# Feasibility Analysis And Economic Valuation Of Hybrid System Having Time Of Use Pricing For Residential Load

**Ravindra Kumar Yadav, P.N. Hrisheekesha, Vikas Singh Bhadoria**

**Abstract**: the worlds demand of electrical energy is escalating very fast mainly due to industrialization and change in life style of human beings. This growing demand of electricity cannot be fulfilled in future because of depletion of fossil fuels with a rapid rate thereby showing the complete depletion within almost 200 years. The world community is examining for new long lasting resources for generation of electricity and the best option is renewable energy resource. In this study a feasibility analysis and financial assessment of grid connected solar PV system along with battery energy storage system for residential load with time of use pricing (TOU) is discussed. The feasibility and financial assessment is accomplished by using HOMER Software. It is observed from this study that the system under consideration gives minimum expenditure with solar PV panels and Battery Energy Storage System (BESS). Simulations results of HOMER demonstrates that the total net present cost, levelized cost of energy, operating cost is reduced significantly when compared with the existing grid system. In this system the purchase price sell back price are equal.

**Index Terms**: Battery Energy Storage System (BESS), HOMER , Levelized Cost of Energy (LCOE), Total Net Present Cost (TNPC), Time of Use (TOU), Utility Grid..

## 1 INTRODUCTION

Escalating global electricity demand and depletion of fossil fuels has created a paramount concern to search for other inexhaustible energy resources to meet the future energy demand. Solar energy is one of renewable energy resource available free of cost and inexhaustible, in view of this a prompt progress in installation of solar panels in residential and institutional buildings are in fashion around the world in past few years [1]. The generated power from solar panels is nourished to grid with a rapid rate in spite of its intermittent and fluctuating nature; the utilities are adopting battery energy storage facility for continuous and reliable power supply to consumers [2]. The distributed generators (DGs) categories and its effects on distribution system are emphasizes in [3-4] which suggested the future scope of DGs.

Further, the utility grid also needs means for energy storage to balance the generation and demand along with providing stability in the utility grid. The energy storage application inculcates capacity firming, spinning reserve, load-leveling, with improved power quality issues and frequency regulation [5-6]. The optimal power management for grid connected solar photovoltaic systems with battery energy storage can be computed using dynamic programming.

BESS system can also be used for peak load saving with the aim to minimize the demand charge by considering different tariffs for the energy from the PV and the utility grid [7]. Improved harmony search algorithm is used to scrutinize the techno-economic optimization of lead-acid storage battery size to minimize the total annual operating cost of grid connected solar PV system with battery energy storage system [8]. In small and medium scale generating systems the battery energy storage is used as a means of power backup facility [9]. BESS can also play the role to minimize the demand charge of energy by using linear programming in dispatch schedule which minimizes the net energy exchanged with the grid [10]. The distributed solar PV power generation being the more cost effective than grid extension shows a viable option to fulfill the future energy needs with increased reliability by using battery energy storage system [11].

The grid connected distributed power generation by PV with battery storage system plays an important role in TOU pricing scenario. The energy demand of consumers is fulfilled by grid and solar PV panels along with battery energy storage system in accordance with TOU pricing. In TOU pricing based system the supplied energy selects the best economical source to supply the power to consumers. The paper is organized as follows: Section II describes the system configuration and Section III presents the system configuration and section III presents the problem formulation. Section IV gives optimization results analysis. Finally, results of simulation study are discussed in details.

## 2 SYSTEM CONFIGUARATION

In this section the description of system component is given. The system component includes HOMER software, Solar PV Generator, battery energy storage system, input data of forecasted residential load and solar radiations at selected location.

### 2.1 Homer Software

Hybrid Optimization of Multiple Electric Renewables abbreviated as HOMER is developed by the National Renewable Energy Laboratory in USA. HOMER is augmented and dispersed by HOMER Energy. HOMER evaluates the designing task of on grid and off grid distributed generators. The block diagram of proposed system is given in Fig.1.


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HOMER requires input data, component costs and resource availability and simulates different feasible system configurations. HOMER provides the opportunities of techno economic evaluation by displaying the simulation results [12].

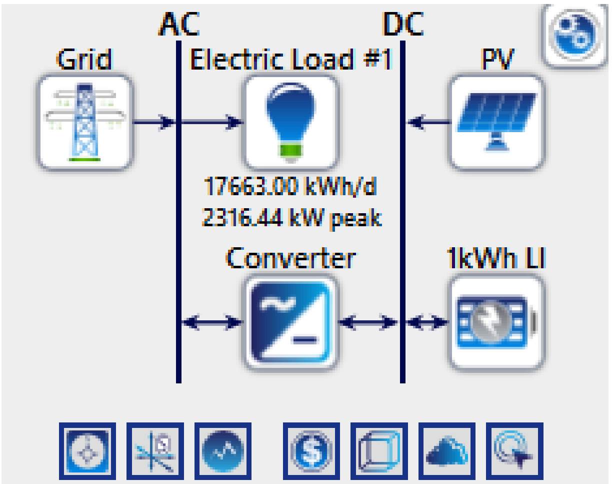


***Fig. 1*** *Block Diagram of Proposed System*

### 2.2 Solar PV Generator

The generic flat plate Solar PV Panels with the lifetime of 25 years and derating factor of 80 percent are considered here. The capital cost is US$1400 for one kW and with zero maintenance cost assumption [13]. The value of solar radiations at the location of forecasted residential load is imported from US National Renewable Energy Laboratory (NREL). The HOMER accepts solar radiations data to any time step down to one minute although time series solar radiation data is most commonly available with an hourly time step. The global horizontal irradiance (GHI) resource data is used to calculate the power output of flat plate solar PV panels because it captures direct, diffuse and reflected radiations. The other parameters of solar PV panels, like maximum output, PV penetration, rated capacity and total production are taken from simulation results.

### 2.3 CONVERTER

The proposed model comprises a converter having rating 1400 kW and efficiency of 95%. The capital and replacement cost are equal and $300 per kilowatt respectively and maintenance cost is assumed to be zero [14]. The replacement cost consideration of converter after 15 years of its lifetime by HOMER software is clearly seen in Fig. 4 and Fig.5. The converter architecture detail is given in Table 4.

***Table 1*** *Solar Architecture*

| Quantity | Value | Units |
|---|---|---|
| Maximum Output | 1539 | kW |
| PV Penetration | 40.4 | % |
| Hours of Operation | 4380 | hrs/yr |
| Rated Capacity | 1601 | kW |
| Mean Output | 298 | kW |
| Mean Output | 7143 | kWh/Day |
| Total Production | 2607343 | kWh/yr |
| Life Cycle | 25 | yr |

***Table 2*** *Converter Architecture*

| Quantity | Value | Units |
|---|---|---|
| Hours of Operation | 4695 | hrs/yr |
| Energy Output | 2446540 | kWh/yr |
| Energy Input | 2575305 | kWh/yr |
| Losses | 128765 | kWh/yr |
| Capacity | 1147 | kW |
| Mean Output | 279 | kW |
| Maximum Output | 1147 | kW |
| Life Cycle | 15 | yr |

### 2.4 Residential load

The forecasted residential load of a smart grid system under time of use pricing (TOU) is taken in the present study [15]. The revenue under TOU pricing was very high when fed with utility grid and the system becomes very expensive for residential customers. The hourly load of a day is taken as input data to HOMER Software and the same load is assumed throughout the year. The day to day load variation is assumed as 10 percent and seasonal variation is 20 percent. The graphical representation daily load variation and monthly load profile by HOMER is shown in Fig. 3.

### 2.5 Battery Energy Storage System

In this study the generic 1kWh Li-ion battery is used as an energy storage device. Proposed system has 200 quantity of Generic Li-ion battery with 100 strings. The capital cost and replacement cost of battery is taken as US$550 each [16]. The maintenance cost is US$10 per kWh yearly. The generic Li-ion battery is the idealized energy storage model in HOMER software. The battery is used to store the energy during off peak hours and supplies this energy in peak hours as well as in nights when solar energy is not available.

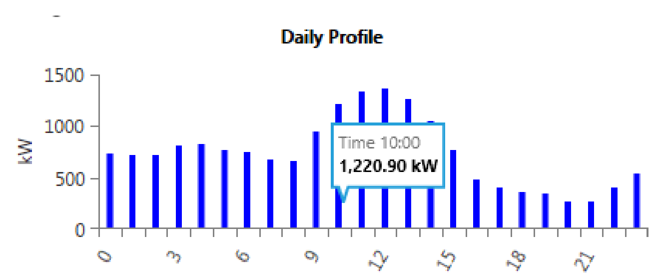


Fig. 2 Daily Load Profile of Residential Load

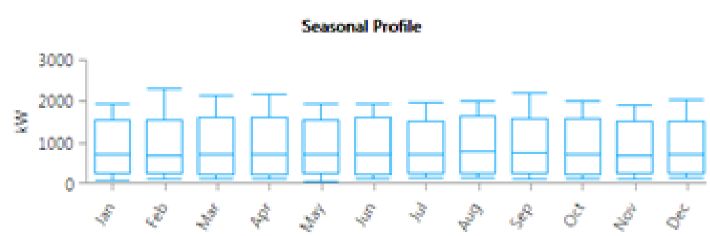


***Fig. 3*** *Seasonal Load Profile Residential Load*

***Table 3** Battery Architecture*

| Quantity | Value | Units |
|---|---|---|
| Energy Output | 36703 | kWh/yr |
| Energy Input | 40613 | kWh/yr |
| Losses | 4070 | kWh/yr |
| Lifetime Throughput | 580332 | kWh |
| Rated Capacity | 200 | kWh |
| Maintenance Cost | 10 | US$/yr |
| Initial state of charge | 100 | % |
| Minimum state of charge | 20 | % |

**2.6 UTILITY GRID**

Utility Grid is the prime source of electricity for the residential consumers. A grid delivers or absorbs the electricity as per demand and rate of exchange of electricity per kWh is taken equal for both the direction of power flow. In HOMER the grid extracts the time of use pricing tariff as an input from user. The energy exchange prices are same for energy taken from grid as well as energy sold to grid.

## 3 ASSESSMENT CRITERIA

The assessment criterion in the present study is based on the main optimization variable total net present cost (TNPC). TNPC is calculated by estimating all the expenditure in the project over its life cycle and the present value of all the revenue collected throughout the project life cycle. The assessment criteria TNPC is given by equation-1 and it is optimized in this study with the help of HOMER software. TNPC expenditure consists of initial capital costs of equipment, replacement costs, maintenance costs, and cost of purchased power from grid. The cost of energy sold to grid and salvage value of converter and battery constitutes system revenue. All the costs are in this study are in US$. The optimization variables are described below

**3.1 Total Net Present Cost (TNPC)**: TNPC gives the life cycle cost of current and base system. The TNPC is estimated for the base system and current system in order to evaluate the performance of current system. The difference of all the expenditure and earnings over the project life cycle constitutes TNPC. A positive value of TNPC over project life cycle indicates for significant saving in the proposed system. HOMER evaluates TNPC by following equation [16].

$$T_{NPC} = T_{AC} / \; CRF(i, n_{project}) \qquad (1)$$

Here the $T_{AC}$ is the total annual cost and $C_{RF}$ is the capital recovery factor respectively, the annual real interest rate is represented by i. $n_{project}$ is the life cycle of project in years.

The total annual cost is the value of net present cost over one complete year and capital recovery factor is used to calculate the residual value of a component at the end of project life cycle [16].

**3.2 Capital Recovery Factor ($C_{RF}$):** Capital recovery factor is a ratio which is used to calculate the present value of an annuity.

(2)

$$C_{RF}(i, n_{project}) = \frac{i(1+i)^{n_{project}}}{[(1+i)^{n_{project}} - 1]} \qquad \text{(iii)}$$

**3.3 Levelized Cost of Energy ($L_{COE}$):** It evaluates the average cost per kWh generated by the solar PV panel / grid [manual/website]. The levelized cost of energy is calculated by expression as shown equation 3.

$$L_{COE} = T_{AC} \;/\; L_{load} \qquad (3)$$

Here $T_{AC}$ is annual cost and $L_{load}$ is the total annual electrical load supplied. The levelized cost of energy decreases with the decrease in total annual cost.

**3.4 Yearly Operational Cost ($Y_{OC}$):** The yearly operational cost is evaluated by adding all the expenditure throughout the year minus initial capital cost. It is represented by equation 4.

$$Y_{OC} = T_{AC} - T_{ICC} \qquad (4)$$

Here, $T_{AC}$ is the total annual cost and $T_{ICC}$ is the total annualized initial capital cost respectively. A decrease in total annual cost decreases the yearly operational cost.

## 4 SIMULATION RESULTS AND ANALYSIS

The HOMER takes input data from different component and simulates the system for optimization of total net present cost (TNPC) and produces the best possible solution for the proposed system. There are 746 feasible solutions and possible results of simulation are shown in Table 4. The different value of solar PV panels is selected from zero watts to 17664 watts which is the average load per day. The TNPC, LCOE and operating cost is compared with each feasible solution and also ensures that all the cost should be minimized. Table 4 displays the different solar PV ratings for the residential load and also gives the fraction of energy exchanged with utility grid. Finally, the solar PV rating of 1601 kW and converter of 1147 kW with Li-ion battery of 200 quantities each of one kWh rating gives the minimum total net present cost (TNPC) for the proposed system. Initial capital cost in Table 4 includes the value of solar panels along with cost of converter and batteries. The 38 percent renewable fraction in Table 4 indicates a decrease in emissions of greenhouse gases. The battery autonomy gives the ratio of battery storage size to electric load and it is 21.7 percent in proposed system.

**4.2 Energy Management**

There are mainly two strategies in order to balance the generation and load in case of grid connected hybrid power system. In this study the generated power of solar PV and utility grid along with stored power in battery is managed to supply the load at all-time steps. The two strategies used by HOMER are load following and cycle charging. In present study cycle charging strategy is utilized by HOMER and it selects the optimal combination of power sources to supply the consumer loads. In cycle charging strategy batteries are charged by grid power as well as solar PV power. If solar PV power is in excess after meeting the demand then it is used to charge the battery and remaining power is sold to grid. If the battery state of charge is below set point and solar Power is not available and grid battery energy cost plus battery wear cost is more than grid purchase price than it is charged up to set point state of charge by grid power. Further when grid purchase price is more than battery energy plus wear cost and Battery is at 20 percent state of charge then battery will supply the load if solar is unable to satisfy the load. The battery minimum state of charge is set at 20 percent and set point the state of charge is 100 percent and it is shown in fig. 5.

### 4.1. Optimization Result Analysis

The proposed system gives minimum expenditure throughout the project life cycle when compared with the existing grid system. The overall expenditure of proposed system and existing grid only is calculated in terms of TNPC, LCOE and YOC. Few possible randomly selcted simulation results of proposed system is shown in Table 4.

***Table 4*** *Possible Simulation Results*

| PV (kW) | Battery (kWh) | Converter (kW) | NPC (US$) | LCOE (US$) | Operating cost (US$/yr) | Initial capital (US$) | Renew. Fraction (%) | Battery Autonomy (hr) | Grid Energy Purchased (kWh) | Grid Energy Sold (kWh) |
|---|---|---|---|---|---|---|---|---|---|---|
| 1601 | 200 | 1147 | 15435860 | 0.184 | 849291 | 4456632 | 38 | 0.217 | 4051223 | 50768 |
| 1600 | 200 | 1287 | 15530960 | 0.184 | 853662 | 4495230 | 38 | 0.217 | 4068318 | 90949 |
| 1733 | 200 | 1204 | 15530960 | 0.183 | 829861 | 4802923 | 40 | 0.217 | 3943968 | 126937 |
| 1565 | 212 | 1218 | 15531610 | 0.184 | 861564 | 4393726 | 37 | 0.230 | 4114208 | 78209 |
| 1752 | 200 | 1571 | 15531630 | 0.183 | 817591 | 4962210 | 41 | 0.217 | 3853819 | 113557 |
| 2065 | 200 | 1186 | 15685010 | 0.183 | 777898 | 5628724 | 45 | 0.217 | 3667906 | 185904 |
| 1513 | 272 | 1473 | 15691070 | 0.186 | 875468 | 4373448 | 36 | 0.296 | 4172382 | 65818 |
| 3533 | 1400 | 2317 | 17328540 | 0.168 | 543920 | 10297000 | 66 | 1.522 | 2736293 | 1546824 |
| 3533 | 800 | 1158 | 18849870 | 0.208 | 714009 | 9619500 | 53 | 0.870 | 3308103 | 550017 |
| 5299 | 200 | 3475 | 18931780 | 0.137 | 350514 | 14400500 | 74 | 0.217 | 2791669 | 4275468 |
| 2650 | 500 | 579 | 18994470 | 0.227 | 922197 | 7072750 | 32 | 0.544 | 4436001 | 39463 |
| 4661 | 224 | 1738 | 19341050 | 0.183 | 544828 | 12297780 | 65 | 0.243 | 2858146 | 1709837 |
| 3533 | 1400 | 1158 | 19385140 | 0.214 | 729888 | 9949500 | 53 | 1.522 | 3308179 | 549996 |
| 5888 | 2000 | 2317 | 22597590 | 0.180 | 470515 | 16515000 | 71 | 2.174 | 2803220 | 3288152 |
| 5299 | 800 | 1158 | 22806350 | 0.245 | 678464 | 14035500 | 57 | 0.870 | 3113853 | 767806 |
| 5299 | 1400 | 1158 | 23341610 | 0.250 | 694341 | 14365500 | 57 | 1.522 | 3113929 | 767790 |
| 17664 | 2000 | 1158 | 55268260 | 0.558 | 747302 | 45607500 | 63 | 2.174 | 2834854 | 1217198 |

In grid system power is supplied to the residential load with time of use pricing over the project span of 25 years. The overall expenditure is shown in fig. 6 as base case. This system is very expensive and also produces greenhouse gases thereby results global warming. On the other hand the proposed hybrid system gives less expenditure when compared with existing grid system. In proposed hybrid system the grid connected solar PV panels with battery energy system is used to supply the residential load. The cash flow of current system is shown in fig. 6. In fig. 6 a high cash flow at the first year of project indicates the initial cost of system which includes capital cost of solar PV panels , cost of converter and cost of BESS. After first year the expenditure is reduced signiificantly as comaperd to base system due to installation of solar panels and battery energy storage. Now, the load demand is fulfilled by solar panels and battery as well as utility grid. At the 15 year of project the cash flow indicates a lagre negative value due to replacement of battery and converter having a life cycle of 15 years respectively as indicated in Table 2 and Table 3. Again the cash flow at end of project life cycle indicates a less negative value due to salvage cost of converter and battery. Salvage cost is the residual cost of the component after its life cycle and HOMER evaluates the salvage cost by cosidering linear depreciation method.

***Table 5*** *Total Net Present Cost of Proposed System*

| Component Name | Capital Cost | Operating Cost | Replacement Cost | Salvage Value | Total Cost |
|---|---|---|---|---|---|
| Generic 1 kWh Li-ion Battery | US$110000 | US$25855 | US$46760 | -US$8784 | US$173741 |
| Generic Flat Plate Solar PV Panels | US$4M | US$206964 | US$0 | US$0 | US$4.21M |
| Utility Grid | US$0 | US$10.6M | US$0 | US$0 | US$10.6M |
| System Converter | US$344238 | US$0 | US$146051 | -US$27488 | US$462801 |
| System | US$4.46M | US$10.8M | US$192721 | -US$36272 | US$15.4 |

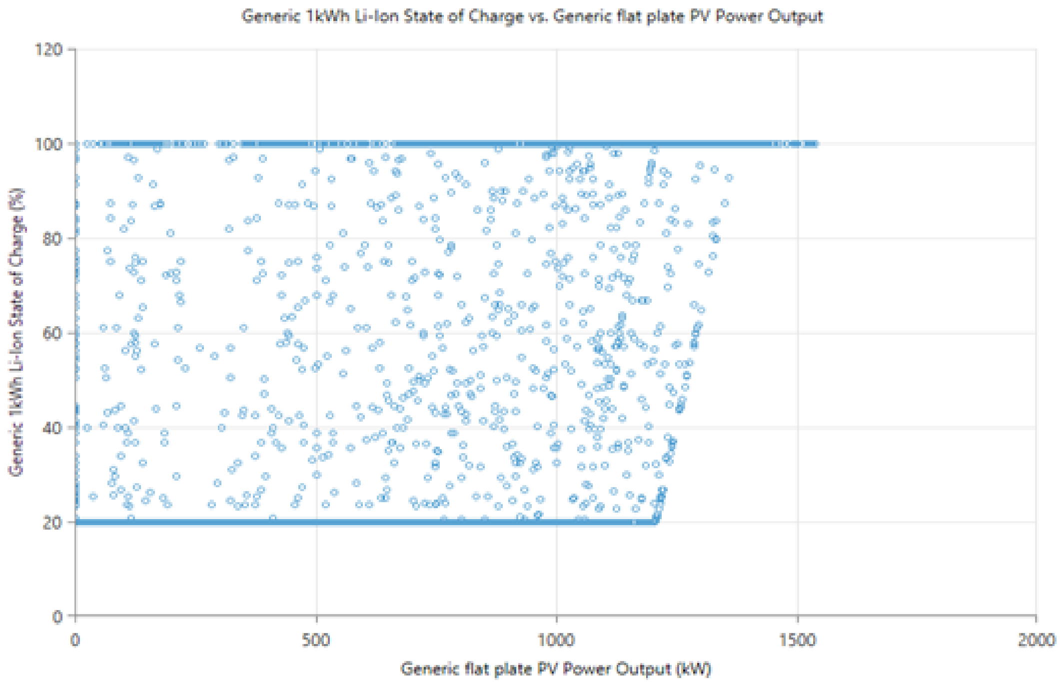


***Fig. 4*** *Battery State of Charge*

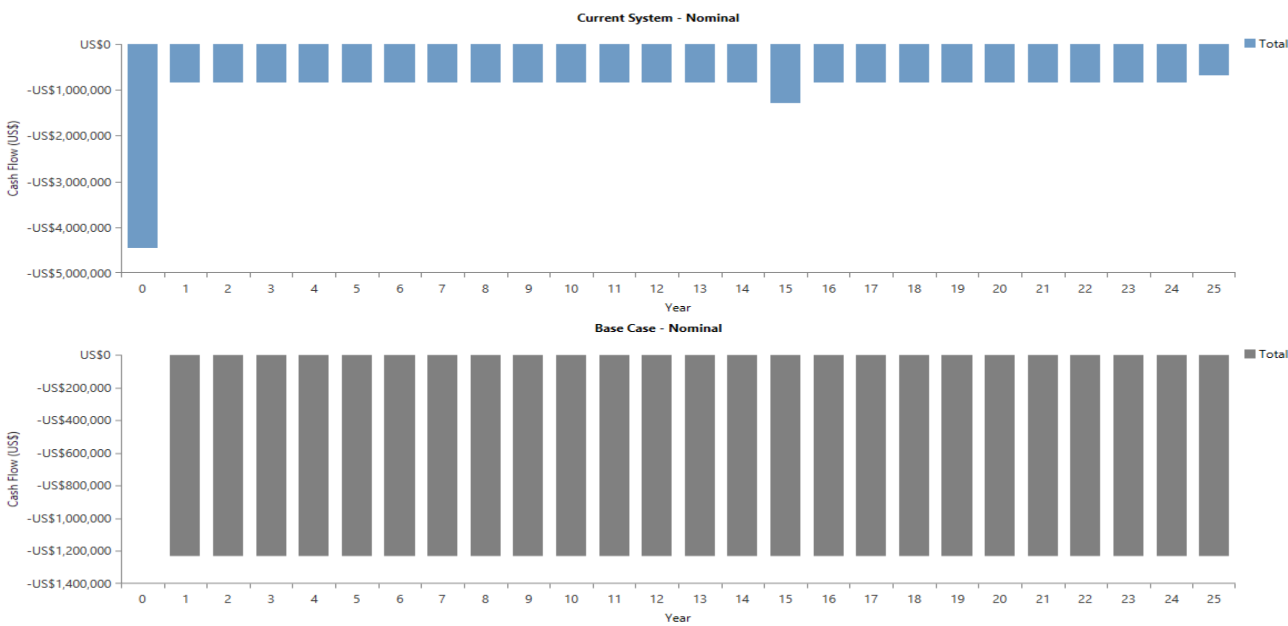


***Fig. 5*** *Cash Flow of Base System and Current System*

## 5 CONCLUSION

An optimum combination of grid connected distributed generating system is proposed here and gives the best possible economical solution. The presence of battery energy storage system provides a power backup in absence of grid supply. Such type of system can be a future option to satisfy the increasing electrical energy demand and also reduce the dependency on fossil fuel. The optimization result shows that the proposed system is cost effective and also promotes the paradigm shift from conventional sources to renewable sources. In this study the peak load is also reduced by consumer itself due to time of use pricing which charges high tariff rates during peak loads.

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