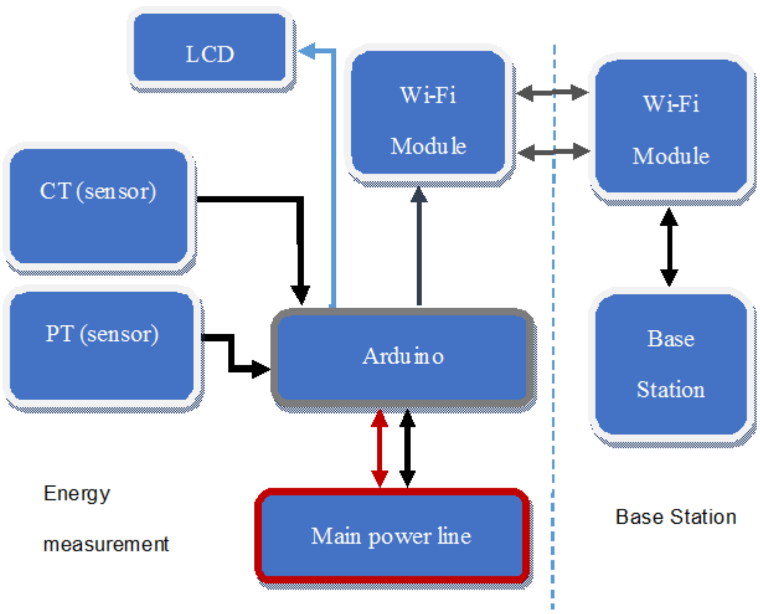

Fig. 1. Overview of the main proposed system.

it can be integrated into the circuit, which takes signal current fed by the C.T., the layout of which is given in Fig. 2. The rest of the reasonably priced components readily available, employed in the proposed system (Fig. 1) are listed in Table 2.

Current Transformer Calculation:
Vout = 0.045V (CT output for 100 Watt Load)
Ip = 0.44A (primary current Clamp meter)
R = 200Ω (calculated Burden Resistor)
For Secondary Current
Is = Vout/R =0.045V/200Ω
Is = 2.2x10^{-4}A

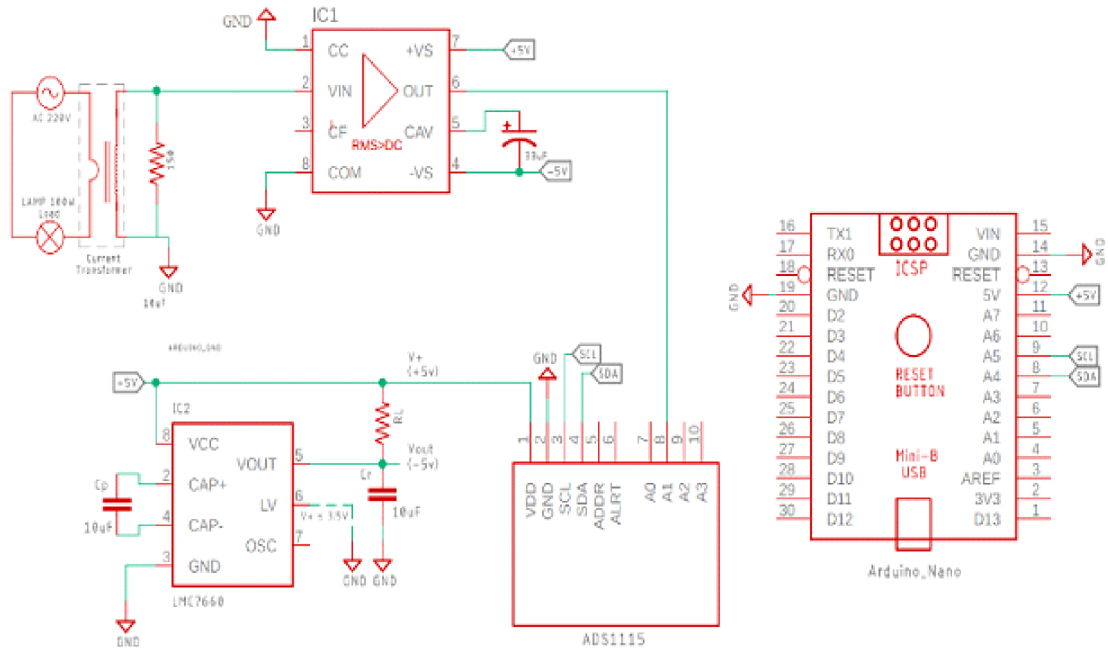

Fig. 2. Schematic for C.T. based current measurement.

Table 2. Components required for current measuring circuit.

No.	Part name	Type	Qty
1	CT	Window	1
2	Arduino	General	1
3	AD736	IC	1
4	ADS1115	16-bit ADC	1
5	LMC7550	I.C.	1
6	Resistors	120 ohm	2
7	Capacitor	$10\mu F$	2
8	Capacitor	$33\mu F$	1
9	Circuit board	Any	1
10	Wires	Gauged	As required

For Secondary Number of Turns:

$$\frac{V_p}{V_s} = \frac{I_s}{I_p} = \frac{N_p}{N_s} \tag{4}$$

Np = (Is x Ns)/Ip = (2.2x10^{-4}A X 2000 turns)/0.44A Np=1 Turn;
Ns = (Ip x Np)/Is = (0.44 X 1)/ 2.2x10^{-4}A
Ns = 2000 Turns.
For Burden Resistor:
R = (Vout $\times$ Ns)/Ip = (0.045 X 2000)/0.44
R=201Ω.

2.2. A.C. voltage measurement

As we use a possible transformer of 220/12 v, we attain 12 v on the section of l.V. Because this voltage is not ideal for Arduino as an input, we require a voltage divider circuit that can provision Arduino the required voltage value as an input. A capacitor is used to improve the step-down voltage. If a voltage supplied is greater than 5v is as an input to the Arduino; it will get corrupted. Therefore, a 5V Zener-diode is attached to maintain Arduino's protection, breaking down if it reaches 5v. This voltage is taken as input via pin 'A0' by Arduino in the shape of analog values between 0 and 1023. Voltage for the formula:

$$n = (230/1023) \times m \quad volts \tag{5}$$

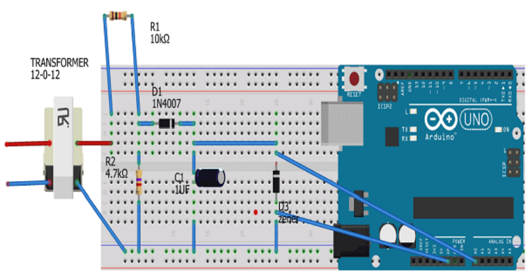

Fig. 3. Voltage measuring circuit.

2.3. Relay board

A two-channel relay interface board is used. In which one relay is used for high priority circuit board tripping, and the second relay is used for low priority circuit board tripping. The corresponding hardware design is developed (Fig. 4) so that each component of Fig. 1 can communicate with each other effectively.

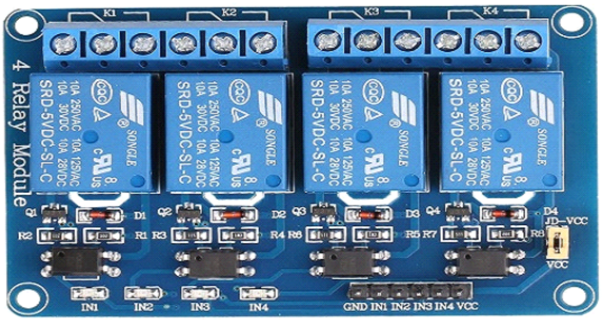

Fig. 4. Two-channel relay board, comprising four relays.

2.4. GUI design

The software side of this system is divided into programmed running on Arduino (C/C++) and GUI running on the base station. In this paper user interface is designed in Visual studio. It is a popular Graphical User Interface that is used in C#. Visual studio is free and open-source software. Some mouse events in GUI are used to shut down and restore.

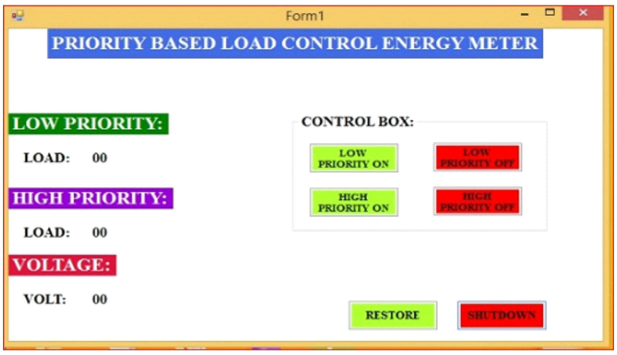

Fig. 5. Complete GUI for energy meter.

A GUI is developed on the unit, which is displays all the actions performed by the system. The user can see all actions performed by the unit's panel, pointing out any errors generated. A GUI sample is shown in Fig. 5.

2.5. Implementation procedure

Fig. 6 displays the whole architecture on which the whole grid is to be laid out. The smart meter consisting of Arduino, as well as both L.P. and H.P. sensors, are to be integrated with the switch panel of the house (or other units). The Arduino must be synced with the panel, so it knows which breakers to trip (H.P.) and which breakers not to trip (L.P.). The L.P. and H.P. sensors further add redundancies in case there is some faulty current leaking into the segregated L.P. systems. The benefit of integrating a code-based system is its ability to quickly detect, isolate, and report the issue to the concerned people, preventing any leading mishap. If the meter detects no problems, all actions can be executed safely.

From any subset of the micro-grid to the base station, the system decides concerned areas to be part of the blackout. Shutdown orders are sent via secured internet to concerned area units. The units, upon receiving the execute call, check which systems are already on that are operating above the assigned threshold. If the threshold current is, for example, 500watts, the unit will sense all the consuming appliances breaker and switch them OFF. After the restore call is sent again to each grid area, the order is executed again. The restored order is also executed in a safe successive manner to ensure the safety and security of people and equipment.

3. Result and discussions

In currently stressed power system layouts, blackouts are carried out to bear the load gaps between power generations frequently, whereas energy meters could be used to switch off the loads directly.

In our case, the load of the high priority circuit board is set to 400 watts while the load of the low priority circuit board is set to 700 watts. When the load shedding time occurs shutdown button will press from the base station, it will trip the low priority circuit board and check the power of the high priority circuit board; if the power is less than 500 Watt, then the high priority circuit board will not shutdown.

If the user increases the load of the high priority circuit board during the load shedding time when the shutdown button is pressed, then both the high priority circuit board and low priority circuit board will trip. When the load shedding time is finished, the reset button will press from the base station; it will work on both the high priority circuit board and low priority circuit board. Also, there are options in the base station to manually on and off the high priority circuit board and low priority circuit board. The resultant layout of the whole procedure is shown in Fig. 7.

3.1. Final energy meter display

An LCD is used to display electronic visuals. We used a 20x4 LCD with an operating voltage of 5V D.C. The data

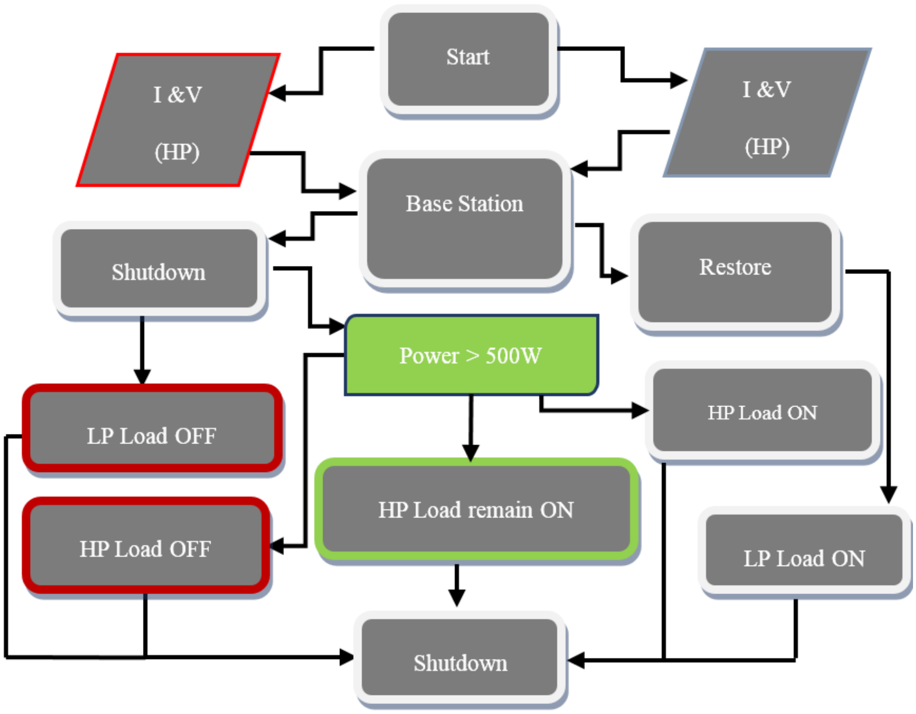

Fig. 6. Architecture Flow Chart.

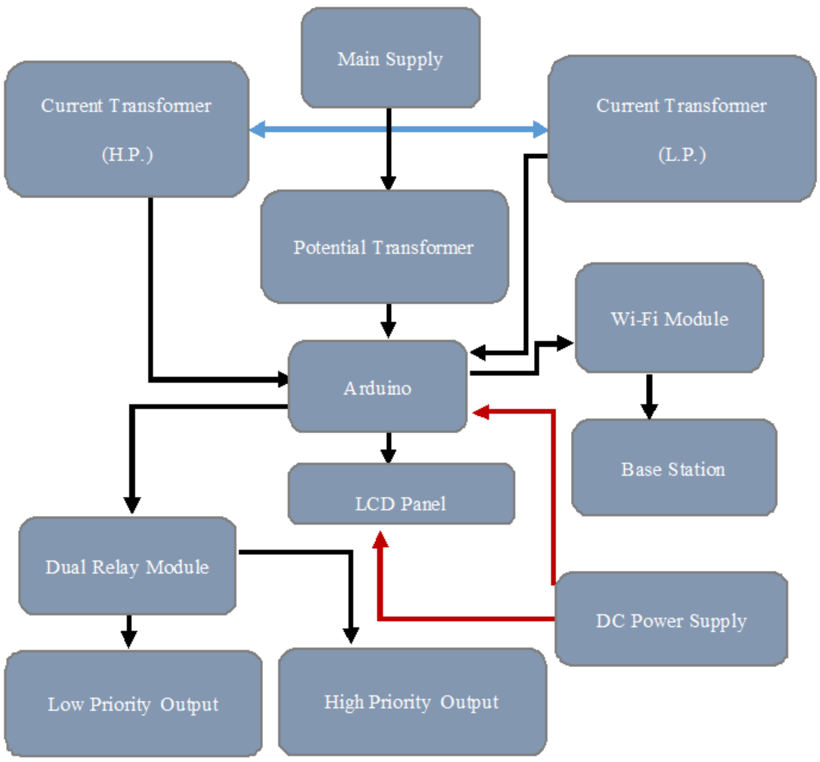

Fig. 7. Resultant Layout.

pins (D4 to D7) of LCD is connected with the Arduino to display each L.P. & H.P. circuit's power reading.

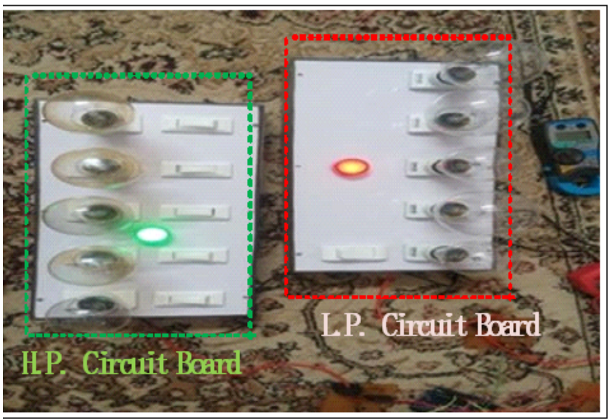

Fig. 8. The low and high priority circuit board.

The H.P. – L.P. circuit is developed, each set comprising four bulbs. In Fig. 8, the left side shows the H.P. series of bulbs, while the right bulb setup shows the L.P. powered bulbs. Both are connected with the meter (Fig. 9) and tested. The results verify that both indeed the turning ON and OFF with assigned coded commands developed and integrated into the Arduino.

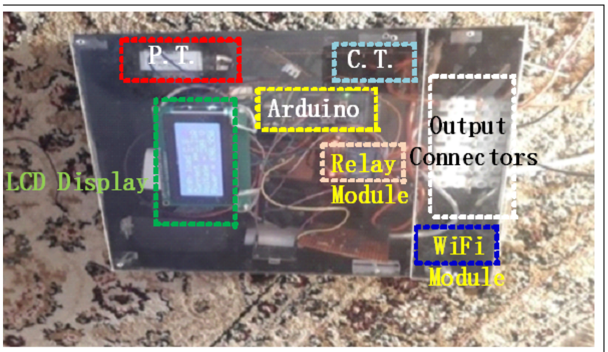

Fig. 9. The smart unit prototype, all working units with LCD.

4. Conclusions

This research strives to launch a framework for energy meters to avoid a complete blackout. The results show that an energy meter is a viable option. The energy meter will help the utility reduce energy loss, load shedding and help the consumers understand their load patterns. It involves a healthy interaction between both user and utility, which will enhance reliability, consistency, and stability in the system. The complete shutdown could be avoided, and a continuous supply of electricity will be ensured to the high priority circuit board by selective load shedding. The graphical user interface provides new techniques to prioritize the load according to the demand, which opens various innovations for end-users to concentrate on the blackout's real problems.

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