A Systematic Approach to Improving Consumers' Comfort through on-Grid Renewable Energy Integration and Battery Storage

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Abstract—This article explores the integration of on-grid renewable energy with battery storage to improve consumers' comfort. Demand response (DR) programs are utilized to balance power supply and demand, offering consumers three response options: reducing consumption, shifting consumption, or utilizing on-site generation. However, these options may temporarily affect comfort. To address this, on-site generation through renewable energy integration has gained attention for its environmental and economic advantages. The study aims to demonstrate an environmentally friendly renewable integration system that resolves electrical power problems, ensures consumer comfort, and provides pollution-free energy. The proposed system primarily relies on solar panels with batteries as backup. Optimization is conducted using the HOMER software, and the system design represents a novel approach for the selected site. Simulation results indicate that the proposed approach significantly enhances consumer satisfaction and lowers energy costs in the absence of DR programs. This research presents a comprehensive analysis of the integration approach, emphasizing its benefits for consumers and the environment. By combining renewable energy integration and battery storage, it contributes to sustainable and comfortable energy solutions for consumers.

1. INTRODUCTION

The rise in energy consumption, combined with population growth and a lack of adequate management strategies, has resulted in a massive increase in energy demand [1,2]. The existing electrical system exacerbates the problem due to its antiquated architecture and redundant and overburdened infrastructure [3].

Because of public awareness of the need to reduce carbon emissions and political pressure, environmental pollution has recently gotten a lot of attention from scientists and environmentalists [4]. Fossil fuels account for about 85% of total global energy use [5]. Excessive use of fossil fuels is linked to a significant increase in CO_2 emissions. The most effective and feasible strategy to promote sustainable development and minimize pollution is to integrate renewable energy resources (RES) into electricity generating [6]. The concept of RES as a replacement for fossil energy sources was born out of the use and optimization of renewable energy sources (RES) [7]. RES systems have recently acquired appeal as a means of increasing energy supply stability by integrating distributed energy resources, such as wind turbines (WTs) and solar panels, with distributed energy storage, such as batteries [8,9].

DSM (Demand Side Management) stands for the modification of consumers' energy consumption patterns to improve the efficiency of electrical energy systems and networks [10–13]. This method alters daily energy consumption patterns to attain a specific load profile [14–16]. The application of DSM in residential load management has been examined by several researchers [17]. Gottwalt et al. ran a simulation to transfer residential loads based on a time of use (TOU) tariff [18]. Ozkan also created a DSM model for residential areas to reduce peak load and energy costs [19]. Bharathi et al. used a genetic algorithm to handle DSM optimization problems for residential load management [20]. In Singapore, Srinivasan et al. created a game theory-based dynamic pricing model for residential and commercial power [21].

Consumers can respond in three ways [22]:

a. Reduce consumption during designated times while maintaining the same habits during other times. This choice entails a brief loss of comfort.
b. Change consumption patterns to avoid the targeted hours and favor other times to maintain consistency in overall consumption.
c. On-site generation.

The supply and demand must be perfectly balanced in real time for the power system to operate reliably. But this balance is not easily achieved because both supply and demand levels can change rapidly and unexpectedly due to many reasons, such as generation unit forced outages, transmission and distribution line outages, and sudden load changes [22,23].

But it is mentioned above that if consumers responded by reducing their consumption or shifting their consumption then these options involve a temporary loss of comfort. If the consumer denied for above both programs, then he/she must choose the on-site generation as a third option.

Energy users are turning to wind and solar energy as a brilliant source of energy as a result of environmental concerns such as global warming and air pollution brought on by the burning of fossil fuels, as well as financial restraints such as high costs. In the recent decade, most energy users have focused their emphasis on wind and solar energy [24,25]. This is due to the benefits of renewable energy, such as reduced greenhouse gas (GHG) emissions and a clean energy source, as well as improved environmental conditions, reduced fossil fuel use, and cheap operating costs [25–27].

Switching to RES is necessary in the current situation since fossil fuels are scarce and the environment is harsh. Common resources include solar and wind energy since they are more modern and durable. Their availability and ease of use make these more popular [28]. When solar and wind energy resources are employed separately, a high generation level must be maintained, resulting in an increase in the capacity of the energy storage battery [29]. Renewable energy generation is primarily designed to meet the electrical power needs of locations where grid supply is a significant [30–32].

Many tribes live in deep forest in poor countries like India and obtaining energy from the grid in these areas is difficult due to long distance from the grid, geological, constitutional, and other constraints. Because of the economic and environmental benefits of renewable energy, renewable energy integration has gotten a lot of attention in recent years [33–36]. The amount of energy that must be purchased from the grid can be reduced with this integrated method.

Global warming, pollution from burning fossil fuels for energy, and their depletion have all contributed to the rapid adoption of renewable energy-based power generation, as described by Bansal and Zobaa [37]. Some research provides insight into how to optimize the hybrid system's net present cost (NPC), fuel cost, operation cost, and cost of energy (COE), which consists of solar panels, WT generators, diesel generators (DGs), and battery storage systems. These variables help a hybrid power system that is

FIGURE 1. Test case location in HOMER.

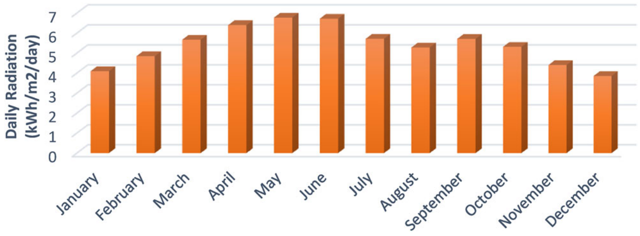

FIGURE 2. Monthly average daily solar radiation.

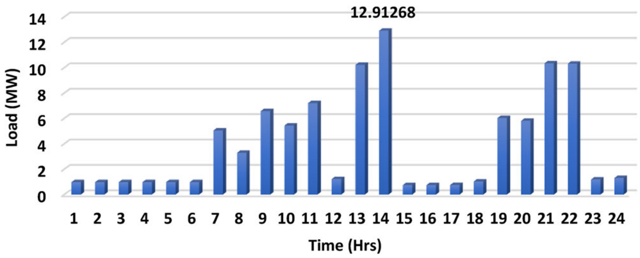

FIGURE 3. Daily load profile for summer.

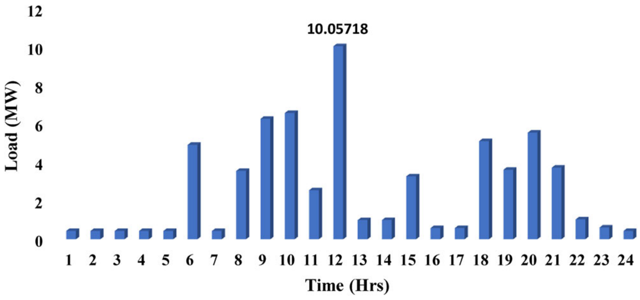

FIGURE 4. Daily load profile for winter.

intended to service a rural community [38–41]. Recent research has focused on using DSM and incorporating renewable energy to achieve a balance between energy generation and consumption. A brief literature survey relevant to renewables advancement is presented given below.

To provide low voltage ride through (LVRT) capability for both symmetrical and asymmetrical grid faults, along with mitigation of DC-link voltage fluctuations, an enhanced finite control set-model predictive control (FCS-MPC) scheme is proposed in [42] for a Permanent Magnet Synchronous Generator (PMSG)-based wind energy conversion system (WECS). With this proposed predictive control approach, optimal switching states for selecting weighting factors (WFs) and reducing the cost function are developed to ensure reliable back-to-back (BTB) converter control and minimize cross-coupling between active power (P) and reactive power (Q) during transient conditions.

The majority of electrical systems, including isolated systems such as water pumping and petroleum extraction, increasingly rely on RES as a critical necessity. Due to fluctuations in electricity generation throughout the day, RES often require an energy storage system (ESS). Given the growing popularity of battery usage, an adaptive control system is necessary to effectively manage the charging and discharging processes of battery systems."

A standalone power system that utilizes photovoltaic, wind, and battery energy to supply the required load, as described in [43,44] introduced a novel concept of adaptive

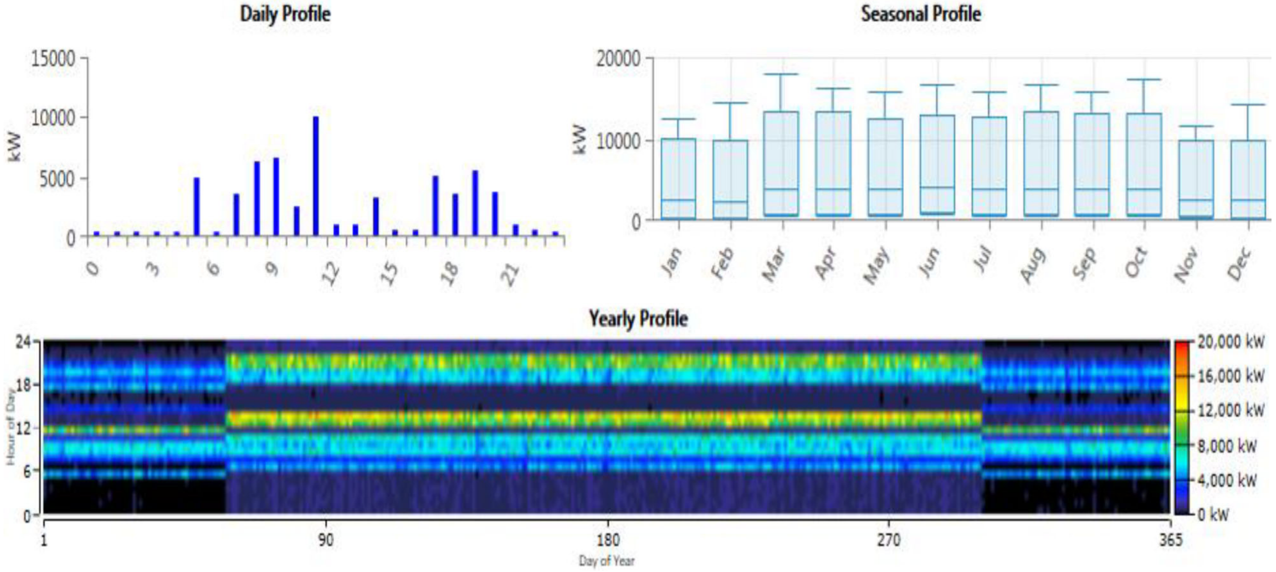

FIGURE 5. Daily average load profile.

Hours	Total summer load in MW	Total winter load in MW
12 midnight–1 am	0.97517	0.43292
1–2 am	0.97517	0.43292
2–3 am	0.97517	0.43292
3–4 am	0.97517	0.43292
4–5 am	0.97517	0.43292
5–6 am	0.97517	4.90892
6–7 am	5.04609	0.43292
7–8 am	3.29117	3.56784
8–9 am	6.57517	6.26792
9–10 am	5.43568	6.57118
10–11 am	7.20568	2.55718
11 am–12 pm	1.22168	10.05718
12–1 pm	10.21868	0.99718
1–2 pm	12.91268	1.00418
2–3 pm	0.74222	3.28272
3–4 pm	0.74222	0.58272
4–5 pm	0.74968	0.58418
5–6 pm	1.02743	5.10418
6–7 pm	6.031938	3.626688
7–8 pm	5.812188	5.545188
8–9 pm	10.338458	3.73422
9–10 pm	10.30872	1.03472
10–11 pm	1.18742	0.61372
11 pm–12 am	1.30742	0.43372

TABLE 1. Details of 24 h electric loads.

	Peak load (MW)			
Types of load area	Time	Summer	Time	Winter
Residential	1–2 pm	12.822	11 am to 12 pm	10.032
Commercial	1–2 pm	0.05146	1–2 pm	0.02446
Institutional	11 am to 1 pm	0.049	2–4 pm	0.022
Community	10 am to 12 pm	0.00922	9 am to 1 pm	0.00472

TABLE 2. Details of summarized peak loads.

MPC for blade pitch control in WECS. Furthermore, the parameters of the proposed controller are selected using the Crow Search Algorithm, an innovative intelligent method. The outcomes of the proposed approach are compared with those of a fuzzy proportional-integral controller. The main objective is to manage and coordinate the energy exchange process among solar energy, the utility network, and battery ESS (BESS) to ensure an adequate electrical supply for SWDP (presumably an abbreviation) while minimizing feed-in tariffs (FiT).

In the presence of system uncertainties, Mohamed et al. [45] investigated the proposed Fuzzy Logic (FL) and HHO-based energy management systems (EMSs). Bipolar direct current (DC) charging stations were recommended by Sadiq etal. [46] as a design guideline. In a microgrid system with a neutral line, a bipolar system can convert a two-wire system into three wires. Additionally, this study suggested a balancing technique based on continuous-control-set-MPC (CCS-MPC), which improves dynamic performance compared to a conventional controller and enables effective regulation of neutral-line voltage while accommodating various output loads.

The main challenges in stabilizing WECS are the uncertainties caused by load variations and wind speed fluctuations. To address this uncertainty, Ali et al. [47] developed a novel robust control approach for WECS blade pitch control with low computational overhead, replacing metaheuristic techniques. An enhanced version of the flow direction algorithm (FDA), referred to as mFDA, was proposed by Elfatah et al. [48] to determine the optimal size for a

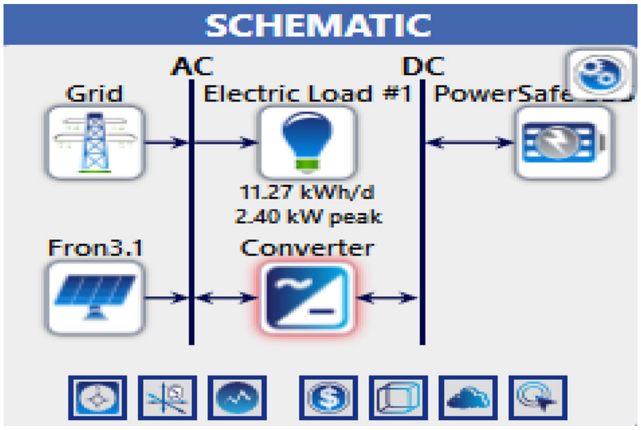

FIGURE 6. Plan layout of a simulated system.

Parameters	Values
Name	Fronius Galvo 3.1-1 with Generic PV
Size (kW)	1
Capital cost (Rs. /-)	35,000
Replacement cost (Rs. /-)	35,000
O and M (Rs. /-)	700
Lifetime (Years)	25
Derating factor (%)	96%

TABLE 3. Costing parameters and specifications of PV panel.

Parameters	Values
Name	EnerSys PowerSafe SBS 90
Number	1
Maximum capacity (Ah)	1.01E + 03
Nominal capacity (kWh)	12.1
Nominal voltage (Volt)	12
Minimum state of charge (%)	10
Lifetime (Years)	10
Max. charge current (Ampere)	900
Capital cost (in Rs.)	13,000
Replacement cost (in Rs.)	13,000
O and M cost (in Rs.)	0

TABLE 4. Costing parameters and specifications of battery.

Description	Specifications
Size (kW)	1
Capital cost (in Rs.)	7000
Replacement cost (in Rs.)	7000
O and M cost (in Rs.)	0
Lifetime (Years)	15
Efficiency (%)	95

TABLE 5. Costing parameters and specifications of converter.

Component	Name	Size and unit
PV	Fronius Galvo 3.1-1 with Generic PV	3.30 kW
PV dedicated converter	Fron3.1 inverter	2.48 kW

TABLE 6. System architecture for PV and grid.

Production	kWh/year	Percentage
Fronius Galvo 3.1-1 with Generic PV	6171	75.7
Grid purchases	1978	24.3
Total	8149	100
Consumption	kWh/year	Percentage
AC primary load	4113	50.5
DC primary load	0	0
Deferrable load	0	0
Grid sales	4036	49.5
Total	8149	100

TABLE 7. Annual electric energy production and consumption.

Quantity	kWh/year	Percentage
Excess Electricity	391	4.79
Unmet Electric Load	0	0
Capacity Shortage	0	0
Quantity	Value	Units
Renewable Fraction	75.7	%
Max. Renew. Penetration	100	%

TABLE 8. Details about the excess, unmet electricity, and renewable fraction.

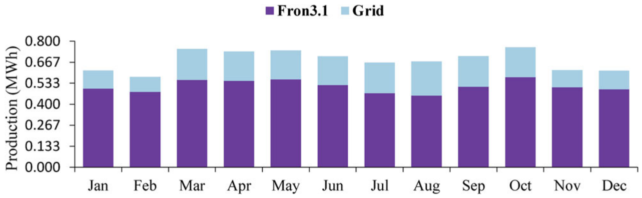

FIGURE 7. Monthly average electric production.

standalone system comprising solar panels, a DG, and a battery bank to meet load demand in Luxor, Egypt. The primary objectives of this research include reducing the size of microgrid components, the likelihood of power supply outages, the NPC of the proposed hybrid power system, and the system's COE.

The implications of ESS and renewable energy fluctuations on microgrid climate change mitigation were studied by Michael et al. [49]. This investigation employed an enhanced

Month	Energy purchased (kWh)	Energy sold (kWh)	Net energy purchased (kWh)	Peak demand (kW)
January	114	357	−243	1.52
February	94.4	345	−250	0.875
March	197	350	−152	1.71
April	185	351	−165	1.88
May	183	357	−173	1.78
June	183	323	−140	1.92
July	194	273	−79.6	1.84
August	216	264	−48.1	1.82
September	195	322	−127	1.79
October	189	369	−180	1.76
November	109	372	−263	1.18
December	118	355	−237	1.06
Annual	1978	4036	−2058	1.92

TABLE 9. Grid analysis: annual energy purchased and sold.

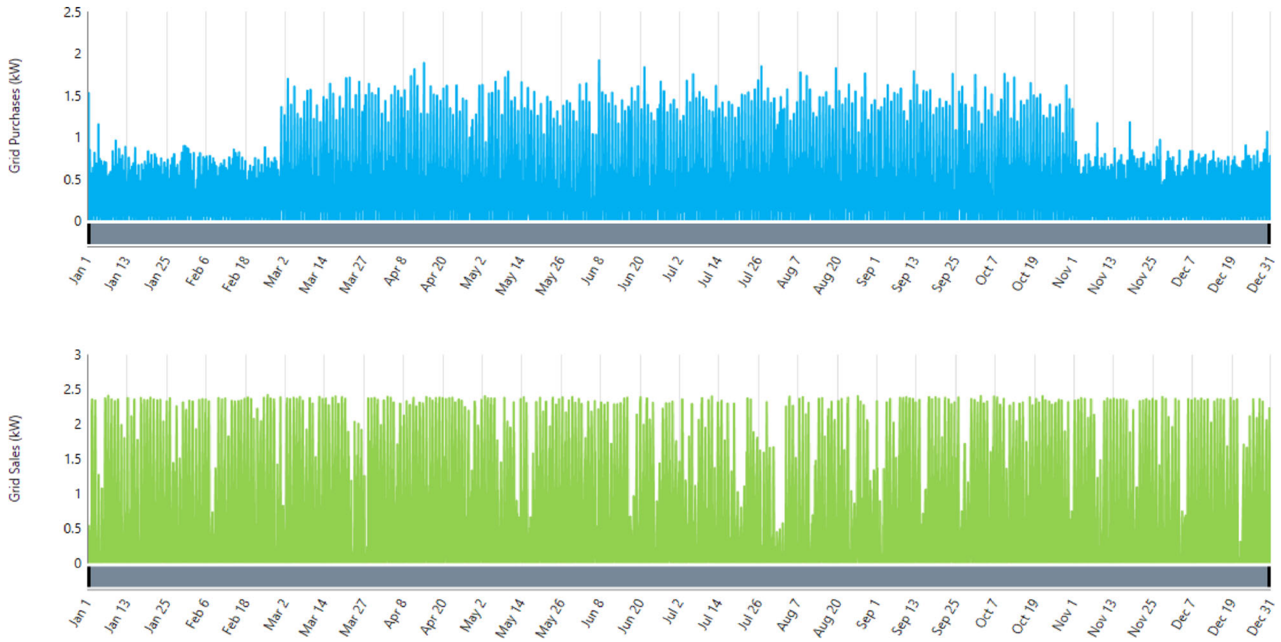

FIGURE 8. Grid purchase and grid sales.

Net present cost (in INR)

Name	Capital	Operating	Replacement	Salvage	Resource	Total
Fronius Galvo 3.1-1 with Generic PV	103,860	26,853	0.00	0.00	0.00	130,713
Grid	0.00	−66,512	0.00	0.00	0.00	−66,512
System	103,860	−39,659	0.00	0.00	0.00	64,201
Annualized costs (in INR)						
Fronius Galvo 3.1-1 with Generic PV	8034	2077	0.00	0.00	0.00	10,111
Grid	0.00	−5145	0.00	0.00	0.00	−5145
System	8034	−3068	0.00	0.00	0.00	4966

TABLE 10. Cost summary for PV and grid.

Component	Name	Size and unit
PV	Fronius Galvo 3.1-1 with Generic PV	3.24 kW
PV dedicated converter	Fron3.1 inverter	2.48 kW
Storage	EnerSys PowerSafe SBS 900	1 Strings
System converter	System converter	0.00402 kW

TABLE 11. System architecture for PV, battery, and grid.

Production	kWh/year	Percentage
Fronius Galvo 3.1-1 with Generic PV	6101	75.5
Grid purchases	1984	24.5
Total	8085	100
Consumption	kWh/year	Percentage
AC primary load	4113	50.8
DC primary load	0	0
Deferrable load	0	0
Grid sales	3977	49.2
Total	8090	100

TABLE 12. Annual electric energy production and consumption.

Quantity	kWh/year	Percentage
Excess electricity	349	4.32
Unmet electric load	0	0
Capacity shortage	0	0
Quantity	Value	Units
Renewable fraction	75.5	%
Max. renew. penetration	100	%

TABLE 13. Details about the excess, unmet electricity, and renewable fraction.

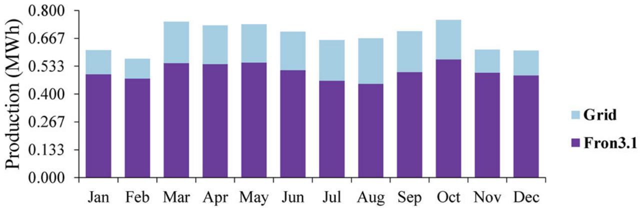

FIGURE 9. Monthly average electric production.

EMS and optimal economic dispatch using mixed-integer linear programming (MILP) computational models. long short-term memory (LSTM) was employed to predict photovoltaic and wind power generation, energy prices, load requirements, and battery degradation. The sizing of the hybrid microgrid system was addressed using the Six Sigma methodology proposed by Kharrich et al. [50] with limited resources.

A hybrid PV/wind/diesel/battery system was designed using three multi-objective optimization methods—Multi-Objective Particle Swarm Optimization (MOPSO), Pareto Envelope-Based Selection Algorithm II (PESA II), and Strength Pareto Evolutionary Algorithm 2 (SPEA2). Three objective functions, NPC, emission penalty cost, and amount of CO_2 emitted, were considered, subject to constraints such as system reliability, availability, and renewable fraction. The performance of grid-connected hybrid systems is primarily determined by their cost-effectiveness, reliability, and capacity to reduce GHG emissions.

According to Barakat et al. [51], a multi-objective optimization of a grid-connected hybrid PV/WT system was developed to provide sufficient energy to a rural community in Ismailia Governorate, Egypt. The optimization aimed to minimize two objective functions, levelized COE (LCOE) and COE, while maximizing the renewable energy fraction (REF) as the third objective function, under various weather conditions. Three scenarios were proposed to assess the connection between the grid and the hybrid system in terms of the grid's capacity to buy or sell energy from/to the hybrid system, categorized based on three perspectives: minimizing COE, maximizing REF, and minimizing GHG emissions, using results obtained from MOPSO. Following are some noteworthy contributions of this work:

a. Selected three load areas namely, 33 kV Jobner (Rajasthan, India) with 6590 Consumers, 33 kV Asalpur (Rajasthan, India) with 10,000 Consumers and 33 kV Deodi (Rajasthan, India) with 1100 Consumers.
b. For further study, selected 33 kV Jobner with 6590 Consumers. Jobner (26.97°N 75.38°E) is a tehsil headquarter and a one of oldest municipality (since 1948) in Jaipur district in the Indian state of Rajasthan. By using three stage survey, collected the 1-year electrical load for given site for the category of load areas as residential, commercial, institutional, and community.
c. To design a hybrid system, collected the details of peak loads for summer and winter seasons and details of incoming and outgoing feeders for selected area.
d. By using HOMER software, proposed four system combinations as (PV + Grid), (PV + Battery + Grid), Grid only, and (Battery + Grid).
e. Finally analyzed these hybrid systems in terms of Cost summary (Annualized cost, NPC, and COE), Electrical summary (Grid purchased and Grid sales), Storage (Nominal Capacity, Lifetime Throughput and Expected Life), and Grid analysis (Energy purchased, Energy

Month	Energy purchased (kWh)	Energy sold (kWh)	Net energy purchased (kWh)	Peak demand (kW)
January	115	353	−238	1.53
February	94.9	341	−246	0.875
March	198	346	−148	1.71
April	186	346	−161	1.88
May	184	351	−167	1.78
June	184	317	−133	1.92
July	195	268	−73.0	1.84
August	217	259	−42.0	1.82
September	195	317	−122	1.79
October	189	363	−174	1.76
November	109	367	−258	1.18
December	119	350	−231	1.06
Annual	**1984**	**3977**	**−1993**	**1.92**

TABLE 14. Grid analysis: annual energy purchased and sold.

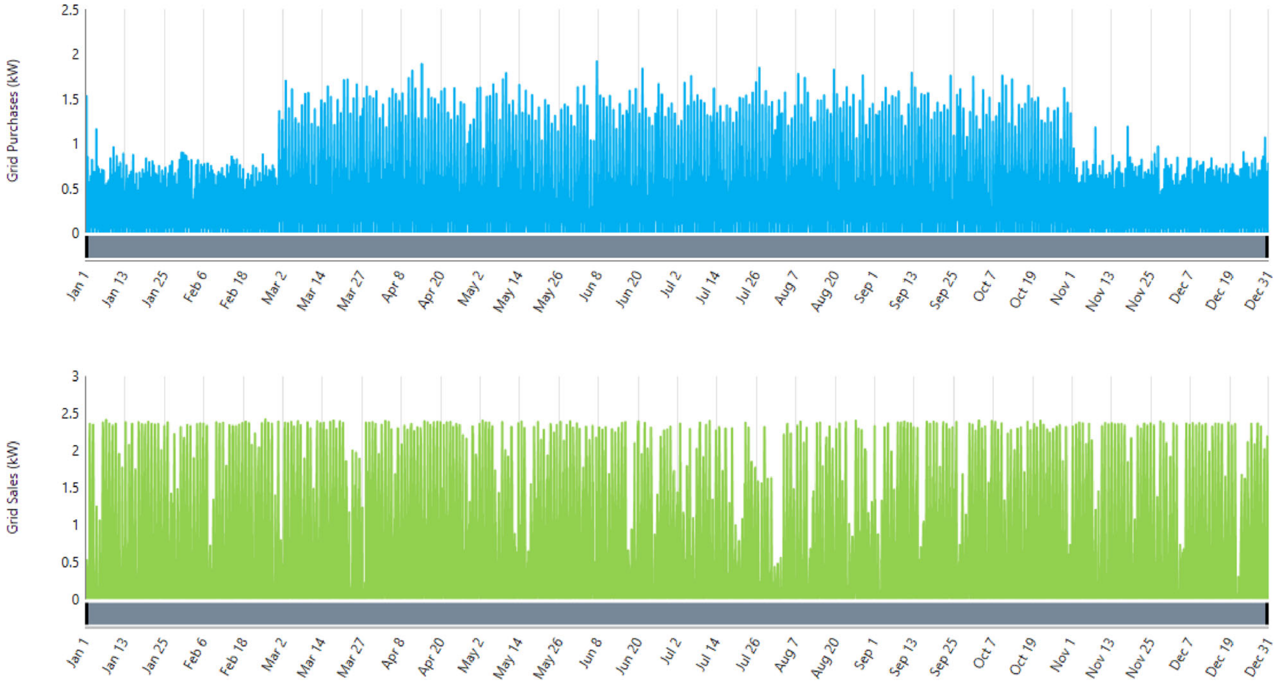

FIGURE 10. Grid purchase and grid sales.

sales and Peak demand). Find out the best optimal combination after comparing all combinations.

In this study, various input parameters were utilized, gathered through pilot and main surveys. Real-time data, including hourly load consumption on a daily basis, average daily load consumption, and peak load demand from different types of consumers (residential, commercial, institutional, and community), was obtained through surveys. Additionally, we contacted officials from the Electrical Utility and Distributor, Rajasthan State Census, and local committee in the headquarters for information. Solar radiation data was sourced from the websites of NREL and MNRE. Data related to the grid substation were obtained by contacting relevant officials. Ratings, sizes of solar panels and batteries, and various input cost parameters were collected from government and private authorized offices and individuals. The relevant system data are presented in Appendix A.

The remaining portions of the paper have been arranged in the given way: In Section 2 gives the problem statement and possible solutions: site selection parameters have discussed in Section 3, information about the designing of system model using HOMER is given in Section 4, simulations results have

Name	Capital	Operating	Replacement	Salvage	Resource	Total
Net present cost (in INR)						
EnerSys PowerSafe SBS 900	13,000	0.00	11,485	−1557	0.00	22,928
Fronius Galvo 3.1-1 with Generic PV	102,095	26,397	0.00	0.00	0.00	128,492
Grid	0.00	−64,407	0.00	0.00	0.00	−64,407
System converter	28.12	0.00	11.93	−2.25	0.00	37.80
System	115,123	−38,010	11,497	−1559	0.00	87,051
Annualized costs (in INR)						
EnerSys PowerSafe SBS 900	1006	0.00	888.39	−120.45	0.00	1,774
Fronius Galvo 3.1-1 with Generic PV	7898	2042	0.00	0.00	0.00	9939
Grid	0.00	−4982	0.00	0.00	0.00	−4982
System converter	2.18	0.00	0.923	−0.174	0.00	2.92
System	8905	−2940	889.31	−120.62	0.00	6734

TABLE 15. Cost summary for PV, battery, and grid.

Production	kWh/year	Percentage
Grid Purchases	4113	100
Total	4113	100
Consumption	kWh/year	Percentage
AC Primary Load	4113	100
DC Primary Load	0	0
Deferrable Load	0	0
Total	4113	100

TABLE 16. Annual electric energy production and consumption.

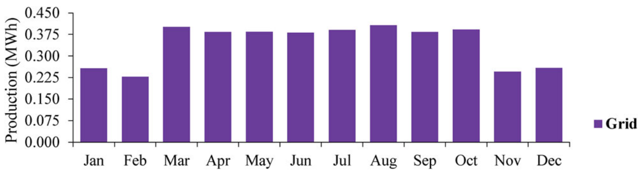

FIGURE 11. Monthly average electric production.

been reported in Section 5. At last, the important findings of the research work given in form of conclusion.

2. PROBLEM STATEMENT AND POSSIBLE SOLUTIONS

The difficulty of generating garbage as a by-product is related with traditional techniques of electricity generation. One of the main reasons for the difficulty in transferring electricity in these places is the lack of grid link with rural locations. There are other restrictions on renewable energy as well, such as average weather, equipment, and cost. The amount of energy utilized decreases because of these limitations, such as wind that blows less regularly and solar energy that is not available on overcast days, which are made worse by climate change. A potential answer to these problems is the installation of a solar photovoltaic system at a remote location. The difficulties of grid transmission and distribution can be overcome by using an off-grid solar PV system in remote locations due to the challenging geographical and climatic conditions.

In this study, we included battery storage as part of our simulation-based analysis of a solar photovoltaic system. The outcomes of the simulation show that the proposed technology can be applied to meet the electrical demands.

3. SITE SELECTION

The size of solar photovoltaic system structures has grown significantly, lowering the cost of installation. Before the system is created, the load demand and available exposure to the sun's rays at the designated location should be assessed. Data on solar radiation for Jobner, Rajasthan, India (26°58.2'N, 75°22.7'E) were obtained for the current

Month	Energy purchased (kWh)	Energy sold (kWh)	Net energy purchased (kWh)	Peak demand (kW)
January	257	0	257	1.66
February	228	0	228	1.92
March	401	0	401	2.40
April	384	0	384	2.15
May	384	0	384	2.08
June	381	0	381	2.20
July	391	0	391	2.10
August	407	0	407	2.22
September	384	0	384	2.09
October	392	0	392	2.30
November	245	0	245	1.53
December	258	0	258	1.90
Annual	**4113**	**0**	**4113**	**2.40**

TABLE 17. Grid analysis: annual energy purchased and sold.

Net present cost (in INR)						
Name	Capital	Operating	Replacement	Salvage	Resource	Total
Grid	0.00	422,705	0.00	0.00	0.00	422,705
System	0.00	422,705	0.00	0.00	0.00	422,705
Annualized costs (in INR)						
Grid	0.00	32,698	0.00	0.00	0.00	32,698
System	0.00	32,698	0.00	0.00	0.00	32,698

TABLE 18. Cost summary for grid.

Component	Name	Size and unit
Storage	EnerSys PowerSafe SBS 900	1 Strings
System converter	System converter	0.0833 kW

TABLE 19. System architecture for battery and grid.

Production	kWh/Year	Percentage
Grid purchases	4106	100
Total	**4106**	**100**
Consumption	kWh/year	Percentage
AC primary load	4113	99.9
DC primary load	0	0
Deferrable load	0	0
Grid sales	2.80	0.0681
Total	**4116**	**100**

TABLE 20. Annual electric energy production and consumption.

EnerSys PowerSafe SBS 900 Statistics		
Quantity	Value	Units
Autonomy	23.2	hrs
Storage wear cost	1.32	INR/kWh
Nominal capacity	12.1	kWh
Usable nominal capacity	10.9	kWh
Lifetime throughput	109	kWh
Expected life	10.0	Years

TABLE 21. Details about the storage: EnerSys PowerSafe SBS 900.

study project from NREL. Figure 1 shows the location search in HOMER.

Figure 2 shows the monthly average of daily sun radiation. Figures 3 and 4 show the daily average load profiles for the two seasons, respectively. Figure 5 shows the daily average load profile for the entire load. With an average energy consumption of 11.27 kWh/d, this data were studied to operate solar photovoltaic systems and control load requirements at specific locations. The load profile has been considered when constructing the solar photovoltaic system. The first survey is done for estimating the load demand, consumer types, and availability of sources. We marked the three load areas during this survey namely, 33 kV Jobner with 6590 Consumers, 33 kV Asalpur with 10,000 Consumers and 33 kV Deodi with 1100 Consumers. Jobner, Rajasthan, India has been examined for this study. Jobner is a tehsil headquarter and a one of oldest municipality (since 1948) in Jaipur district in the Indian state of Rajasthan. Then there are number of main surveys are done for detailed information. During the surveys, the number of consumers in 33 kV Jobner given as:

- Residential Consumers – 6000
- Commercial Consumers (Floor mill – 10, Offices – 50, and Shops – 500) – 560
- Institutional Consumers (Schools) – 20
- Community Consumers (Hospitals) – 10

Details of 24 h actual load for summer and winter seasons is given in Table 1. Area wise detailed load given in Appendix A. Details of peak load with time and seasons, according to load area is given in Table 2. By using HOMER, the annual average energy use is calculated as, 11.27 kWh/d, with a peak load of 2.40 kW.

4. DESIGNING OF SYSTEM MODEL IN HOMER

HOMER is a hybrid power system design and optimization platform with a wide range of input and output data and sensitivity variable functions that makes it easier to analyze the generating power systems for stand-alone applications [52]. Before simulating the system in HOMER, we must fix a number of variables and limitations, including the power transmission mechanism, the load profile over a year, the energy resources taken into consideration, the costing of the components to be used, and the technical requirements of the components.

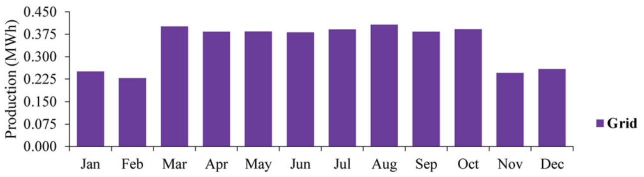

FIGURE 12. Monthly average electric production.

The modeling program HOMER is used to simulate an output design for the most energy-efficient power system for a specific site using all the data that has been gathered from surveys and other sources. The advanced streamlining model simulation tool HOMER repeatedly conducts many hourly simulations to determine the optimal supply and demand coordination. The cost of the life cycle is also considered in this model when grading the most suitable and optimized systems [52].

In HOMER, a simulated model was created during the current research project. PV, battery, converter, and grid make up the designed model. Figure 6 depicts the plan layout of a simulated system. To verify the structural execution of the system model under various situations and to identify the best choice, the system is assessed using actual solar irradiation for the selected location. For the best HOMER results in this case, the size of the converter and the battery storage capacity are both taken into consideration as decision variables. Tables 3–5 give the costing parameters and specifications of PV panel, battery, and converter, respectively.

The following parameters are constrained in some section during the analysis and design:

- The maximum annual capacity shortage is taken as 0% and 5% for analysis.
- The maximum renewable fraction is taken from 0% to 100%.
- The minimum state of charge of battery is fixed at 10% by selecting this one in HOMER.
- Operational and maintenance cost is taken 2% of capital cost of particular apparatus.

Month	Energy purchased (kWh)	Energy sold (kWh)	Net energy purchased (kWh)	Peak demand (kW)
January	250	2.80	247	1.66
February	228	0	228	1.92
March	401	0	401	2.40
April	384	0	384	2.15
May	384	0	384	2.08
June	381	0	381	2.20
July	391	0	391	2.10
August	407	0	407	2.22
September	384	0	384	2.09
October	392	0	392	2.30
November	245	0	245	1.53
December	258	0	258	1.90
Annual	4106	2.80	4103	2.40

TABLE 22. Grid analysis: annual energy purchased and sold.

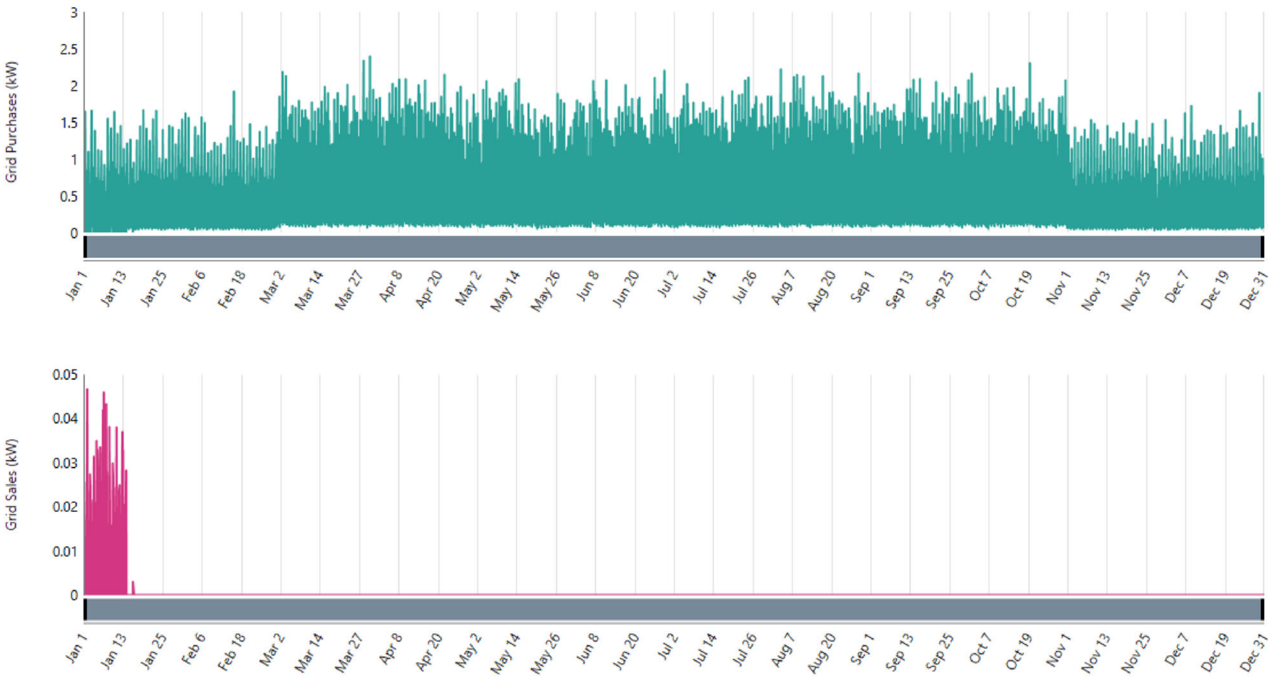

FIGURE 13. Grid purchase and grid sales.

Name	Capital	Operating	Replacement	Salvage	Resource	Total
Net present cost (in INR)						
EnerSys PowerSafe SBS 900	13,000	0.00	11,485	−1557	0.00	22,928
Grid	0.00	421,656	0.00	0.00	0.00	421,656
System converter	583.33	0.00	247.49	−46.58	0.00	784.25
System	13,583	421,656	11,732	−1604	0.00	445,368
Annualized costs (in INR)						
EnerSys PowerSafe SBS 900	1006	0.00	888.39	−120.45	0.00	1774
Grid	0.00	32,617	0.00	0.00	0.00	32,617
System converter	45.12	0.00	19.14	−3.60	0.00	60.66
System	1051	32,617	907.54	−124.05	0.00	34,451

TABLE 23. Cost summary for battery and grid.

- Type of deferrable load is zero or not assumed of this type of load in the study.

5. SIMULATION RESULTS

The simulations were carried out using HOMER Pro 3.14.5, an optimization programme, and a machine with a Pentium IV processor running at 2.69 GHz and 1.84 GB of RAM. To demonstrate the effectiveness of the designed system, four system configurations have been used.

- **SYSTEM 1:** PV + Grid
- **SYSTEM 2:** PV + Battery + Grid
- **SYSTEM 3:** Grid only
- **SYSTEM 4:** Battery + Grid

5.1. SYSTEM 1: PV + Grid

System architecture for PV and Grid given in Table 6. We proposed adding 3.3 kW of PV. This would reduce operating costs to −3068 INR/year. Total investment has a

Configuration	Cost (INR)		System Renewable fraction (%)	Fron 3.1 PV + Battery		Grid	
	NPC	COE		Capital cost (INR)	Production (kWh/year)	Energy purchased (kWh)	Energy old (kWh)
PV + Grid	64,201	0.609	75.7	103,860	6171	1978	4036
Grid only	422,705	7.95	NA	NA	NA	4113	0
PV + Battery + Grid	87,051	0.832	75.5	102,095 + 13,000	6101	1984	3977
Battery + Grid	445,368	8.37	NA	13,000	NA	4106	2.80

TABLE 24. Overall system summary.

payback of 2.90 years and an internal rate of return (IRR) of 34.4%.

Tables 7 and 8 contain detailed information on annual electric energy production and consumption, and details about the excess, unmet electricity, and renewable fraction, respectively. Total renewable fraction is given by 75.7% and remaining fulfilled by the grid supply.

The unmet monthly average load is almost 0 kWh/year, which demonstrates the feasibility for supplying power within strict constraints. Monthly average electrical production is depicted in Figure 7. According to Table 9, the yearly energy consumption is 1978 kWh and the annual energy output is 4036 kWh. The graphic data of grid purchases and grid sales are displayed in Figure 8. The cost summary for PV and grid is displayed in Table 10.

5.2 SYSTEM 2: PV + Battery + Grid

Table 11 provides the system architecture for PV, batteries, and the grid. 12 kWh of battery capacity and 3.2 kW of PV were our suggested additions. This would reduce operating costs to −2172 INR/year. Total investment has a payback of 3.23 years and an IRR of 30.7%.Tables 12 and 13 contain detailed information on annual electric energy production and consumption, and details about the excess, unmet electricity, and renewable fraction, respectively, for this hybrid combination. Total renewable fraction is given by 75.7% and remaining fulfilled by the grid supply.Figure 9 displays the monthly average electrical production, and the unmet monthly average load is virtually 0 kWh/year, further demonstrating the capability for supplying electricity within strict constraints. According to Table 14, the yearly energy consumption is 1984 kWh and the annual energy output is 3977 kWh. Figure 10 shows the graphical data of grid purchase and grid sales. Table 15 shows the cost summary for PV, battery, and grid.

5.3 SYSTEM 3: Grid Only

The X9CH + 6J Machhar Khani, Rajasthan, India's electric needs are satisfied. Currently, the annual operating cost for energy is 32,698 INR. Table 16 contains detailed information on annual electric energy production and consumption, and the excess, unmet electricity, and renewable fraction, are almost zero for this configuration.Figure 11 displays the monthly average electricity production. According to Table 17, the annual energy used is 4113 kWh, while the annual energy sold to the grid is 0 kWh. Table 18 shows the cost summary for grid.

5.4 SYSTEM 4: Battery + Grid

System architecture for battery and grid is given in Table 19. We proposed adding 12 kWh of battery capacity. This would reduce operating costs to 33,400 INR/year.Tables 20 and 21 contain detailed information on annual electric energy production and consumption, and details about the Storage (EnerSys PowerSafe SBS 900) Statistics (cost, capacity, life, and throughput).

Figure 12 displays the monthly average electrical generation, and the unmet monthly average load is very close to 0 kWh/year. According to Table 22, the annual energy used from the grid is 4106 kWh, while the annual energy sold to the grid is 2.80 kWh. Figure 13 shows the graphical data of grid purchase and grid sales. Table 23 shows the cost summary for battery and grid.

An unbiased hybrid electrical power production system with attributes like financial viability, dependability, and environmental friendliness was developed because of the study's research-focused approach. The calculated data demonstrate the economic viability of the proposed solution. The established HES system is more affordable for these sites than a grid-connected supply system because connecting remote areas to the grid is expensive and challenging due to numerous natural impediments.

5.5. Overall Summary

The overall system summary is presented in Table 24 for comparison. In this table, we compare various systems developed during our project based on several criteria, including establishment cost, renewable power contribution, solar and battery costs, and energy exchange with the grid. The NPC for the Grid system, PV + Grid, PV + Grid with Battery, and Grid with Battery are ₹64,201, ₹4,22,705, ₹87,051, and ₹4,45,368, respectively. It can be illustrated from this data that the power system integrating the grid with solar PV and battery is more reliable and cost-effective to operate compared to other grid integration systems. However, due to the operational cost of the battery, it is slightly higher than the Solar PV + Grid systems. Nevertheless, the battery provides backup power, increasing reliability and consumer comfort.

6. CONCLUSIONS AND RECOMMENDATIONS

This study has explored the integration of on-grid renewable energy with battery storage to enhance consumers' comfort. The study focused on demand side management, where consumers have three response options: reducing consumption, shifting consumption, or utilizing on-site generation. If consumers are unable or unwilling to reduce or shift consumption, on-site generation becomes crucial for maintaining user comfort. Based on the outcomes of this study and a review of the literature, it is evident that Rajasthan, India, with its high solar radiation availability, is particularly suitable for implementing this technology. The following are the key conclusions of this research:

a. The designed on-grid renewable integration system, utilizing PV panels and batteries, provides power during demand response (DR) events (on-site generation) with a lower COE. This arrangement significantly improves consumers' comfort.
b. Solar radiation can be effectively harnessed to generate power for remote and unserved areas, contributing to cleaner electricity production.
c. The system serves as a tool to promote environmental responsibility among the public, encouraging the adoption of sustainable energy practices.
d. The described electrification method presents a promising solution for rural areas in Rajasthan, introducing electricity to previously underserved locations and improving quality of life.
e. The proposed technology offers notable advantages, including high PV utilization rates, reliable power distribution, and reduced component capacity requirements based on peak loads. Moreover, it is environmentally friendly, with no harmful gas emissions.
f. The main characteristics of the hybrid system that is being presented are the high percentage of PV generation that is used, the dependability of power delivery, and the reduction in component capacity as a function of peak loads. The system that is being shown emits no hazardous gases and is environmentally beneficial.

In conclusion, this research highlights the potential of on-grid renewable energy integration with battery storage to improve consumers' comfort while providing a sustainable and environmentally friendly energy solution for Rajasthan, India. The study has utilized average solar radiation; however, this approach may result in underutilization of solar radiation during certain hours, particularly when the load demand is low. Nevertheless, this limitation can be mitigated in another application of this technique by incorporating additional methods, such as solar thermal applications. Enhancing the performance of the proposed system relies heavily on selecting the appropriate input parameters for all design sections. These parameters encompass determining the solar radiation for each hour to align with load demand requirements and making judicious choices regarding the size and rating of solar panels and associated equipment, including converters and batteries.

The future scope entails crucial recommendations about local biomass resource assessment, consideration of government subsidies' impact on electricity costs, and exploring biomass waste repurposing for enhanced sustainability in the integrated Solar-Biomass system.

AUTHORS' CONTRIBUTIONS

A.K Sharma, D K Doda: Conceptualization, Formal analysis, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft. B P Soni: Formal analysis, Investigation, Methodology, Validation, Visualization, Investigation, Methodology, Writing – original draft, review & editing. R. C. Bansal: Conceptualization, Supervision, Writing – review & editing. D K Palwalia: Conceptualization, Formal analysis, Supervision, Writing – review & editing.

ETHICAL APPROVAL

This declaration is "not applicable".

DISCLOSURE STATEMENT

The authors declare that they have no known competing interests.

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AVAILABILITY OF DATA AND MATERIALS

The data used to support the findings of this study are available from the authors upon request.

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APPENDICES

APPENDIX A – LOAD DATA

Hours	Refrigerator (1) 120 W	TV (1) 70 W	Washing Machine (1) 1500 W	Iron Box (1) 1000 W	Lighting (3) 10 W	Ceiling Fan (3) 45 W	AC (1) 1500 W	Water Heater (Geyser) (1) 1000 W	Water Pump (1) 746 W	Microwave Oven (1) 900 W	Mixer Grinders (1) 500 W	Total Load (W)	Jobner city Load (6000 Consumers) MW
12 midnight–1 am	72	NIL	NIL	NIL	NIL	90	NIL	NIL	NIL	NIL	NIL	162	0.972
1–2 am	72	NIL	NIL	NIL	NIL	90	NIL	NIL	NIL	NIL	NIL	162	0.972
2–3 am	72	NIL	NIL	NIL	NIL	90	NIL	NIL	NIL	NIL	NIL	162	0.972
3–4 am	72	NIL	NIL	NIL	NIL	90	NIL	NIL	NIL	NIL	NIL	162	0.972
4–5 am	72	NIL	NIL	NIL	NIL	90	NIL	NIL	NIL	NIL	NIL	162	0.972
5–6 am	72	NIL	NIL	NIL	NIL	90	NIL	NIL	NIL	NIL	NIL	162	0.972
6–7 am	72	NIL	NIL	NIL	20	NIL	NIL	NIL	746	NIL	NIL	838	5.028
7–8 am	72	NIL	NIL	NIL	20	NIL	NIL	NIL	NIL	450	NIL	542	3.252
8–9 am	72	NIL	750	NIL	10	NIL	NIL	NIL	NIL	NIL	250	1082	6.492
9–10 am	72	70	750	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	892	5.352
10–11 am	72	70	NIL	1000	NIL	45	NIL	NIL	NIL	NIL	NIL	1187	7.122
11am–12 pm	72	70	NIL	NIL	NIL	45	NIL	NIL	NIL	NIL	NIL	187	1.122
12–1 pm	72	70	NIL	NIL	NIL	45	1500	NIL	NIL	NIL	NIL	1687	10.122
1–2 pm	72	70	NIL	NIL	NIL	45	1500	NIL	NIL	450	NIL	2137	12.822
2–3 pm	72	NIL	NIL	NIL	NIL	45	NIL	NIL	NIL	NIL	NIL	117	0.702
3–4 pm	72	NIL	NIL	NIL	NIL	45	NIL	NIL	NIL	NIL	NIL	117	0.702
4–5 pm	72	NIL	NIL	NIL	NIL	45	NIL	NIL	NIL	NIL	NIL	117	0.702
5–6 pm	72	NIL	NIL	NIL	NIL	90	NIL	NIL	NIL	NIL	NIL	162	0.972
6–7 pm	72	70	NIL	NIL	20	90	0	0	746	0	0	998	5.988
7–8 pm	72	70	NIL	NIL	30	90	0	NIL	NIL	450	250	962	5.772
8–9 pm	72	70	NIL	NIL	30	45	1500	NIL	NIL	NIL	NIL	1717	10.302
9–10 pm	72	70	NIL	NIL	30	45	1500	NIL	NIL	NIL	NIL	1717	10.302
10–11 pm	72	70	NIL	NIL	10	45	NIL	NIL	NIL	NIL	NIL	197	1.182
11 pm–12 am	72	NIL	NIL	NIL	10	135	NIL	NIL	NIL	NIL	NIL	217	1.302

TABLE A1. Summer-residential.

Hours	Refrigerator (1) 120 W	TV (1) 70 W	Washing Machine (1) 1500 W	Iron Box (1) 1000 W	Lighting (3) 10 W	Ceiling Fan (3) 45 W	AC (1) 1500 W	Water Heater (Geyser) (1) 1000 W	Water Pump (1) 746 W	Microwave Oven (1) 900 W	Mixer Grinders (1) 500 W	Total Load (W)	Jobner city Load (6000 Consumers) MW
12 midnight–1 am	**72**	NIL	NIL	NIL	NIL	90	NIL	NIL	NIL	NIL	NIL	162	0.972
1–2 am	**72**	NIL	NIL	NIL	NIL	90	NIL	NIL	NIL	NIL	NIL	162	0.972
2–3 am	**72**	NIL	NIL	NIL	NIL	90	NIL	NIL	NIL	NIL	NIL	162	0.972
3–4 am	**72**	NIL	NIL	NIL	NIL	90	NIL	NIL	NIL	NIL	NIL	162	0.972
4–5 am	**72**	NIL	NIL	NIL	NIL	90	NIL	NIL	NIL	NIL	NIL	162	0.972
5–6 am	**72**	NIL	NIL	NIL	NIL	90	NIL	NIL	NIL	NIL	NIL	162	0.972
6–7 am	**72**	NIL	NIL	NIL	20	NIL	NIL	NIL	746	NIL	NIL	838	5.028
7–8 am	**72**	NIL	NIL	NIL	**20**	NIL	NIL	NIL	NIL	450	NIL	542	3.252
8–9 am	**72**	NIL	750	NIL	**10**	NIL	NIL	NIL	NIL	NIL	**250**	1082	6.492
9–10 am	**72**	70	**750**	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	892	5.352
10–11 am	**72**	**70**	NIL	1000	NIL	45	NIL	NIL	NIL	NIL	NIL	1187	7.122
11 am–12 pm	**72**	**70**	NIL	NIL	NIL	45	NIL	NIL	NIL	NIL	NIL	187	**1.122**
12–1 pm	**72**	**70**	NIL	NIL	NIL	45	1500	NIL	NIL	NIL	NIL	1687	10.122
1–2 pm	**72**	**70**	NIL	NIL	NIL	45	1500	NIL	NIL	450	NIL	2137	12.822
2–3 pm	**72**	NIL	NIL	NIL	NIL	45	NIL	NIL	NIL	NIL	NIL	117	0.702
3–4 pm	**72**	NIL	NIL	NIL	NIL	45	NIL	NIL	NIL	NIL	NIL	117	0.702
4–5 pm	72	NIL	NIL	NIL	NIL	45	NIL	NIL	NIL	NIL	NIL	117	0.702
5–6 pm	**72**	NIL	NIL	NIL	NIL	90	NIL	NIL	NIL	NIL	NIL	162	0.972
6–7 pm	**72**	70	NIL	NIL	**20**	90	NIL	NIL	**746**	NIL	NIL	998	5.988
7–8 pm	**72**	**70**	NIL	NIL	**30**	90	NIL	NIL	NIL	**450**	**250**	962	5.772
8–9 pm	**72**	**70**	NIL	NIL	**30**	45	1500	NIL	NIL	NIL	NIL	1717	10.302
9–10 pm	**72**	**70**	NIL	NIL	**30**	45	1500	NIL	NIL	NIL	NIL	1717	10.302
10–11 pm	**72**	70	NIL	NIL	**10**	45	NIL	NIL	NIL	NIL	NIL	197	1.182
11 pm–12 am	**72**	NIL	NIL	NIL	10	135	NIL	NIL	NIL	NIL	NIL	217	1.302

TABLE A2. Winter-residential.

		Offices (50)			Shops (500)			
Hours	Flour mill (10) 746 W	Coffee machine (20) 1000 W	Light-ing (4) 10 W	Ceiling Fan (2) 45 W	Light-ing (1) 10 W	Ceiling Fan (1) 45 W	Total Load in W	Total Load in MW
12 midnight–1 am	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL
1–2 am	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL
2–3 am	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL
3–4 am	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL
4–5 am	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL
5–6 am	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL
6–7 am	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL
7–8 am	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL
8–9 am	NIL	10,000	2000	4500	5000	22,500	**44,000**	**0.044**
9–10 am	7460	NIL	2000	4500	5000	22,500	**41,460**	**0.04146**
10–11 am	7460	NIL	2000	4500	5000	22,500	**41,460**	**0.04146**
11 am–12 pm	7460	NIL	2000	4500	5000	22,500	**41,460**	**0.04146**
12–1 pm	7460	NIL	2000	4500	5000	22,500	**41,460**	**0.04146**
1–2 pm	7460	10,000	2000	4500	5000	22,500	**51,460**	**0.05146**
2–3 pm	NIL	NIL	2000	4500	5000	22,500	**34,000**	**0.034**
3–4 pm	NIL	NIL	2000	4500	5000	22,500	**34,000**	**0.034**
4–5 pm	7460	NIL	2000	4500	5000	22,500	**41,460**	**0.04146**
5–6 pm	7460	10,000	1500	2250	5000	22,500	**48,710**	**0.04871**
6–7 pm	5968	NIL	1500	2250	5000	22,500	**37,218**	**0.037218**
7–8 pm	5968	NIL	NIL	NIL	5000	22,500	**33,468**	**0.033468**
8–9 pm	2238	NIL	NIL	NIL	5000	22,500	**29,738**	**0.029738**
9–10 pm	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL
10–11 pm	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL
11pm–12 am	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL

TABLE A3. Summer-commercial.

		Offices (50)			Shops (500)			
Hours	Flour mill (10) 746 W	Coffee machine (20) 1000 W	Light-ing (4) 10 W	Ceiling Fan (2) 45 W	Light-ing (1) 10 W	Ceiling Fan (1) 45 W	Total Load in W	Total Load in MW
12 midnight–1 am	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL
1–2 am	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL
2–3 am	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL
3–4 am	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL
4–5 am	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL
5–6 am	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL
6–7 am	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL
7–8 am	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL
8–9 am	NIL	10,000	2000	NIL	NIL	NIL	12,000	0.012
9–10 am	7460	NIL	2000	NIL	5000	NIL	14,460	0.01446
10–11 am	7460	NIL	2000	NIL	5000	NIL	14,460	0.01446
11–12 pm	7460	NIL	2000	NIL	5000	NIL	14,460	0.01446
12–1 pm	7460	NIL	2000	NIL	5000	NIL	14,460	0.01446

(*Continued*)

TABLE A4. (*Continued*).

		Offices (50)			Shops (500)			
Hours	Flour mill (10) 746 W	Coffee machine (20) 1000 W	Light-ing (4) 10 W	Ceiling Fan (2) 45 W	Light-ing (1) 10 W	Ceiling Fan (1) 45 W	Total Load in W	Total Load in MW
1–2 pm	7460	10,000	2000	NIL	5000	NIL	24,460	0.02446
2–3 pm	NIL	NIL	2000	NIL	5000	NIL	7000	0.007
3–4 pm	NIL	NIL	2000	NIL	5000	NIL	7000	0.007
4–5 pm	7460	10,000	2000	NIL	5000	NIL	24,460	0.02446
5–6 pm	7460	NIL	1500	NIL	5000	NIL	13,960	0.01396
6–7 pm	5968	NIL	1500	NIL	5000	NIL	12,468	0.012468
7–8 pm	5968	NIL	NIL	NIL	5000	NIL	10968	0.010968
8–9 pm	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL
9–10 pm	NIL	NIL	500	NIL	NIL	NIL	500	0.0005
10–11 pm	NIL	NIL	500	NIL	NIL	NIL	500	0.0005
11 pm–12 am	0	0	500	0	0	0	500	0.0005

TABLE A4. Winter-commercial.

	School (20)					
Hours	Lighting (30) 10 W	Ceiling fan (30) 45 W	Water pump (1) 746 W	Computer lab (20) 40 W	Total load in W	Total load in MW
12 midnight–1 am	NIL	NIL	NIL	NIL	NIL	NIL
1–2 am	NIL	NIL	NIL	NIL	NIL	NIL
2–3 am	NIL	NIL	NIL	NIL	NIL	NIL
3–4 am	NIL	NIL	NIL	NIL	NIL	NIL
4–5 am	NIL	NIL	NIL	NIL	NIL	NIL
5–6 am	NIL	NIL	NIL	NIL	NIL	NIL
6–7 am	NIL	NIL	**14,920**	NIL	**14,920**	**0.01492**
7–8 am	**6000**	**27,000**	NIL	NIL	**33,000**	**0.033**
8–9 am	**6000**	**27,000**	NIL	NIL	**33,000**	**0.033**
9–10 am	**6000**	**27,000**	NIL	NIL	**33,000**	**0.033**
10–11 am	**6000**	**27,000**	NIL	NIL	**33,000**	**0.033**
11–12 pm	**6000**	**27,000**	NIL	**16,000**	**49,000**	**0.049**
12–1 pm	**6000**	**27,000**	NIL	**16,000**	**49,000**	**0.049**
1–2 pm	**6000**	**27,000**	NIL	NIL	**33,000**	**0.033**
2–3 pm	NIL	NIL	NIL	NIL	NIL	NIL
3–4 pm	NIL	NIL	NIL	NIL	NIL	NIL
4–5 pm	NIL	NIL	NIL	NIL	NIL	NIL
5–6 pm	NIL	NIL	NIL	NIL	NIL	NIL
6–7 pm	NIL	NIL	NIL	NIL	NIL	NIL
7–8 pm	NIL	NIL	NIL	NIL	NIL	NIL
8–9 pm	NIL	NIL	NIL	NIL	NIL	NIL
9–10 pm	NIL	NIL	NIL	NIL	NIL	NIL
10–11 pm	NIL	NIL	NIL	NIL	NIL	NIL
11 pm–12 am	NIL	NIL	NIL	NIL	NIL	NIL

TABLE A5. Summer-institutional.

Hours	School (20)					
	Lighting (30) 10 W	Ceiling fan (30) 45 W	Water pump (1) 746 W	Computer lab (20) 40 W	Total load in W	Total load in MW
12 midnight–1 am	NIL	NIL	NIL	NIL	NIL	NIL
1–2 am	NIL	NIL	NIL	NIL	NIL	NIL
2–3 am	NIL	NIL	NIL	NIL	NIL	NIL
3–4 am	NIL	NIL	NIL	NIL	NIL	NIL
4–5 am	NIL	NIL	NIL	NIL	NIL	NIL
5–6 am	NIL	NIL	NIL	NIL	NIL	NIL
6–7 am	NIL	NIL	NIL	NIL	NIL	NIL
7–8 am	NIL	NIL	14,920	NIL	**14,920**	**0.01492**
8–9 am	NIL	NIL	NIL	NIL	NIL	NIL
9–10 am	NIL	NIL	NIL	NIL	NIL	NIL
10–11 am	6000	NIL	NIL	NIL	**6000**	**0.006**
11–12 pm	6000	NIL	NIL	NIL	**6000**	**0.006**
12–1 pm	6000	NIL	NIL	NIL	**6000**	**0.006**
1–2 pm	6000	NIL	NIL	NIL	**6000**	**0.006**
2–3 pm	6000	NIL	NIL	16,000	**22,000**	**0.022**
3–4 pm	6000	NIL	NIL	16,000	**22,000**	**0.022**
4–5 pm	6000	NIL	NIL	NIL	**6000**	**0.006**
5–6 pm	NIL	NIL	NIL	NIL	NIL	NIL
6–7 pm	NIL	NIL	NIL	NIL	NIL	NIL
7–8 pm	NIL	NIL	NIL	NIL	NIL	NIL
8–9 pm	NIL	NIL	NIL	NIL	NIL	NIL
9–10 pm	NIL	NIL	NIL	NIL	NIL	NIL
10–11 pm	NIL	NIL	NIL	NIL	NIL	NIL
11 pm–12 am	NIL	NIL	NIL	NIL	NIL	NIL

TABLE A6. Winter-institutional.

Hours	Hospital (10)					
	Lighting (15) 10 W	Ceiling fan (15) 45 W	Refrigerator (1) 120 W	Sterilizer (1) 1500 W	Total load in W	Total load in MW
12 midnight–1 am	200	2250	720	NIL	**3170**	**0.00317**
1–2 am	200	2250	720	NIL	**3170**	**0.00317**
2–3 am	200	2250	720	NIL	**3170**	**0.00317**
3–4 am	200	2250	720	NIL	**3170**	**0.00317**
4–5 am	200	2250	720	NIL	**3170**	**0.00317**
5–6 am	200	2250	720	NIL	**3170**	**0.00317**
6–7 am	200	2250	720	NIL	**3170**	**0.00317**
7–8 am	200	2250	720	3000	**6170**	**0.00617**
8–9 am	200	2250	720	3000	**6170**	**0.00617**
9–10 am	1000	4500	720	3000	**9220**	**0.00922**
10–11 am	1000	4500	720	3000	**9220**	**0.00922**
11–12 pm	1000	4500	720	3000	**9220**	**0.00922**
12–1 pm	1000	4500	720	NIL	**6220**	**0.00622**
1–2 pm	1000	4500	720	NIL	**6220**	**0.00622**
2–3 pm	1000	4500	720	NIL	**6220**	**0.00622**
3–4 pm	1000	4500	720	NIL	**6220**	**0.00622**
4–5 pm	1000	4500	720	NIL	**6220**	**0.00622**

(*Continued*)

TABLE A7. (*Continued*).

Hours	Hospital (10)					
	Lighting (15) 10 W	Ceiling fan (15) 45 W	Refrigerator (1) 120 W	Sterilizer (1) 1500 W	Total load in W	Total load in MW
5–6 pm	1500	4500	720	NIL	**6720**	**0.00672**
6–7 pm	1500	4500	720	NIL	**6720**	**0.00672**
7–8 pm	1500	4500	720	NIL	**6720**	**0.00672**
8–9 pm	1500	4500	720	NIL	**6720**	**0.00672**
9–10 pm	1500	4500	720	NIL	**6720**	**0.00672**
10–11 pm	200	4500	720	NIL	**5420**	**0.00542**
11 pm–12 am	200	4500	720	NIL	**5420**	**0.00542**

TABLE A7. Summer-community.

Hours	Hospital (10)					
	Lighting (15) 10 W	Ceiling fan (15) 45 W	Refrigerator (1) 120 W	Sterilizer (1) 1500 W	Total Load in W	Total Load in MW
12 midnight– 1 am	**200**	NIL	**720**	NIL	**920**	**0.00092**
1–2 am	**200**	NIL	**720**	NIL	**920**	**0.00092**
2–3 am	**200**	NIL	**720**	NIL	**920**	**0.00092**
3–4 am	**200**	NIL	**720**	NIL	**920**	**0.00092**
4–5 am	**200**	NIL	**720**	NIL	**920**	**0.00092**
5–6 am	**200**	NIL	**720**	NIL	**920**	**0.00092**
6–7 am	**200**	NIL	**720**	NIL	**920**	**0.00092**
7–8 am	**200**	NIL	**720**	NIL	**920**	**0.00092**
8–9 am	**200**	NIL	**720**	**3000**	**3920**	**0.00392**
9–10 am	**1000**	NIL	**720**	**3000**	**4720**	**0.00472**
10–11 am	**1000**	NIL	**720**	**3000**	**4720**	**0.00472**
11–12 pm	**1000**	NIL	**720**	**3000**	**4720**	**0.00472**
12–1 pm	**1000**	NIL	**720**	**3000**	**4720**	**0.00472**
1–2 pm	**1000**	NIL	**720**	NIL	**1720**	**0.00172**
2–3 pm	**1000**	NIL	**720**	NIL	**1720**	**0.00172**
3–4 pm	**1000**	NIL	**720**	NIL	**1720**	**0.00172**
4–5 pm	**1000**	NIL	**720**	NIL	**1720**	**0.00172**
5–6 pm	**1500**	NIL	**720**	NIL	**2220**	**0.00222**
6–7 pm	**1500**	NIL	**720**	NIL	**2220**	**0.00222**
7–8 pm	**1500**	NIL	**720**	NIL	**2220**	**0.00222**
8–9 pm	**1500**	NIL	**720**	NIL	**2220**	**0.00222**
9–10 pm	**1500**	NIL	**720**	NIL	**2220**	**0.00222**
10–11 pm	**500**	NIL	**720**	NIL	**1220**	**0.00122**
11 pm–12 am	**500**	NIL	**720**	NIL	**1220**	**0.00122**

TABLE A8. Winter-community.

Hours	Residential total load in MW	Commerc-ial total load in MW	Institutional total load in MW	Community total load in MW	Total summer load in MW	Total summer load in KW
12 midnight to 1 am	0.972	NIL	NIL	**0.00317**	**0.97517**	975.17
1–2am	0.972	NIL	NIL	**0.00317**	**0.97517**	975.17
2–3am	0.972	NIL	NIL	**0.00317**	**0.97517**	975.17
3–4am	0.972	NIL	NIL	**0.00317**	**0.97517**	975.17
4–5am	0.972	NIL	NIL	**0.00317**	**0.97517**	975.17
5–6am	0.972	NIL	NIL	**0.00317**	**0.97517**	975.17
6–7am	5.028	NIL	0.01492	**0.00317**	**5.04609**	5046.09
7–8am	3.252	NIL	0.033	**0.00617**	**3.29117**	3291.17
8–9am	6.492	0.044	0.033	**0.00617**	**6.57517**	6575.17
9–10am	5.352	0.04146	0.033	**0.00922**	**5.43568**	5435.68
10–11am	7.122	0.04146	0.033	**0.00922**	**7.20568**	7205.68
11–12 pm	1.122	0.04146	0.049	**0.00922**	**1.22168**	1221.68
12–1 pm	10.122	0.04146	0.049	**0.00622**	**10.21868**	10218.68
1–2 pm	**12.822**	0.05146	0.033	**0.00622**	**12.91268**	12912.68
2–3 pm	0.702	0.034	NIL	**0.00622**	**0.74222**	742.22
3–4 pm	0.702	0.034	NIL	**0.00622**	**0.74222**	742.22
4–5 pm	0.702	0.04146	NIL	**0.00622**	**0.74968**	749.68
5–6 pm	0.972	0.04871	NIL	**0.00672**	**1.02743**	1027.43
6–7 pm	5.988	0.037218	NIL	**0.00672**	**6.031938**	6031.938
7–8 pm	5.772	0.033468	NIL	**0.00672**	**5.812188**	5812.188
8–9 pm	10.302	0.029738	NIL	**0.00672**	**10.338458**	10338.46
9–10 pm	10.302	NIL	NIL	**0.00672**	**10.30872**	10308.72
10–11 pm	1.182	NIL	NIL	**0.00542**	**1.18742**	1187.42
11 pm–12 am	1.302	NIL	NIL	**0.00542**	**1.30742**	1307.42

TABLE A9. Total load for summer.

Hours	Residential total load in MW	Commerc-ial total load in MW	Institutional total load in MW	Community total load in MW	Total summer load in MW	Total summer load in KW
12 midnight–1 am	0.432	NIL	NIL	**0.00092**	**0.43292**	432.92
1–2 am	0.432	NIL	NIL	**0.00092**	**0.43292**	432.92
2–3am	0.432	NIL	NIL	**0.00092**	**0.43292**	432.92
3–4am	0.432	NIL	NIL	**0.00092**	**0.43292**	432.92
4–5am	0.432	NIL	NIL	**0.00092**	**0.43292**	432.92
5–6am	4.908	NIL	NIL	**0.00092**	**4.90892**	4908.92
6–7am	0.432	NIL	NIL	**0.00092**	**0.43292**	432.92
7–8am	3.552	NIL	0.01492	**0.00092**	**3.56784**	3567.84
8–9am	6.252	0.012	NIL	**0.00392**	**6.26792**	6267.92
9–10am	6.552	0.01446	NIL	**0.00472**	**6.57118**	6571.18
10–11am	2.532	0.01446	0.006	**0.00472**	**2.55718**	2557.18
11am to 12 pm	**10.032**	0.01446	0.006	**0.00472**	**10.05718**	10057.18
12–1 pm	0.972	0.01446	0.006	**0.00472**	**0.99718**	997.18
1–2 pm	0.972	0.02446	0.006	**0.00172**	**1.00418**	1004.18
2–3 pm	3.252	0.007	0.022	**0.00172**	**3.28272**	3282.72
3–4 pm	0.552	0.007	0.022	**0.00172**	**0.58272**	582.72
4–5 pm	0.552	0.02446	0.006	**0.00172**	**0.58418**	584.18

(*Continued*)

TABLE A10. (*Continued*).

Hours	Residential total load in MW	Commerc-ial total load in MW	Institutional total load in MW	Community total load in MW	Total summer load in MW	Total summer load in KW
5–6 pm	5.088	0.01396	NIL	**0.00222**	**5.10418**	5104.18
6–7 pm	3.612	0.012468	NIL	**0.00222**	**3.626688**	3626.688
7–8 pm	5.532	0.010968	NIL	**0.00222**	**5.545188**	5545.188
8–9 pm	3.732	NIL	NIL	**0.00222**	**3.73422**	3734.22
9–10 pm	1.032	0.0005	NIL	**0.00222**	**1.03472**	1034.72
10–11 pm	0.612	0.0005	NIL	**0.00122**	**0.61372**	613.72
11 pm–12 am	0.432	0.0005	NIL	**0.00122**	**0.43372**	433.72

TABLE A10. Total load for winter.