POWERING CELLULAR BASE STATIONS

A QUANTITATIVE ANALYSIS OF ENERGY OPTIONS

Solar PV, Diesel Generators, Batteries and Electrical Grid

Ashok Jhunjhunwala

Bhaskar Ramamurthi

Sriram Narayanamurthy

Janani Rangarajan

Sneha Raj

Telecom Center of Excellence (RiTCOE)
Indian Institute of Technology, Madras

Foreword

Telecommunications networks are critical infrastructure that needs assured power supply 24x7. Before the advent of cellular wireless telecommunications, wired telecom infrastructure used to be largely confined to telephone exchanges. Even if there were remote units with electronics on the streets, these units required modest levels of power, and this power was supplied from the exchange using the cable infrastructure. With cellular systems replacing wired systems in a big way, and with coverage becoming ubiquitous, the number of base stations in the country has grown enormously. Currently, the number of sites hosting base stations is in excess of 4 lakhs. These base stations are on rooftops of buildings in the cities, and at the bases of remotely located towers in rural areas. They need grid power supply and autonomous power backup.

The amount of power needed at each base station is also much higher, exceeding a couple of kilowatts, depending on the size and age of the systems deployed. Often, the electronics needs cooling as well. The locations, at which these base stations are present, lack reliable power supply and some have no grid availability in the first place. Thus there arises a need to provide power backup in the form of generators and storage batteries. These backup systems were implemented in a band-aid fashion over the years, since (a) they were not required in many other geographies before the large Indian deployment started, and thus no well-engineered solution was readily available, and (b) the scale of the backup needed in India too kept increasing as power supply became more erratic and cellular coverage began penetrating rural areas.

The consequence is that we have today back-of-the-envelope solutions that are not optimally engineered, that are often over-designed in order to meet unknown future needs without heeding efficiency, and that ignore the benefits that could accrue from renewable sources such as solar photo-voltaics (PV). If the financial and environmental costs of such sub-optimal designs were negligible, one could ignore the issue. However, the high operational expenditure on account of back-up power supply, and the environmental cost of DG sets and back-up batteries, has forced us to look afresh at the entire problem.

This report is a comprehensive effort to grapple with the issue of providing power backup for telecom base stations. It makes no *a priori* assumptions neither about the suitability or otherwise of batteries, DG sets, or solar PV, the availability of grid power nor the power consumption of the base stations. The key aspect of the approach taken is that the optimal back-up solution is found through simulations, given the set of assumptions. A sophisticated simulator has been developed into which one can input the parameters, and obtain the optimal mix of battery backup, solar PV capacity, and DG set capacity. The required power level, the temperature profile, grid availability profile, relative costs of DG power, solar PV, and battery storage can be fed into the simulator to arrive at the optimal solution. One can also consider retrofitting older base stations to reduce power requirements (mainly cooling requirements) and changing the optimal mix. One can perform "what-if" analysis to determine how the optimal mix will change if grid availability changes, and plan a more robust solution if such is needed. When grid availability improves at a location, one can change the backup arrangements at the next available opportunity, or increase the electronics at the site if needed.

Thus, the methodology espoused by this report yields a **location-specific solution, which optimizes capital and operational expenditure.** Operators can dynamically track the optimality of their implementations in a location-specific manner as the assumptions change, and either fortify the power backup, remove excess capacity, or add to the base station electronics as needed. The simulator and system-dimensioning tool is very useful both for *ab initio* design of new sites, and for tracking the performance and up-gradation of existing sites.

Several hundred examples of typical base stations configurations, power backup capacities, and grid availability assumptions have been considered and the cost of the backup power evaluated, with realistic models for the cost of finance. While these serve as examples for the way in which the methodology and simulator is to be used, they also enable us to arrive at some broad recommendations for the way forward with regard to the use of solar PV, DG sets, and batteries in the right mix to achieve a cost and energy-efficient power backup solution. We are also able to point out the critical areas where further research will lead to significant improvements.

We hope the user community - telecom manufacturers, tower infrastructure companies, power backup system providers, operators, regulator, and policy-making government agencies - find this report and the simulator/tool useful. We believe it is a first, and important step, in addressing these pressing issues of cost effectiveness, energy efficiency and carbon footprint of our telecom infrastructure. The Reliance-IIT Madras, Telecom Centre of Excellence (RITCoE) was set up, among six others in sister institutions, with a specific mandate for conducting research on energy-related issues. With the release of this report, RITCoE has made its first major contribution in this regard.

The problem of energy efficiency in the Indian context has only begun to be addressed. Much more remains to be uncovered, and much remains to be accomplished. We hope that the utility of this work will serve to emphasize the need for strong research efforts within the country as the only way to properly address our specific technological challenges. We also hope that this work also demonstrates the effectiveness and value of academia-industry collaboration, which was pioneered in an institutional framework through the TCoEs. We look forward to critiques of this report, as well as feedback from the use of the simulator. We are committed to continue our work in this area, and to improve the simulator and the approach itself in subsequent releases.

The authors would like to thank Reliance Communications, Department of Telecommunications, and IIT Madras for the support and encouragement provided to RITCoE.

Bhaskar Ramamurthi

Chairman, Governing Council, RiTCOE, IIT Madras

TABLE OF CONTENTS

Section 1: Basic Introduction

The Indian telecom sector is one industry, which has rapidly grown in the last decade and is still expected to grow steadily. As on May 31st 2012 [1], India's urban tele-density was 169.17% while the rural tele-density was 40.21%. Of the 960 million subscribers, the share of rural subscribers is just 35%. These figures indicate that the future market will be the rural area.

In recent times, however, the mobile operators are undergoing serious difficulty in preventing financial loss. Competition has brought down tariff significantly and reduced the margin. At the same time, there has been an increase in cost due to higher cost of spectrum as well as the lack of reliable 24x7 grid power. One of the casualties of this squeeze is the delay in the rollout of wireless broadband services in India, which, in the absence of wire line infrastructure, is the main hope for India to catch up with the rest of the world.

One solution to the present tangle is to bring-down the operation costs. In the absence of poor and unreliable electrical-power infrastructure, these operation costs are dominated by energy-costs at the cell-sites [2]. As the network expands more into rural areas, this cost rises further as the power-shortage increases. More than 70% of the 400,000 Base Transceiver Sites (BTS) sites in India are faced with the lack of power supply for over 8 hours a day; many face much larger power-cuts. During power-cuts, the telecom operators have to power these sites with diesel generators and battery back-ups, which today have prohibitive costs.

The Indian telecom industry consumes more than 2 billion liters of diesel and emits over 5 metric tons of CO_2. Further, diesel also gets pilfered in the rural areas. Energy, power and fuel amount to 30-35% of total network OPEX. Hence if the telecom industry has to expand in the rural areas, there is an urgent need for an alternative source of power supply so as to cut the costs and contain the amount of non-renewable energy being consumed.

There have been several research reports in recent times on this topic. They have pointed out to the fact that powering BTS sites with diesel has two adverse implications:

1. High Costs: The cost involved in using diesel is very high and it is estimated that the Indian telecom industry spends over 85 billion rupees on diesel every year [3]
2. The depletion of a non-renewable energy source which leads to high carbon footprints and is hazardous for the environment [4]

Some of the recent reports have also concluded by saying that the use of renewable energy sources like solar energy and wind energy can be explored as a viable option for replacing diesel in powering the BTS sites worldwide [5] and specifically in India [6].

1.1 Powering the Indian BTS sites

In India today, the BTS sites are primarily powered by the electrical power-grid, a battery back-up and a diesel generator. The power from the grid is available at a tariff of ₹5 to 6 per unit (kWh). If this power were available 24 hours a day, it would not amount to such a high power cost. However, this is not the case in most of India. While in urban areas, the typical power-cuts may be two to eight hours a day, it may go up to 20 hours a day in rural areas. Further, almost 18% of BTS sites [7] are off-grid.

As telecom service is to be provided 24 hours a day, without any interruption, all telecom equipment have battery back-ups. The batteries used are mainly Lead-Acid, though in recent times, Lithium-polymer batteries are being increasingly used. These batteries are mostly considered as a part of Capital expenditure (CAPEX) and rarely does one compute its impact in terms of operation expenditure and compare it with the cost of power from the electrical grid. These batteries have a finite life associated with a number of charge-discharge cycles and need regular replacement. Box 1.1 presents the specifications and cost of the batteries and the results of an exercise to treat some typical batteries as purely an operational expenditure (OPEX). Using 14% as finance cost (interest rate), the CAPEX is converted into yearly installments to be paid to a bank for financing the battery and cost per unit of power (kWh) is computed and plotted as a function of number of charge-discharge cycles used in a day. Two commonly used batteries, one Lead-Acid and another Lithium-Polymer are used for this exercise; these are not the high-performing batteries available today[1], but the ones typically used till recently by many operators.

The results are astonishing. The Lead Acid battery cost is over ₹25 per unit of electricity for one charge-discharge cycle per day and falls to ₹23 per unit even with four charge-discharge cycles per day. For Lithium battery, the situation is equally dismal, starting close to ₹25 per unit for a single charge-discharge cycle and falling to just over ₹19 per unit for four cycles per day. This cost is over and above the cost of charging the battery. Today, higher performance Lead Acid and Lithium-Polymer batteries are available, which would (as discussed later) reduce the costs. But still the *battery-storage costs per unit of electricity would work out several times that obtained from the grid-power*.

As batteries are recognized to be expensive, diesel generators are also used at most sites. Typical generators used are of 15kVA capacity, costing about ₹2.5 Lakhs and have a typical life of 10 years. The amount of diesel used per unit of electricity is given in Box 1.2; note that it varies with the load that the generator drives, and for low load percentage (of maximum load of 12kW), the quantity of diesel required per unit of electricity produced goes up drastically. Taking the current costs of diesel at ₹45 per liter and cost of maintenance of generator as ₹7 per hour, the unit cost of electricity produced is plotted verses the generator load in the Box. Once again, the cost per unit of electricity delivered by the diesel generator is several times that of grid-tariff. Worse, the cost per unit increases sharply as percentage load goes down. Most BTS sites use DG at low load for a significant percent of time.

Further, diesel is a commodity, which is pilfered rather easily; exact consumption of the diesel towards powering of BTS site is difficult to measure[2]. Pilferage adds significantly to the costs of diesel at a BTS site. This has not been included in the costs presented in Box 1.2.

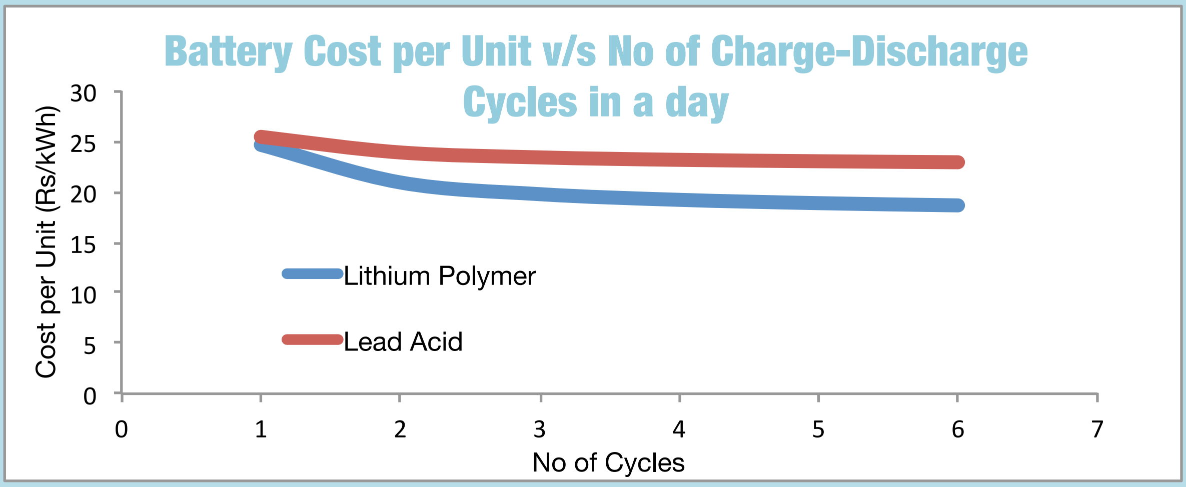
---

[1] *Better Lead acid and Lithium Polymer batteries will be used later in the report for actual cost computations*

[2] *In the last couple of years, there has been a host of companies attempting to add equipment to measure the exact consumption of diesel remotely; however, the benefit of these efforts have not become yet obvious to an operator, given that there are costs involved in adding these extra equipment.*

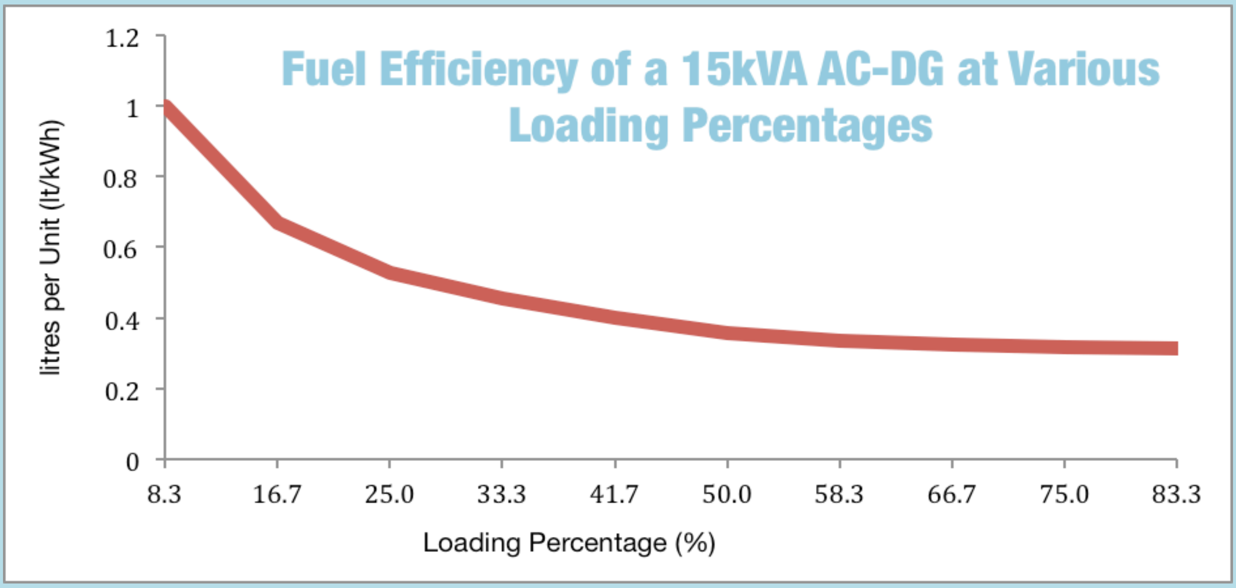
Thus, we have a scenario where most of the BTS sites in India are powered by a combination of supply from the electric grid (wherever and whenever possible), batteries and diesel generators. The high-cost of battery back-ups and diesel generators skew the total power cost for the BTS sites to a very significant extent. Higher the unreliability of the grid-power availability, higher would be the total power cost at the site. As one goes away from the metros to the towns and to the villages, the availability of grid-power decreases. The OPEX associated for rural sites therefore is much higher than that for an urban site. Given that the rural sites are less loaded (as the subscriber density is less) and the Average Revenue per User (ARPU) in rural area is less than for urban areas, the rural BTS site becomes that much less attractive for an operator. The operators start neglecting the rural sites affecting the availability and Quality of Service (QoS) in rural areas.

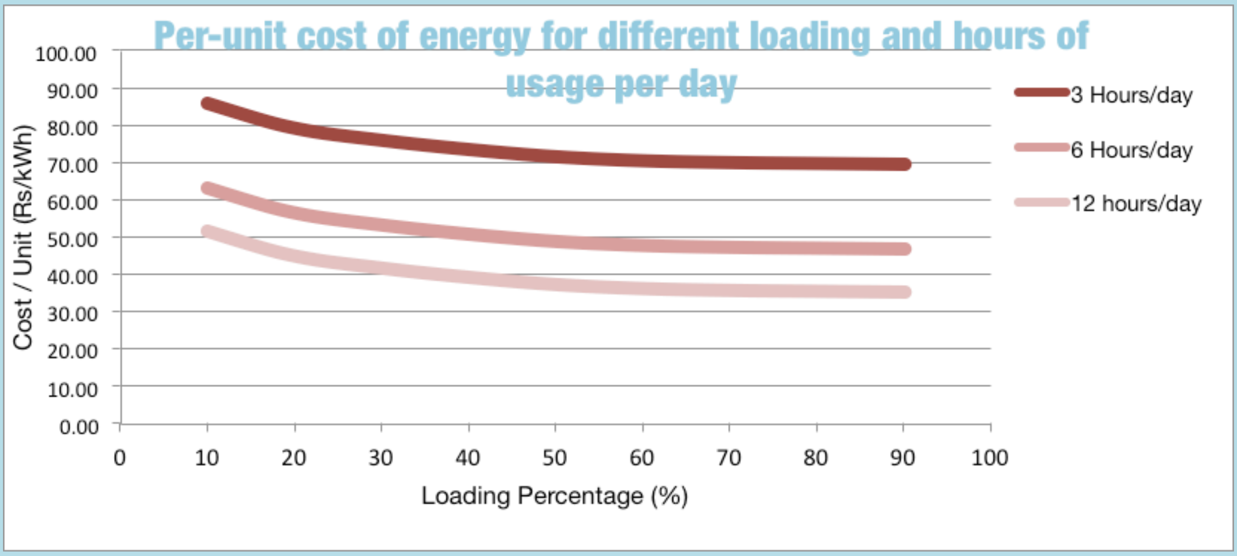
	LEAD ACID	LITHIUM POLYMER
Life Time (Charge Discharge Cycles)	700	2000
Cost per kWh (say 24V, 40Ah) in INR	5000	25000
% Discharge in each cycle	40%	80%
Energy Loss in charging/discharging	15%	5%



BOX 1.1: UNIT COST OF ENERGY DELIVERED BY SOME TYPICAL BATTERIES[3]

[3] *All other costs are included. Capital Expenditure of the battery is considered to be financed at an interest cost of 14%. Life of the battery is computed based on number of charge-discharge cycles per day and total life cycle of the battery. Using this, finance costs per year for the battery are computed. Using total units of energy delivered in a year (number of cycles per day x battery capacity x discharge percentage allowed x 365), the unit cost of energy delivered by the battery is obtained. Losses are also taken into account. Cost of energy for charging the battery is not included, as it will depend on source used for charging.*





BOX 1.2: PER UNIT COST OF ELECTRICITY DELIVERED BY A TYPICAL AC DIESEL GENERATOR (DG)[4]

[4] *A 15 kVA AC generator gives a maximum of 12 KW of power (0.8 power-factor). The capital cost is ₹250,000 which is financed at interest rate of 14% for its life-time of 10,000 run hours; for example for three hours of DG usage per day, life would be nearly ten years, contributing to yearly cost of ₹50,158. The maintenance cost is taken as ₹7 per hour of usage. Diesel cost is taken as ₹45 per liter. Total cost per unit of electricity generated is then computed adding the yearly contribution due to the cost of generator, maintenance cost and cost of fuel used for different generator loading and for 3, 6 and 12 hours a day usage.*

1.2 So are there Alternatives?

Given the above scenario, is there a solution to lower the high OPEX for BTS sites contributed by power? There have been a number of solutions that have been proposed over the last few years. A number of trials have been conducted, and often vendors, tower-operators and telecom operators have declared that they have found the magic wand. But none of these alternative solutions scale. As soon as one attempts to use them in some substantial numbers, the cost-benefit ratio starts getting skewed. The promised projections go awry and the deployment starts fizzling out.

Before we discuss why the solutions fail to fulfill the promised potential, let us look at the kind of elements that these alternatives build upon. They are:

1. **Use of better batteries**: Both the Lead Acid as well as Lithium Polymer battery have been improving rapidly. Use of better battery and better battery management certainly helps.

2. **Use of different kind of diesel generators**: DC generators do have much less variation in the amount of diesel used per unit of electricity with the generator-load as compared to that for AC generator. They, therefore, help as the loads vary. Similarly, use of a governor with an AC generator improves its efficiency for lower loads. Using these alternatives reduces the amount of diesel consumption at a site.

3. **Use of better remote monitoring and management**: Monitoring enables one to figure out what is going wrong; remote management enables one to attempt to optimize use of different sources. It promises prevention of pilferage and reduction of total cost by optimized use of sources.

4. **Use of renewables, especially solar photo-voltaic (PV) as a source to power BTS sites**: As discussed the costs of solar PV has been falling rapidly and it promises interesting opportunities.

Each of these elements helps in reducing operational expenditure at BTS site. But the reason why none of the solutions have made significant difference so far is because of the great divergence in conditions at different sites. What works at some site may not work at another place. Some sites have very frequent power failure, whereas others have less. Some have high loads (multiple BTS and air-conditioners), whereas others have much less. The tenancy (number of operators in sharing the shelter) is different for different sites. The temperature at some BTS sites is very high, while at others, the climate is more temperate. Therefore there cannot be a single solution, which will apply across all the sites. Also, these are not new sites. Equipment has already been purchased and deployed. So one cannot totally change them and the CAPEX / OPEX need to be taken into account, when new techniques are introduced. Keeping these variations in mind, a need for analyzing the energy consumption in the BTS shelter becomes important.

The report therefore proposes and uses **a simulation tool** developed at TCOE, IIT Madras, where each site could be independently analyzed. Different power-sources (existing and proposed) and their specifications can all be given as inputs. The site geography is given as an input, thereby enabling an estimation of temperature profile and sunlight availability profile; the geography also enables one to provide an estimate of grid-availability during 24 hours. The loads at the site are given as inputs. The logic used to control each source is also an input. The simulation tool then simulates the state of power generated and used every minute and computes the costs involved. The simulation is carried out for multiple days and usage of each source and the cost associated with each is then computed. The size and nature of sources chosen and the logic used to turn them on and off can be varied and the results analyzed and compared to the other, so as to find the most optimum solution for the site.

This report provides a **quantitative analysis** of the various costs involved in powering BTS sites in India. This report does a detailed computation of costs related to powering BTS sites with different configurations, geography, time of the year and using different fuel sources. The report also brings out how the usage of renewable energy helps in quantitative terms. Furthermore, the report also lists recommendations categorized under three segments namely Research & Development, Adaptation & Adoption and Policy Measures.

Section 2: Simulation Tool to Analyze and Optimize Energy Usage at BTS sites

As mentioned previously, a single power solution will not suit the needs of all the BTS sites in India. Hence, a customizable simulation tool has been developed to quantitatively analyze the energy usage in the base station shelter and control different sources of power, enabling optimization of energy usage and costs for each site. The solution evaluates the energy usage depending on the geography and the time of the year. The simulation enables various sources of power to be mixed judiciously so as to drive the load optimally, ensuring a reduction of OPEX. Additionally, this simulator facilitates the addition of new parameters and altering the values of the existing parameters.

The section starts with a brief description of loads at BTS shelter, which the simulator takes into account. It then discusses the site-specific data required by the simulator. Further, it describes how the data with respect to energy sources are provided to the simulator. It then briefly describes the technique used by the simulator. Finally it discusses in detail the different outputs that are obtained using the simulator and could be used for optimization of energy usage at the BTS site.

2.1 Loads at the BTS shelter

BTS tower provides communication access to the mobile phone subscribers located within a certain radius from the tower. The BTS (Base Transceiver Station) equipment forms the core component of the tower, providing radio access to the mobile phones and hence needs to be powered 24 x 7 three-sixty-five days a year without any interruption, for ensuring reliable connectivity. The BTS used to have its electronics in a shelter near the tower and signals were taken up to tower where the transceivers and antennas were mounted. This is referred to as indoor BTS. The electronics of the BTS is designed to operate at a maximum temperature of 35 to 45°C and therefore needs to be cooled. Blower-fans could be used at lower temperatures, but as the ambient temperature exceeds 35°C, one needed air-conditioners to cool the shelter.

Further, batteries are placed in the shelter, to provide the back up in case of power-failure. Typical batteries need to operate at 27°C so that their lifetime performance does not deteriorate. The shelter also has a power combiner and convertor unit (called Integrated Power Unit or IPU), which combines various sources of power and converts it to 48V DC; battery used is 48V DC and all telecom equipment are designed to have 48V DC as its power input.

The energy-loads at a shelter therefore consist of BTS load, cooling load and miscellaneous loads.

Nowadays, many a times, one uses outdoor-BTS where the electronics is outdoors at the base of the tower or mounted on the tower along with the transceivers and antenna. The batteries are then placed outdoor in a chiller and shelters are avoided.

BTS Load: As the power consumed by the BTS does not vary very significantly over the day, the load profile is assumed to be a constant. Typically 800W is consumed by a new BTS.

Cooling Load: The energy consumed by equipment which is used in removing heat from the shelter or conditioning of the required electronics are classified here as cooling loads.

Air Conditioner: As the BTS electronics have a maximum temperature of operation and also the heat generated by the electronics is to be removed from the shelter, an air conditioner is required; the air-conditioner can be set up to start operation at some specific temperature. Depending on the ambient temperature and the sunlight falling on the shelter, the electricity required by the air-conditioner would vary and can be given as an input to the simulator. The cut-off temperature of the air conditioner is typically set to 35˚C and the maximum power consumption of the air conditioner is typically 2kW.

Battery Chiller: The lifetime of a battery is a function of the ambient temperature depending upon the type of the battery. As the temperature increases by 10˚C, the lifetime of a typical lead acid battery is reduced to half of its actual value. Batteries also produce heat while charging, which accounts for increase in the temperature of the battery unit. The experimental results show that a typical battery has the best lifetime when maintained at 27˚C. If the battery is placed in the shelter, the air-conditioner in the shelter maintains its temperature to 27◦C. Since other equipment in the shelter can operate at higher temperatures, this results in excessive cooling and high power-bills. An alternative used sometimes nowadays, is to place the battery in a separate cabinet, which is cooled separately. A battery-chiller is used for this purpose. Depending on the size and the nature of batteries used, the power-consumption of the chiller would vary. Typically a chiller consumes 100 to 300W of power.

Miscellaneous Loads: Battery charging is also a load that needs to be considered. Other additional loads include fans and lights in a shelter, which typically consume 100W.

2.2 Site Specific Data

The location of a site and the day of the year play an important role in determining the power-usage at a BTS site. The ambient temperature profile for each geographical location determines the cooling load on the air conditioner and the sun's irradiance determines the amount of power that a solar panel, if used, would provide. The simulation has hourly temperature and solar-irradiance (also called insolation profile) as input parameters.

2.3 Types of Shelter

The shelter design plays an important role in determining the amount of cooling load that would be required at any site. The typical size of a 3A shelter is around 20 m^2 and can contain up to 3 tenancy BTS. Today, the BTS used are either of the indoor or the outdoor type. The indoor BTS is placed in shelters like the 3A shelter, whereas the outdoor BTS is mounted on the tower, the batteries are placed in a chiller and the power equipment is kept in a suitable housing. In recent times, there have been some attempts to retro-fit the existing BTS shelter, so as to have separate compartments for batteries and the rest of the equipment, with the two being cooled to different temperatures, hence optimizing the cooling load. The three types of sites are described in Boxes 2.1, 2.2 and 2.3.

2.4 Typical Energy Sources used at BTS site

A BTS site is typically powered by multiple sources, which include the grid supply, the diesel generator (DG), solar-PV and batteries. Detailed data about the sources needs to be fed into the simulator, before it is run. The set of data required for each of the sources is discussed below.

2.4.1 Diesel Generator

When the grid fails, the battery drives the load and in the process discharges to a certain level. To prevent batteries from discharging further, a DG is turned ON to drive the load as well as to recharge the battery. Essentially, a DG is turned on when all other sources together are not able to meet the power-demand of the site.

The capacity of the DG varies according to the tenancy (number of operators using the site) of the BTS shelter. With an increase in the tenancy of the BTS shelter, the size of the diesel generator goes up. The fuel consumed by the DG depends on the load at which the generator is operating (as a percentage of DG's capacity). There are two kinds of diesel generators. The conventional DG is the Alternate Current (AC) generator, where the 230V AC power signal is converted to 48V Direct Current (DC) power before it is used for charging the battery or for driving the telecom equipment. The AC is used to drive the air-conditioner directly. The DC diesel generator, on the other hand, has DC output, which charges the battery directly and drives the telecom equipment. The DC output needs to be converted to AC to power the air-conditioner. The relation of fuel efficiency at various loading percentages is shown in Fig. 2.1 for a typical AC DG with a capacity of 15kVA and DC DG of 12kW capacity[5]:

Box 2.1: Conventional Indoor BTS Shelter

Typically, a conventional BTS shelter contains the BTS equipment, the power unit (AC-DC), batteries and an air conditioner. The shelter is maintained at 27 degrees centigrade by a 1.5 ton air conditioner for ensuring optimal lifetime of the batteries. In the absence of batteries, the shelter is cooled to 35 degrees centigrade for safe operation of the BTS electronics. Maximum power consumption of the air conditioner is typically 2kW. It consumes 50% of power till the ambient temperature reaches 35°C and linearly increases to its maximum value when it reaches 45°C. The variation of power consumption of the air conditioner with the ambient temperature is provided as an input to the simulator.

Box 2.2: Retro Fitted BTS

In a retro fitted type of BTS, the equipment and the batteries are cooled separately. The battery bank is separately enclosed in chiller cabinet maintained at 27˚C. A fan is used to remove the heat till the temperature of the shelter remains below 40°C and if the temperature rises above it, then a 2kW air conditioner is used. The variation of power consumption of the battery chiller with the temperature is provided as an input to the simulator. An illustration of the same has been discussed in Section 3.2.6.

[5] *Based on the load at which the DG is operated, the cost of running the DG per hour is calculated. The maintenance cost/hour is added to this to arrive at the operational cost of running the DG per hour. The CAPEX costs associated are discussed later in section 3.2.2*

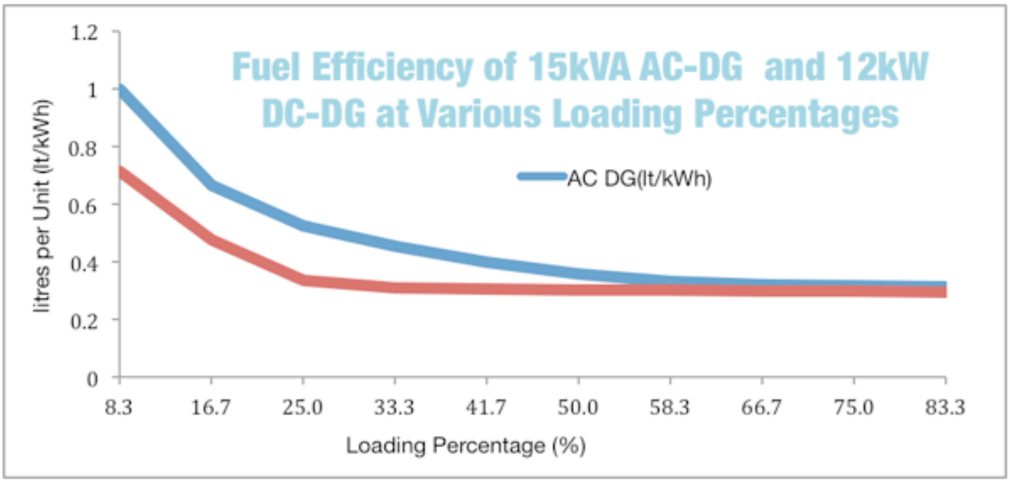


FIGURE 2.1: EFFICIENCY OF AC AND DC DIESEL GENERATORS AT DIFFERENT LOADING PERCENTAGES

The advantage in fuel consumed per unit of electricity generated is significant at lower loads in a DC DG; this is because the speed of the generator can be controlled as per the load requirement, whereas in an AC-DG this cannot be easily achieved. Furthermore as AC to DC conversion is avoided, the losses associated with it, while charging the battery or using it to drive telecom equipment is avoided. However, as air-conditioners normally use AC power, DC to AC conversion losses will come in when air-conditioner is turned on.

BOX 2.3: TYPICAL OUTDOOR BTS

A typical Outdoor BTS is designed to operate at higher temperature conditions with just a fan and eliminates the need of an air conditioner. The batteries are encased separately in a chiller cabinet, which is maintained at the temperature required to enhance the lifetime of the batteries. The power variation of the chiller with the temperature is provided as an input to the simulator and is further discussed in section 3.2.6.

2.4.2 Battery

In India, grid failure is a common occurrence. In order to ensure that the functioning of the BTS shelter is unaffected during the lack of power supply from the grid, a battery is used as the primary back up source of power. Lead acid batteries are predominantly used because of their lower prices and easy availability. Lately, Lithium polymer batteries that have a much higher charging rate, depth of discharge and higher lifetime are being used in BTS sites. The simulator has been designed to take different battery specifications and different battery charging-discharging models as discussed below. New models can be added as and when necessary.

Battery Parameters and their Impact

The parameters of the battery that are considered in the simulation and their impact are discussed in this section.

a. Battery Nominal Capacity*:* The nominal capacity of a battery, which is expressed in Ah or Ampere-hour capacity, is the current a battery can provide over a specified period of time. For example, 100Ah of 1.75V/cell battery means that the battery can provide 10 Amps for 10 hours to an end of discharge voltage of 1.75V per cell. Typical values of capacity considered in the simulation for Lead Acid and Lithium Polymer are 600Ah and 150Ah respectively.

b. Battery Voltage: A battery-string or battery-bank comprises of a number of cells/batteries connected in series to produce a battery or battery string with the required usable voltage/potential e.g. 6V, 12V, 24V, 48V, 110V. In BTS applications, the voltage is predominantly 48Volts, while 24 Volts is used in some of the older BTS.

c. Cycle Life: The cycle life is the number of cycles (charge/discharge) a battery provides before it is no longer usable. A battery is considered non-usable if its nominal capacity falls below 80 percent. The number of cycles depends on the depth-of-discharge levels of operation of the battery. In most of the telecom BTS applications the typical discharge percentage is around 40% for Lead Acid and 80% for Lithium Polymer Battery. The cycle life of a new battery with the above mentioned configuration is typically around 1500 charge-discharge cycles for Lead Acid and 6000 charge-discharge cycles for Lithium Polymer battery.

d. Charging Rate (C rate): The charging or discharging rate of a cell or battery defines how fast the battery can be filled with charge and is expressed in terms of its total storage capacity in Ah or mAh. So a rate of 1C discharging rate means transfer of all of the stored energy in one hour; 0.1C means 10% transfer in one hour, or full transfer in 10 hours; 5C means full transfer in 12minutes, and so on. Similarly, charging rate of 0.1C would imply that a battery with zero charge would get fully charged in 10 hours. Lead acid batteries have a lower charging rate compared to Lithium Polymer battery. The typical charging rates for Lead Acid and Lithium polymer batteries are 0.2C and 1C respectively.

e. Partial State of Charging Levels (psoc): The batteries have a nonlinear charging characteristic, which is based on their SoC (state of charge) levels. The charging rates keep decreasing as the battery reaches a higher rate of SoC for Lead Acid battery and hence we judiciously consider the SoC levels to operate from 30% to 70% SoC levels where the charging rate is almost linear (Figure 2.2).

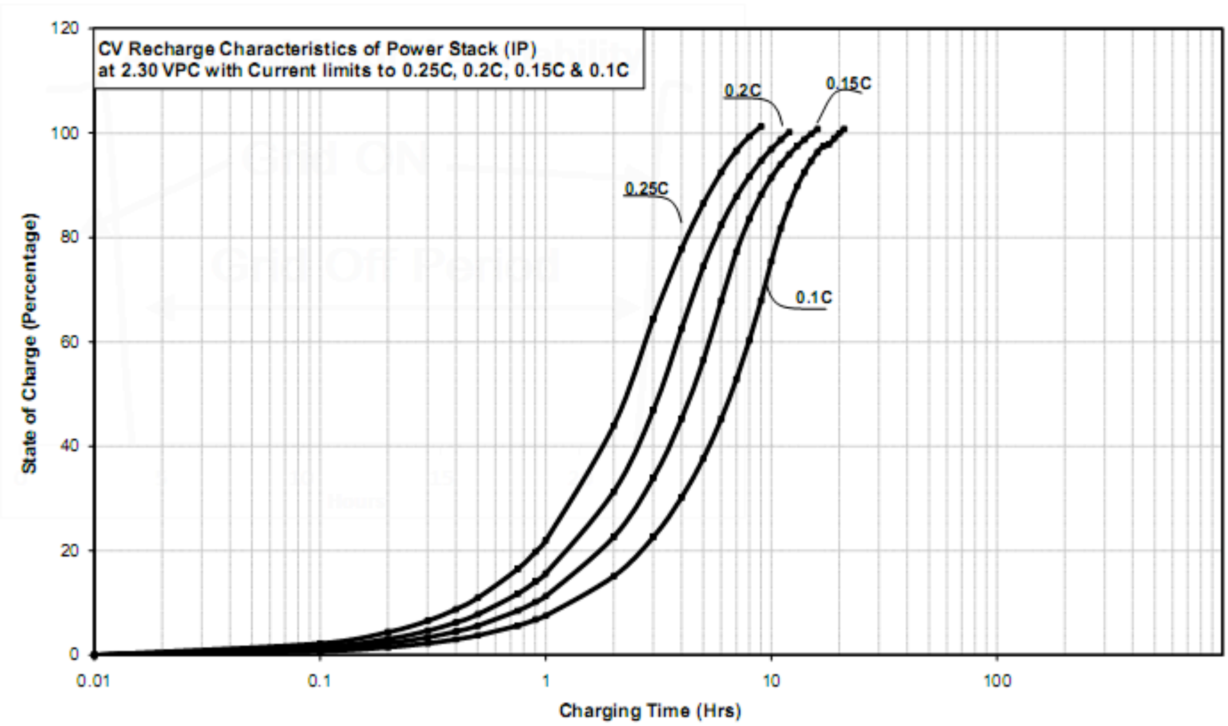


FIGURE 2.2: TYPICAL RECHARGE CHARACTERISTICS OF A LEAD ACID BATTERY [8]

As the charging characteristics of Lithium Polymer battery do not vary much with the SoC levels, linear charging models can be used.

f. Battery Efficiency/Energy Loss: This term describes the proportion of a secondary battery's nominal capacity, which is lost during charging, and not returned using discharge. The efficiency of a Lead Acid battery can be as low as 85% while the Lithium Polymer has a very high efficiency of 99%.

g. Battery Cost/kWh: Battery manufacturers price their batteries in terms of its capacity given in kWh. This value indicates the amount of energy that the battery can deliver at the specified voltage rating during its lifetime. The price for the Lead Acid and Lithium Polymer battery can vary widely and can be as low as 5000 ₹/kWh and as high as 45000 ₹/kWh respectively. However, as depth of discharge and number of charge/ discharge cycles can vary widely, this needs to be converted into cost per unit of electricity delivered. The costs for the battery are converted into OPEX by yearly installment based payment method at typically 14% interest rate (this can be changed for specific cases) as discussed in section 1.1, Box 1.1.

2.4.3 Solar PV

India, being a tropical country, has high amounts of solar insolation in most parts. Generally, the initial capital expenditure involved in using solar PV is high and is detrimental for the adoption of solar PV as a source of power generation. But, in the recent days the falling prices of the solar PV seems to change the scenario. The following Box 2.4 presents the calculation of cost per unit of energy. The depreciation for capital goods is used to allocate costs on a yearly basis; to this the yearly interest cost and the OPEX is added to obtain the total costs of energy in a year. The assumptions include ₹45 per Watt (p) for solar panels and only ₹15 per Watt (p) for rooftop installation, 1800 hours equivalent of peak sunlight in central parts of India and 11% interest rate for a 20-year finance. Even if a slightly lower equivalent peak sunlight hours (1650 hours as applicable in Chennai) is taken, the costs would be less than ₹5 per unit. Note that this is the cost of DC energy generated right at the site, which could be used to charge battery and drive telecom equipment.

The assumptions considered for the calculation of the cost per unit from a solar panel are tabulated below:

Parameter	Value
Cost of PV Panel per kW	₹ 60,000
Losses (%)	10
Number of sun-hours per day	6h
Total number of sun-days per year	300

Table 2.1 Assumptions for the cost per unit calculation of the solar PV

- Cost of a panel along with the BOS (Balance of System costs) is taken as ₹60/Wp.
- **The CAPEX is converted to yearly installments payable for 20 years with 11% interest.**
- Total Units generated per year = sun hours per day × sun-days per year

  Using the above relation, the total units generated per year are calculated to be 1800.
- Price per unit = $\frac{\textbf{Yearly installment}}{\textbf{Total units generated per year X Efficiency}}$

Box 2.4: Energy Costs of Solar PV Panels

2.4.4 Integrated Power Unit (IPU)

The Integrated Power Unit consists of a power-convertor and power-management unit within the BTS shelter. The IPU has a remote transfer unit, battery charger, SOC measurement unit, DG fuel level sensor, AC-DC converter, DC-AC convertor (when needed) and a DC-DC converter. The four primary functions of an IPU (elaborated in Box 2.5) are:

1. Remote monitoring of the BTS shelter
2. Power Processing
3. Controlled Switching to switch right power sources and loads
4. Power-conversion

Remote monitoring of the BTS shelter:

The BTS has several parameters (alarms) that can be monitored remotely. They include:

- The EB mains failure alarm, which is used to detect the grid supply to the BTS shelter and an alarm to indicate low battery.
- An alarm to detect the DG's failure to start/stop.
- The alarm to indicate that the DG fuel level has fallen below a critical value.
- An alarm for AC critical parameters, which indicates when to turn on the primary AC and the secondary alarm to turn ON the second AC.
- The temperature sensor alarm, to caution when the temperature rises beyond a critical value in the BTS shelter.
- An indicator alarm to mention the state of charge of a battery, so as to turn ON the DG.
- Indicators to monitor the state of health of the battery and of the power equipment (rectifier).

Power Processing unit:

As mentioned earlier, the BTS shelter gets power supplied from three sources, namely the EB mains, the battery and the diesel generators. The BTS equipment runs normally on 48V DC. The typical EB grid supply to the BTS shelter is a 3 phase, 230V AC.

The EB mains and the diesel generator give a 230V AC, which has to be converted to 48V DC. An AC-DC converter is used to convert from 230V AC to 48V DC. The battery bank directly gives a 48V DC.

Box 2.5: An Overview of the functions of the Integrated Power Unit

2.4.5 Grid Assumptions and Costs

Grid power-availability and its timings are specific to the site. The tariff of grid power is typically ₹5 per kWh, but could vary from state to state and would depend on classification of BTS by power utilities as commercial or non-commercial.

Grid- power availability could vary a lot depending upon the state, specific location within the state, time of the year, state of power-sources and demand at any specific time. It is possible to specify any arbitrary availability in the simulation. However, we have considered some scenarios where the grid supply is assumed to be available for four hours and for eight hours at different times of the day. The grid availability has been modeled into either single burst or multiple bursts and listed as cases. These models could be readily used during simulation and one or the other may give a reasonable understanding for most parts of the country at different time of the year.

A single burst of 4 or 8 hours is taken during day or night as shown in table 1 below (cases 1, 2, 4 and 5). In cases of multiple bursts, the bursts are separated equally throughout 24 hours (cases 3, 6, 7).

Case	Bursts	Grid (hrs)	Timing of power availability in a day
1	Single Burst	4	11pm – 3am (Night Grid)
2	Single Burst	4	11am – 3pm (Day Grid)
3	Multiple Burst	4	11pm to 12am, 5 -6am, 11am to 12pm, 5-6pm
4	Single Burst	8	11pm – 7am (Night Grid)
5	Single Burst	8	11am – 7pm (Day Grid)
6	Multiple Burst	8	11pm to 12am, 2am – 3am, 5am – 6am, 8am – 9am, 11am – 12pm, 2pm- 3pm, 5pm – 6pm, 8pm – 9pm
7	Multiple Burst	8	11pm to 1am, 5am – 7am 11am to 1pm, 5pm to 7pm

TABLE 2.2: GRID AVAILABILITY CASES

2.5 Simulation Technique

Sources and loads are modeled according to their type and characteristics. The tool ensures that all the models and its dependencies for processing its inputs are provided by the user. The power demands of the load models are catered by the source models with a resolution of 1 minute using a controller block by using a priority allocation algorithm.

Power Mixing and Allocation: When the grid is available, it is always assumed to be the first to be used to power the site. Sites with battery backup charge when the grid is available and discharges to the load during its absence. When the site has no battery backup or if the battery is discharged to a specified level (which needs to be specified before simulation), the DG is turned ON to cater to the load and also recharge if applicable. Similarly, the DG turn-off when the battery is charged to a specific level needs to be specified.

2.5.1 Outputs of the Simulator

The simulator is designed to analyze the system in a holistic manner at every minute of the site's runtime. The simulator output provides a very detailed graphical dashboard, which enables one to correlate the state of load and source conditions. It also provides detailed output, which can be imported to any database for analysis and visualization. It can become a tool for optimizing costs or carbon emission, if one wants.

It is possible to simulate various cases, involving a combination of using the AC DG/DC DG, Lead Acid battery/ Lithium Polymer battery and the addition of PV. The classification of cases considered in the simulation is based on:

- Type of Diesel Generator considered
    - AC DG
    - DC DG
- Type of Battery at the site
    - Lead Acid battery
    - Lithium polymer battery
- Addition of PV to the site with battery

In the next chapter, we will take up simulation and analysis of several cases, as an illustration. The following cases will be simulated and analyzed:

A	AC Gen only		
B	AC Gen	+ Lead Acid battery	
C	AC Gen	+ Lithium Polymer battery	
D	AC Gen	+ Lead Acid battery	+ Photovoltaic panel
E	AC Gen	+ Lithium Polymer battery	+ Photovoltaic panel
F	DC Gen only		
G	DC Gen	+ Lead Acid battery	
H	DC Gen	+ Lithium Polymer battery	
I	DC Gen	+ Lead Acid battery	+ Photovoltaic panel
J	DC Gen	+ Lithium Polymer battery	+ Photovoltaic panel

TABLE 2.3 LISTING OF SIMULATED CASES

Output Parameters of the Simulator

This section presents some typical outputs of the simulator.

A. Energy Consumption by the loads for 24 hours

The total energy consumption of the shelter is mainly the BTS equipment load (800W+100W) and the cooling load (2kW Air Conditioner). The percentage of equipment load and the cooling load consumption in a typical day is shown in table 2.4.

Consumption	kWh/day	% (Cons/day)
Equipment Load	22.00	39.29
Cooling Load	34.00	60.71
Total Load	56.00	100.00

TABLE 2.4: POWER CONSUMPTIONS BY THE LOADS

B. Sources

The energy produced by each source and the associated cost per unit calculated by the simulator is displayed in a tabular form. Furthermore, there is a column which shows the total cost of energy per day. Table 2.5 captures some typical results.

Source	kWh/day	% (Prod/Day)	Cost/Unit (Rs/kWh)	Total Cost Energy/Day(Rs)
Grid	11.89	15.50	5.00	59.47
Generator	21.42	27.92	14.75	315.96
Battery	21.42	27.92	13.33	285.58
Solar PV	22.00	28.67	4.70	103.47
Total	77.00	100.00		764.47

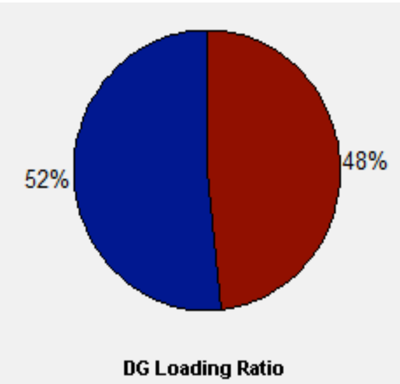
TABLE 2.5 CONTRIBUTIONS OF DIFFERENT SOURCES

C. DG Output Parameters:

Figs. 2.3 and2.4 and the Table 2.6 presents typical simulator output, showing the amount of fuel consumed by the DG, the loading on the generator as a percentage of its maximum capacity, the number of times it was switched ON and it's total run time. The generation cost is also computed and is displayed with the output results.

Parameter	Value	Units
Average Litres of fuel consumed/day	4.62	Litres/day
Average DG Run time/day	2.00	Hours/day
Average Number of times the DG is turned ON/day	2.05	
DG Generation Cost	15.39	Rs/kWh

TABLE 2.6 DG OUTPUT PARAMETERS



Loading Ratio (%)	Time Fraction (%)
70.00	51.75
80.00	48.25

FIGURE 2.3: DG LOADING PERCENTAGES AND TIME FRACTIONS

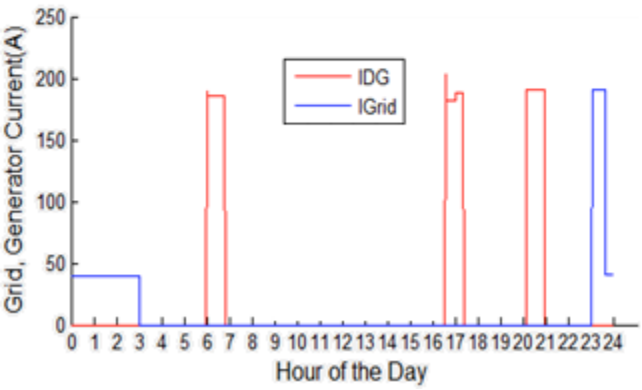


FIGURE 2.4 PROFILES OF THE SOURCE CURRENTS ACROSS THE DAY

The generator is turned ON at various instants in a 24 hour period and depending on the state of charge of the battery at the instant, the duration of the DG run is decided. An illustration of power produced by the generator (IDG) and the duration for which the generator and grid remains functional is shown in Fig. 2.4. Depending on the load at any instant, the generator is loaded at different levels; loading ratio is ratio of the load driven by the generator as a percentage of maximum load that the DG can drive. Typical loading ratios and their corresponding time fractions are shown as a pie chart in Fig. 2.3 for a quick intuitive insight.

D. Battery Output Parameters:

Table 2.7 and Fig. 2.5 show some typical battery related parameters as obtained from the simulator.

Parameter	Value	Units
Average Charge-Discharge Cycles/day	4.00	Cycles/day
Battery Lifetime	4.11	Years
Average Battery Charging Energy by DG/day	17.16	kWh/day
Average Battery Charging Energy/day	21.30	kWh/day
Average Battery Energy Delivered/day	21.42	kWh/day
Battery Charging Load	22.00	kWh/day
Average Battery Energy Cost	13.33	Rs/kWh

TABLE 2.3 OUTPUT PARAMETERS FOR THE LITHIUM ION BATTERY WITH LIFETIME OF 6000 CYCLES

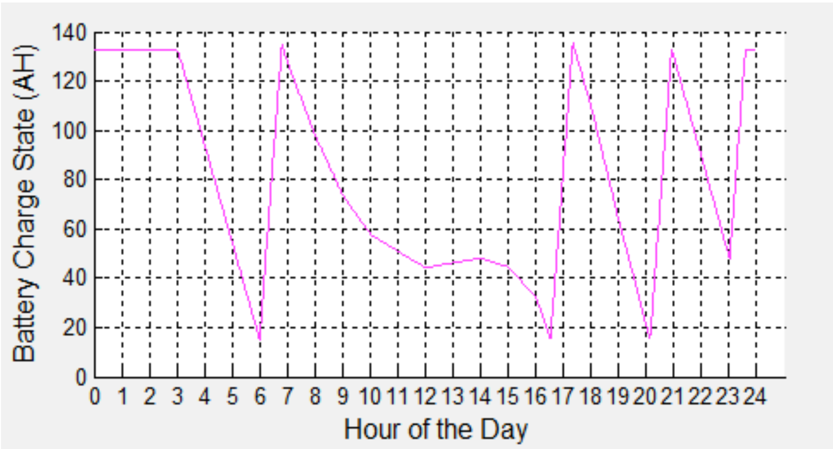


FIGURE 2.5 BATTERY CHARGE- DISCHARGE CYCLES

It can be seen that the simulation tool takes in to account the different loads, various sources of energy and other data relevant to the geography of a BTS site and comprehensively simulates the site. The output of the simulation tool includes the total energy consumption per day of the BTS site, the total cost of energy per day, the energy contribution by each source and the associated cost per unit of the energy generated by every source. These calculations give in-depth insights into the contribution of each source of energy used to the energy cost of the site and hence aids in the designing of an optimal cost effective site-specific power-solution.

3. Powering Options for the Indian BTS Sites: Energy Costs as obtained using Simulations

3.1 The BTS site - variety

As mentioned previously, most of the BTS sites in India are indoor BTS shelters; the new ones are however the outdoor BTS shelters and there are some sporadic attempts to retrofit sites. Each of these three types of the BTS shelters have been considered here in the simulation. Variation is however not limited to the type of sites. Though, the basic configuration of the site constitutes the BTS, grid as an energy source, battery as a backup and DG as an alternate source of energy, the sizing, usage and type of each of these constituents vary significantly between different sites. Some sites may also be powered by renewable energy sources like the PV. The section therefore reports the results of simulation carried out for several of these variations encountered in a BTS site. These variations give us a deeper insight into the cost and energy associated with them by enabling comparison with its alternatives.

The results here do tell us a lot about what is likely to work and what is not likely to work in India. However, it should be pointed out that the simulation results are limited by the cases for which the simulation has been carried out. Someone may have or come up with a new battery with different characteristics, with a new kind of generator, with a new source of power, and the results may change. The simulator could then quickly be used to show the potential of the new sub-systems. Also, one may come up with a different strategy for using battery- generator (like when to turn a generator on and off) and in some specific conditions, one may be able to get very different results. Each such innovation would help and comparison of the new solution with other solutions can be made quickly using the simulator.

The results presented here however do reflect the general scenario of BTS sites in India and commonly available options. The parameters used in simulations are given in section 3.2

3.2 Parameters used in Simulations

3.2.1. Grid Availability

The duration of grid availability varies from shelter to shelter. Further, the total time for which the grid is available could also be in a single burst of grid supply or multiple bursts. The duration of grid availability considered for the simulation is 4hours and 8hours. Additionally, the grid is modeled either as a single burst or multiple bursts (1hour, 2hours or 4hours) of supply as presented in Table 2.2 in section 2 and reproduced here as Table 3.1.

Case	Bursts	Grid (hrs)	Timing of power availability in a day
1	Single Burst	4	11pm – 3am (Night Grid)
2	Single Burst	4	11am – 3pm (Day Grid)
3	Multiple Burst	4	11pm to 12am, 5 -6am, 11am to 12pm, 5-6pm
4	Single Burst	8	11pm – 7am (Night Grid)
5	Single Burst	8	11am – 7pm (Day Grid)
6	Multiple Burst	8	11pm to 12am, 2am – 3am, 5am – 6am, 8am – 9am, 11am – 12pm, 2pm- 3pm, 5pm – 6pm, 8pm – 9pm
7	Multiple Burst	8	11pm to 1am, 5am – 7am 11am to 1pm, 5pm to 7pm

TABLE 3.1 GRID-AVAILABILITY CASE USED IN SIMULATIONS

3.2.2 Diesel Generator Parameters

When supply from the grid is unavailable, the BTS shelter is powered by the DG. Though AC DGs have been used for a long time due to their ease of availability, these days DC DGs are also being increasingly available. DC DGs come with the advantage of direct DC power and higher efficiencies at lower loadings. The need for two kinds of DG has been described in section 2.3.1 and hence the simulations have considered both AC DGs and DC DGs in order to aid comparison of costs. The assumptions for each of these generators are as tabulated in Table 3.2.

Parameter	AC DG	DC DG
Size	15kVA	12kW
Capital Cost ₹	2, 50, 000	2, 50, 000
Lifetime (hours)	10,000	10,000
Maintenance Costs (₹/hour)	7	7

TABLE 3.2: ASSUMPTIONS FOR AC DG AND DC DG

The DG load depends on the BTS equipment used at the site and state of battery when the DG is turned on. The fuel efficiency of the DG at various loading percentages is as presented in Fig. 2.1.

The cost of energy produced by the DG is contributed by three elements: CAPEX for DG, its maintenance cost and cost of the fuel consumed. The contribution of CAPEX is computed using 14% interest rate and linear depreciation over the usage of DG for its life-time (number of years depends on number of hours of DG usage per day). The fuel cost depends on the efficiency at which the DG is running (depending upon the load).

The calculations could be described in two steps:

1. Yearly Installment is calculated based on the CAPEX, interest rate and the total lifetime of the DG. Based on this, and the number of hours used in a year, we get the cost per hour of its operation.

2. Maintenance cost at ₹7/hour along with the OPEX due to fuel consumed is then added to the value calculated in step1 to arrive at the total OPEX of running the DG per hour.

Fig. 3.1 provides the cost of the AC and DC generator for assuming diesel costs of ₹45 per liter and assuming the DG is used for 3 hours per day. Similar curves can be obtained for different hours of usage, and are used in the stimulations.

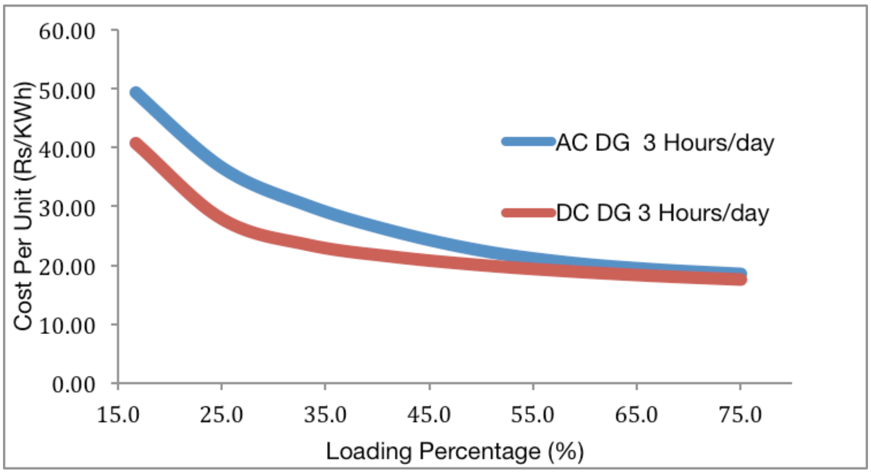


FIGURE 3.1: COST PER UNIT OF ELECTRICITY PRODUCED BY AC AND DC DIESEL GENERATORS AT VARIOUS LOADING PERCENTAGES ASSUMING 3 HOURS OF USAGE PER DAY AND DIESEL PRICE OF 45 PER LITER

3.2.3: Battery used in Simulations

Four different batteries have been used in simulations, one type of Lead Acid battery and three different types of Lithium Polymer batteries, labeled as Lithium1, Lithium2 and Lithium3. The capacity of Lead acid batteries used is 600Ah (at 48V), whereas smaller Lithium Polymer batteries of 150 Ah or 100 Ah capacity (all at 48V) are used, as the depth of discharge of Li batteries is higher and because they can withstand much higher charge-discharge cycles. The Lithium1 used is highest performing and most expensive battery; the costs of Lithium2 and Lithium3 batteries differ by ₹5000; the former has high DOD but less number of cycles whereas the latter has lower DOD, but high number of cycles. The charging / discharging rates for Lead Acid battery is one fifth of its capacity(C) of C/5 per hour, whereas that for all the three types of Lithium batteries, it is as high as C per hour. Table 3.3 presents the parameters of the four types of batteries.

Parameter	Lead Acid	Lithium 1	Lithium2	Lithium3
Capacity (Ah), 48V	600	150	150	150
Lifetime (Cycles)	1500	6000	3000	6000
DOD	40%	80%	80%	60%
Cost /kWh (₹)	6000	45000	25000	20000
Charging Rate	C/5	C	C	C
Charging Method	Non Linear	Linear	Linear	Linear
Charge Discharge Cycle SOC	30 – 70 %	10 – 90%	10 – 90%	10 – 70 %
Efficiency%	85	99	99	99

TABLE 3.3: PARAMETERS OF FOUR TYPES OF BATTERIES USED IN SIMULATIONS

3.2.4. Solar Photovoltaic (PV) Panels used in simulations

The prices of Solar PV has been reducing rapidly over the last year and half and the panels are available between ₹40 and 45 per W (peak). Solar PV can be mounted on the BTS shelters with overhang and could also provide shade to the shelter. Cost of installed solar PV has been assumed to be ₹60,000 per kW of peak power. The table below lists the parameters used in the simulations. The number of sun-days has been assumed to be 300. The sun typically shines in India for 12 hours a day, but with varying solar insolation as shown in Fig 3.3; it typically amounts to 6 hours of equivalent peak insolation. Depending on the exact site and orientation, this 300 x 6 or 1800 hours of peak sunlight could vary from 1650 to 1850 hours in most of India. The price per unit of electrical power generated by solar PV is computed using these parameters, assuming 11% interest rate[6] and a life-time of 20 years for the panel, similar to the calculations performed in section 1.2

Parameter	Value
Cost of PV Panel per kW	₹ 60,000
Losses (%)	10
Number of sun-hours per day	6h
Total number of sun-days per year	300

TABLE 3.4: PARAMETERS FOR THE SOLAR PV

3.2.5 Solar Insolation and Temperature Profile used in Simulations

Insolation Profile: Availability of light energy by the sun determines the power-output of a photovoltaic panel. This irradiance data is measured in watts/m^2 and varies with the geography of the place. The simulation uses the insolation data for Delhi (INDIA) during the month of July is shown in the Fig.3.2.

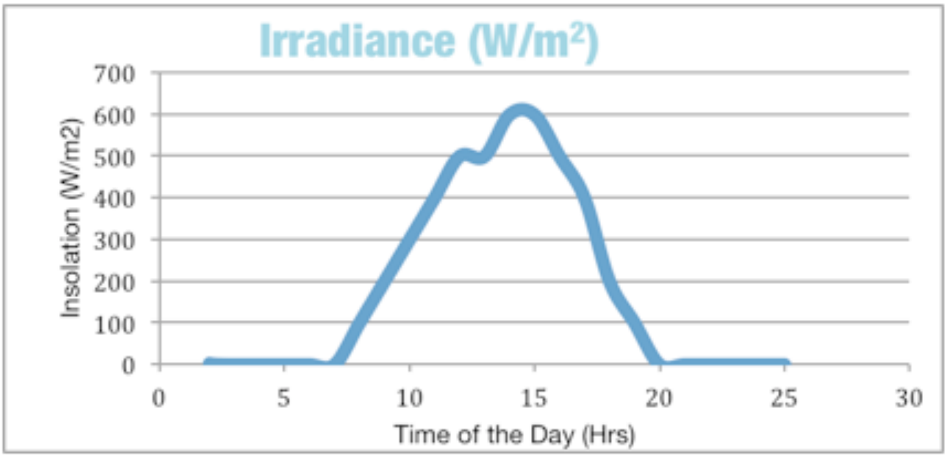


FIGURE 3.2: TYPICAL IRRADIANCE PROFILE FOR DELHI IN JULY FOR A 24-HOUR PERIOD

[6] *Lower interest rate is assumed for solar PV as the financing for solar PV is for a long-term period of 20 years and the ups and downs of interest can be averaged over the years. This is further discussed in Section 4.*

Temperature Profile: As the ambient temperature due to the sun adds on to the heat load inside the shelter, the temperature profile for the day is an input used for calculating the cooling load on the air conditioner and the chiller. The simulation uses the temperature profile for a typical day in the month of July at Delhi (INDIA) is given in Fig. 3.3.

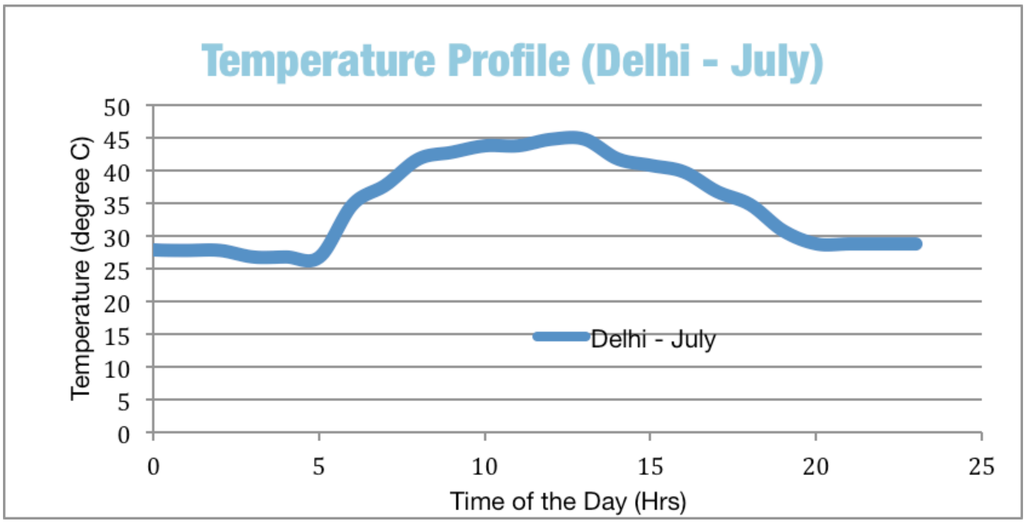


FIGURE 3.3: TYPICAL TEMPERATURE PROFILE FOR DELHI IN JULY OVER A 24-HOUR PERIOD

3.2.6 Types of BTS Sites Simulated

The detailed simulations were carried out for three types of BTS sites:

1. Conventional Indoor BTS referred to as Indoor
2. New Outdoor BTS referred to as Outdoor
3. Retrofit of conventional Indoor BTS referred to as Retrofitted

The capacity of solar PV used for the three sites is chosen based on the load requirement for each of the shelter types and are as shown in Table 3.5. The optimization of PV sizing is discussed in section 3.3.3

Shelter Type	PV Capacity
Indoor	4.8 kW
Outdoor	1.6 kW
Retrofitted	4.8 kW

TABLE 3.5: SOLAR PV CAPACITY USED FOR THE DIFFERENT SITES

Indoor shelter

The conventional Indoor shelter has batteries, the power-conditioning equipment (referred to here as Integrated Power Unit or IPU) and the BTS equipment in the single shelter. As heat is generated by these equipment, it is extracted by an air-conditioner. Batteries require the temperature to be maintained at 27°C for maximum life.[7] To carry out the required cooling, the Indoor shelter is assumed to

[7] *Different batteries are affected to a different extent with temperature. In simulations in this section, it is assumed that all batteries require a constant temperature of 27°C.*

have a 1.5 ton air-conditioner with a maximum power consumption of 2kW. The power consumption is a function of the ambient and the internal temperature. It was assumed that the air conditioner operates at 50% loading till 35◦C considering the on and off duty cycles to remove the internally generated heat by the BTS. From 35◦C the power consumption linearly increases to its maximum value till 45°C.

Retro Fitted BTS

It is possible to retrofit the conventional BTS site, by creating a partition in the shelter, creating a separate partition for battery and for BTS and IPU equipment. The battery bank is separately enclosed in chiller cabinet, which maintains the temperature at 27˚C, and the partition does not require air-conditioning. A fan of 200W is assumed to be used to remove the BTS heat load in the other chamber till the ambient temperature reaches 40◦C; the air-conditioner is turned on only at 40◦C, and its power consumption linearly increases to 1 kW for ambient temperature of 45◦C and then increases a little more rapidly to consume the maximum air-conditioner power of 2kW at 50◦C. The cooling load for the battery-chiller is low, with a maximum of 100W for lithium polymer and 300W for lead acid battery. The power consumption is assumed to be 50% of the maximum till battery cut-off temperature (27◦C) to remove heat due to battery charge-discharge; it is assumed to increase to 100% when this temperature is crossed.

Outdoor BTS

Outdoor type of BTS can withstand high temperatures and does not require cooling. The heat generated is dissipated using a high CFM fan in the BTS cabinet itself.

Batteries for the backup are separately enclosed in chiller cabinet, which maintains the temperature at 27˚C. The cooling load for the chiller is assumed to be same as that in Retro-fitted BTS.

3.2.7 Simulation cases: Variety of Energy Sources used

Several different combinations of sources are used for simulation. To begin with we list ten configurations (A to J), where AC or DC generator, different kind and size of batteries and solar PV of different size:

A. AC Generator only (no battery or solar PV)
B. AC Generator plus 600Ah Lead Acid battery (no solar PV)
C. AC Generator plus 150 Ah Lithium-1 battery (no solar PV)
D. AC Generator plus 600Ah Lead Acid battery plus solar PV panel of 4.8kW or 1.6kW
E. AC Generator plus 150 Ah Lithium-1 battery plus solar PV panel of 4.8kW or 1.6 kW
F. DC Generator only (no battery or solar PV)
G. DC Generator plus 600Ah Lead Acid battery (no solar PV)
H. DC Generator plus 150 Ah Lithium-1 battery (no solar PV)
I. DC Generator plus 600Ah Lead Acid battery plus solar PV panel of 4.8kW or 1.6 kW
J. DC Generator plus 150 Ah Lithium-1 battery plus solar PV panel of 4.8kW or 1.6 kW

These simulations enable one to understand the relative merits of use of AC and DC Generator, Lead Acid and Lithium Polymer battery (illustrated by Lithium-1 battery) and solar PV better. Subsequently, eight more cases are simulated; all of them use Lithium Polymer batteries, but of different size and using different technologies (Lithium-1, Lithium-2 and Lithium-3 batteries specified in table 3.2). This is done to understand the impact of these new batteries on the results better. The eight cases use:

K. AC Generator plus 100Ah Lithium-1 battery (with no solar PV)
L. AC Generator plus 100Ah Lithium-1 battery plus solar PV panel of 4.8kW or 1.6 kW
M. AC Generator plus 150Ah Lithium-2 battery plus solar PV panel of 4.8kW or 1.6 kW
N. AC Generator plus 150Ah Lithium-3 battery (with no solar PV)
O. AC Generator plus 150Ah Lithium-3 battery plus solar PV panel of 4.8kW or 1.6 kW
P. DC Generator plus 100Ah Lithium-1 battery (with no solar PV)
Q. DC Generator plus 100Ah Lithium-1 battery plus solar PV panel of 4.8kW or 1.6 kW
R. DC Generator plus 150Ah Lithium-2 battery plus solar PV panel of 4.8kW or 1.6 kW

Thus total numbers of simulations carried out are: 3 types of BTS sites x 18 variety of energy sources x 7 kinds of grid availability or 378 different simulations.

3.2.8 Financial Parameter Assumptions in Simulations

Here is a summary of the financial parameters assumed in the simulations:

1. Grid-power tariff per unit: ₹5
2. Diesel price per liter: ₹45
3. Interest rate for DG, Battery (mid-term): 14%
4. Interest rates for solar PV (long-term): 11%

3.3 Simulation Results

The simulation is carried out for 20 days at a time, assuming that the battery is fully charged on day zero; but on subsequent days, the battery charge is the left over charge of the previous day. Carrying out the simulation for 20 days neutralizes the impact of fully charged battery on day zero. The results are averaged over all the days and presented as cost per day for each case. Temperature profiles and solar insolation profile are assumed to be constant over these days. We start with detailed results of a simulation in 3.3.1.

3.3.1 Detailed Simulation Results for a specific case

Simulation results of one of the cases is presented in detail here; the specific case uses all three energy sources, an AC generator, 600Ah Lead acid battery 4.8kW PV listed as case “D” in section 3.2.7. The simulation is carried out assuming 4-hour grid availability in the nighttime in a single-burst, or what is referred to as case 1 in section 3.2.1. The output of the simulator consists of graphical curves describing the state of the site for the first 24-hour period with a resolution of 1 minute.

Fig. 3.4 provides the ambient temperature variation, and the variation of load current and source currents (due to battery and PV). Even though the temperature and currents vary every minute, the plots are done using hourly average values. It is very evident that the load current varies with the ambient temperature due to the increased cooling load. As the temperature and insolation profile are highly correlated, one might observe that the output by the solar PV also varies accordingly.

The battery, as a backup source, plays a very vital role during the absence of grid (3 A.M to 11 P.M) compensating for the power produced by the PV.

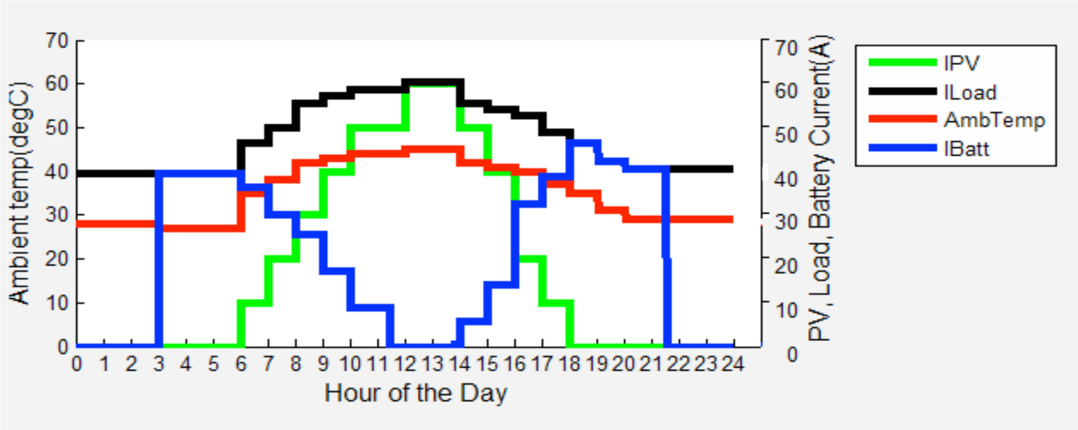


FIGURE 3.4: SOLAR PV CURRENT, BATTERY CURRENT, LOAD CURRENT (A) AND AMBIENT TEMPERATURE (˚C)

The state of charge of the battery indicated in figure 3.5 decreases indicating it driving the load till the specified lower levels. Once the lower levels are reached, the Diesel generator kicks in as shown in Fig. 3.6. Fig. 3.6 also shows the grid-current. Note that the current of the Diesel generator droops in a non-linear fashion due to the charging characteristics of the battery modeled in the simulation and also the fact that the PV is providing a part of the power.

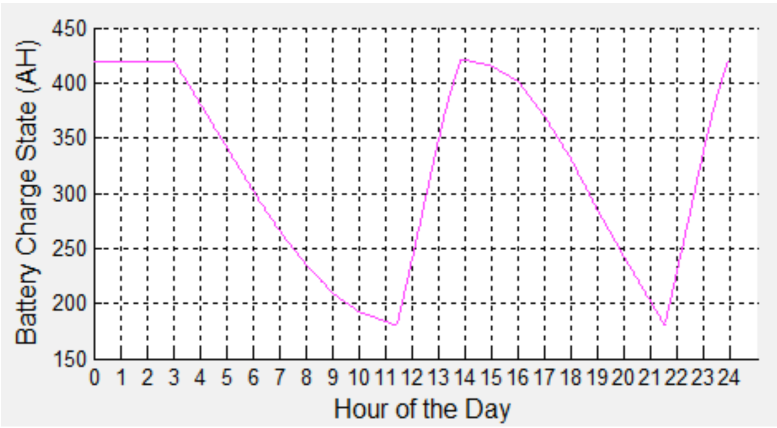


FIGURE 3.5: STATE OF CHARGE OF THE BATTERY (AH)

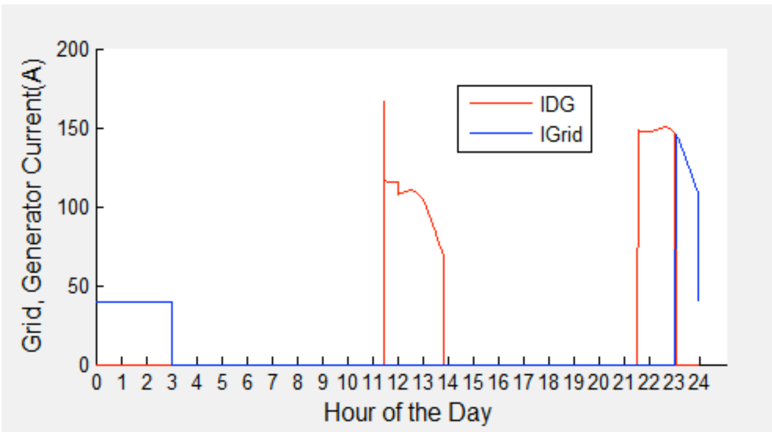


FIGURE 3.6: DIESEL GENERATOR CURRENT, GRID CURRENT (A)

Dashboard Results:

The dashboard contains detailed calculated results of the energy consumption by various loads and the energy production by each of the sources as shown in Table 3.6.

Energy Production				
Source	kWh/day	% (Prod/Day)	Cost/Unit (Rs/kWh)	Total Cost Energy/Day(Rs)
Grid	11.41	14.59	5.00	57.04
Generator	22.24	28.87	26.38	586.80
Battery	23.00	29.51	14.35	329.97
Solar PV	21.12	27.02	4.70	99.33
Total	78.00	100.00		1081.73

TABLE 3.6: ENERGY PRODUCTION BY EACH SOURCE

Energy Consumption			
Consumption	kWh/day	% (Cons/day)	
Equipment Load	22.00	40.00	
Cooling Load	33.00	60.00	
Total Load	55.00	100.00	

TABLE 3.7: LOADS AND THEIR ENERGY CONSUMPTIONS FOR A SPECIFIC CASE

Table 3.7 presents the load and energy consumption for this specific case (it was earlier presented for a general case in section 2.5.1.) a day. 55 units of electricity are consumed in the day, of which the equipment consumes 22 units and cooling load amounts to 33 units of electricity. As the cost of energy produced by the DG is based on the loading of the DG, a pie chart with loading ratios and their time fractions is displayed as shown in Fig. 3.7.

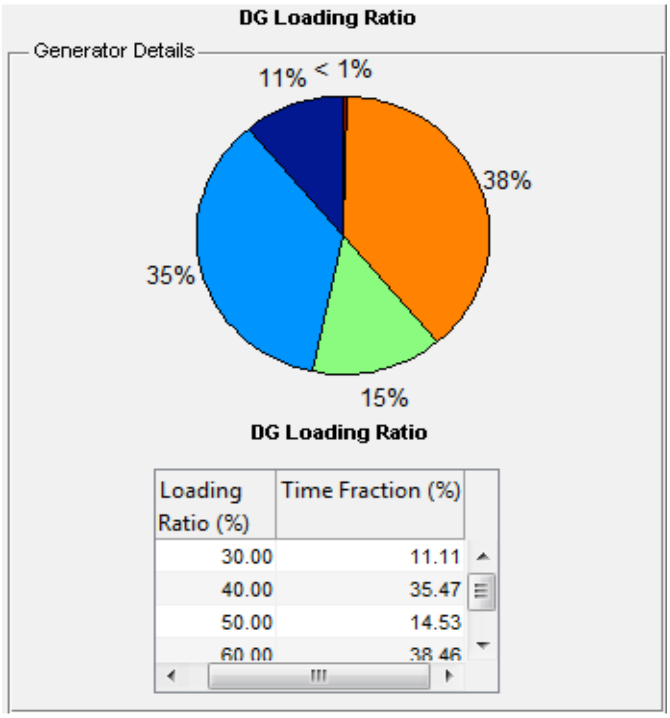


FIGURE 3.7: DG LOADING RATIO

The average fuel consumed per day by the diesel generator and the number of hours it runs are factors which contribute to the DG energy costs; they are presented in Table 3.8.

DG Parameters

Parameter	Value	Units
Average Litres of fuel consumed/day	8.95	Litres/day
Average DG Run time/day	4.00	Hours/day
Average Number of times the DG is turned ON/day	1.95	
DG Generation Cost	26.38	Rs/kWh

TABLE 3.8: DG RELATED PARAMETERS

The battery related parameters including the number of charge-discharge cycles per day, its total lifetime and the amount of energy used for charging the battery are presented in Table 3.9; these parameters contribute to the energy costs of the battery.

Battery Parameters

Parameter	Value	Units
Average Charge-Discharge Cycles/day	2.00	Cycles/day
Battery Lifetime	2.05	Years
Average Battery Charging Energy by DG/day	18.94	kWh/day
Average Battery Charging Energy/day	22.50	kWh/day
Average Battery Energy Delivered/day	23.00	kWh/day
Battery Charging Load	23.00	kWh/day
Average Battery Energy Cost	14.35	Rs/kWh

TABLE 3.9: BATTERY RELATED PARAMETERS

3.3.2 Summary of Simulation Results and Discussions

The results for 378 simulations discussed in section 3.2.7 are tabulated and compared in this section.

3.3.2.1 Conventional Indoor BTS Shelter

We start with simulations of conventional Indoor BTS site. As discussed, the simulations are focused on the sites with poor grid-power availability, so as to bring out the importance of optimization. We therefore start with the case where the grid-power is totally available only for four hours (single and multiple bursts) and then look at the cases, where the power availability is slightly better, say for eight hours a day (in single and multiple bursts). We initially simulate ten kinds of sites (followed by eight more); with different kind of generators, batteries and solar PV panel sizing. Note that PV size, wherever used is 4.8 kW

The summary of the results for four-hour grid availability with 600 Ah (48Volts) Lead Acid battery or 150Ah (48Volts) Lithium Polymer is given in Table 3.10.

	4 hours grid	No of units (kWh)	Case 1		Case 2		Case 3	
			Cost / day ₹	Cost/unit ₹	Cost / day ₹	Cost/unit ₹	Cost / day ₹	Cost/unit ₹
A	AC Gen only	53	2200	42	2218	42	2200	42
B	AC Gen + Le Acid	55	1372	25	1339	24	1203	22
C	AC Gen + Li-1	55	1345	24	1302	24	1190	22
D	AC Gen + Le Acid+ PV	55	1082	20	1038	19	853	16
E	AC Gen + Li-1 + PV	55	905	16	1060	19	851	15
F	DC Gen only	53	1789	34	1806	34	1790	34
G	DC Gen + Le Acid	55	1290	23	1247	23	1143	21
H	DC Gen + Li-1	55	1296	24	1256	23	1157	21
I	DC Gen + Le Acid+ PV	55	985	18	983	18	826	15
J	DC Gen + Li-1 + PV	55	878	16	1026	19	835	15

Table 3.10: Simulation Results for 4-hour grid case for Indoor BTS; Lead Acid battery used is 600Ah whereas Li-1 battery used is 150Ah; PV used is 4.8 kW

The following are the inferences drawn from the simulated results presented here:

- In general, use of a battery along with AC generator brings down the operation costs per day by 40 to 50% and use of solar PV along with battery and generator further reduces the costs per day by 25 to 30%. More deeper look gives some specific insights:
    - When the site is running on DG alone, the DC DG has a clear advantage when compared to AC DG in all the 3 cases.
    - In these cases, the nature (technology) of battery used (Lead Acid or Li Polymer) does not seem to impact the results; only for case 1 (night-grid), Li-1 battery gives appreciable advantage when AC generator and PV is used. The energy cost reduces to ₹15 to 16 per unit for case 1 to 3.
    - When DC DG is used, having a battery (of either kind) does gives less advantage as compared to cases where AC Generator is used.

- In Cases 1 and 3, the impact of adding solar PV is more significant. However, in case 2, where grid availability is assumed to coincide with maximum sunlight availability, the impact of addition of solar PV is less.
- Grid availability in multiple burst of one hour (case 3) has marginal impact as compared to that in case 1, where the grid-availability is in the night.
- It should be noted that when batteries are used, total power consumed increases as compared to when the batteries are not used (55kW as compared to 53 kW). This is due to cooling required by the batteries.

Li Polymer batteries are more expensive (higher CAPEX) than Lead Acid battery, but can have more number of charge discharge cycles and can be used at higher depth of discharge without considerable reduction in its lifetime. As shown in Table 3.2, there are great variety of Lithium batteries and using them in different capacities and technologies may have an impact on energy costs per day. Therefore, we repeat the above computations, this time with different Lithium Polymer batteries: 100Ah Li-1 battery, 150Ah Li-2 battery and 150 Ah Li-3 battery. The results are presented in table 3.11 in rows K to R.

	4 hours grid	No of units (kWh)	Case 1		Case 2		Case 3	
			Cost / day ₹	Cost/unit ₹	Cost / day ₹	Cost/unit ₹	Cost / day ₹	Cost/unit ₹
K	AC Gen+ Li-1	55	1407	26	1376	25	1327	24
L	AC Gen+ Li-1+PV	55	1017	18	1128	21	932	17
M	AC Gen+Li-2+PV	55	898	16	1059	19	847	15
N	AC Gen+Li-3	55	1157	21	1128	21	1047	19
O	AC Gen+Li-3+PV	55	845	15	888	16	731	13
P	DC Gen+Li-1	55	1297	24	1269	23	1231	22
Q	DC Gen+Li-1+PV	55	940	17	1044	19	875	16
R	DC Gen+Li-2+PV	55	870	16	1025	19	831	15

TABLE 3.11: SIMULATION RESULTS FOR 4 HOUR GRID CASES FOR INDOOR BTS WITH 100AH LI-1 OR 150Ah LI-2 OR 150Ah LI-3 BATTERIES; PV USED IS 4.8 kW

The results show that the smaller battery does not make any appreciable difference in the per day energy costs as compared to the earlier cases, except that Li-3 batteries with PV (row O) gives a new low cost in all cases (with price per unit of energy as low as ₹13 per unit), indicating that optimisations can indeed be carried out as different batteries are selected. The general conclusions however remain same, i.e.

- In all the cases, the DC DG has an advantage over the AC DG.
- Addition of battery brings down the costs by 40 to 50% with AC generator (and less with DC generator) and the addition of PV further brings down the costs by 25 to 30% Also, the impact of PV is more pronounced in the night grid case (case 1) as compared to the day grid (case 2).

We now move on to simulate the case where the grid-power is available for eight hours. Table 3.12 presents the results for this, when grid-power availability is single burst night time (case 4) and day time (case 5), as well as for mutiple bursts of one hour and two hours in cases 6 and 7 respectively, as defined in table 3.1. The batteries here are 600Ah (48V) Lead acid battery or 150Ah (48V) Li Polymer battery (Li-1).

	8 hours grid	No of units	Case 4		Case 5		Case 6		Case 7	
		KWh	Cost/ day	Cost/ unit	Cost/ day	Cost/ unit	Cost/ day	Cost/ unit	Cost / day	Cost/ unit
A	AC Gen	53	1815	34	1837	35	1815	34	1821	34
B	AC Gen+ Le Acid	55	1266	23	1210	22	775	14	778	14
C	AC Gen + Li-1	55	1186	22	1072	19	821	15	1010	18
D	AC Gen+ Le Acid+PV	55	823	15	929	17	590	11	586	11
E	AC Gen + Li-1+ PV	55	764	14	916	17	562	10	720	13
F	DC Gen only	**53**	1486	28	1508	28	1489	28	1494	28
G	DC Gen + Le Acid	55	1185	22	1128	21	775	14	778	14
H	DC Gen + Li-1	55	1145	21	1039	19	820	15	985	18
I	DC Gen+Le Acid+ PV	55	776	14	879	16	590	11	586	11
J	DC Gen+ Li-1+PV	55	747	14	890	16	562	10	712	13

TABLE 3.12: SIMULATION RESULTS FOR 8-HOUR GRID CASE FOR INDOOR BTS; LEAD ACID BATTERY USED IS 600Ah WHEREAS LI-1 BATTERY USED IS 150Ah; PV USED IS 4.8 kW

The simulation shows results that are very similar to that for four hour grid-availability case. However, the use of a battery along with AC generator brings down the operation costs per day only by 30% for cases 4 and 5; for cases 6 and 7, it is brought down as 50% similar to that in 4 hour grid case; use of solar PV along with battery and generator further reduces the costs per day by 30 to 35% for cases 4 and 5 and by 20 to 25% for cases 6 and 7. When the site is running on DG alone, the DC DG has a clear advantage when compared to AC DG in all the cases, however lesser than in 4-hour grid cases. In most of these cases, the nature (technology) of battery used (Lead Acid or Li Polymer) makes marginal impact on the results. When DC DG is used, having a battery (of any kind) does bring down the energy costs only by 20 to 25% for cases 4 and 5, but by 50% for cases 6 and 7. Solar PV makes less difference in case 5, where the grid availability is assumed to coincide with maximum sunlight availability. But in night time grid availability (case 4) and multiple bursts grid availability (case 6 and 7), the solar PV impact is very pronounced. The most significant result is that the cost per unit of energy is down to ₹10 to 12 per unit in some cases, when PV is used.

Let us again look at cases where other Li-1 (100 Ah) and Li-2 and Li-3 battery (150Ah) are used. These results for 8-hour grid are presented in Table 3.13.

	8 hours grid	No of units (kWh)	Case 4		Case 5		Case 6		Case 7	
			Cost /day	Cost/ unit	Cost / day	Cost/u nit	Cost /day	Cost/u nit	Cost /day	Cost/ unit
K	AC Gen+Li-1	55	1234	22	1141	21	959	17	1135	21
L	AC Gen+Li-1+PV	55	800	15	1028	19	639	12	851	15
M	AC Gen+Li-2 +PV	55	796	14	1030	19	643	12	849	15
N	AC Gen + Li-3	55	1044	19	965	18	754	14	917	17
O	AC Gen+Li-3+ PV	55	677	12	786	14	431	8	699	13
P	DC Gen+ Li-1	55	1142	21	1068	19	916	17	1060	19
Q	DC Gen+Li-1+PV	55	747	14	950	17	638	12	799	15
R	DC Gen+ Li-2+PV	55	743	14	952	17	642	12	797	14

TABLE 3.13 SIMULATION RESULTS FOR 8 HOUR GRID CASES FOR INDOOR BTS WITH 100Ah LI-1 OR 150Ah LI-2 OR 150Ah LI-3 BATTERIES; PV USED IS 4.8kW

Once again, just like in four-hour grid-availability case, the results for use of different Li batteries do not make any appreciable difference in the per day energy costs as compared to that when 150Ah Li-1 battery is used in these cases. The exception is use of 150Ah Li-3 battery with AC generator and PV, in which case the costs per day touches new lows for each of the case 4, 5, 6 and 7; In fact, in case 6, where grid is available in one hour burst, Li-3 battery brings down the energy costs to as low as

₹431 per day (or down to as ₹8 per unit). The general conclusions remain same, i.e. use of any battery along with PV gives the lowest energy costs; PV does not make as much a difference when grid-availability coincides with maximum sunlight-availability, but in all cases, it does make a difference.

So for the conventional outdoor BTS, the general recommendations will be as follows:

1. As most sites already have AC generator, fresh CAPEX expenditure for a DC generator may not be advisable, as proper batteries offset the advantages.

2. Proper batteries would be of great advantage; the choice of battery makes smaller difference and Lithium Polymer battery will be preferable where the grid-power-availability is very bursty. Larger Lead Acid battery with PV gives great performance when long hours of outage are expected.

3. Solar PV will always help greatly, unless grid-availability coincides with sun-light hours.

4. Li-3 has superior performance vis-a-vis Li-1 and Li-2 especially when PV is used. The cost reduction to ₹8 per unit for 8 hour grid is very promising, as it is close to grid prices.

3.3.2.2 Outdoor BTS Shelters

We now present the results for Outdoors base station. Here the shelter is not used; consequently there is no air-conditioner. The battery is placed in a chiller. The total amount of power consumed per day comes down significantly and varies between 22 and 29 units, depending upon the size of battery used (amounting to losses while charging the battery). The solar PV size therefore is reduced to 1.6kW, wherever used. We again begin with the results of simulations for the 4 hour-grid and then move on to that for 8 hour-grid. Table 3.14 presents the results for 4-hour grid

	4 hours grid	No of units	Case 1		Case 2		Case 3	
		kWh	Cost/day ₹	Cost/unit ₹	Cost/day ₹	Cost/unit ₹	Cost/day ₹	Cost/unit ₹
A	AC Gen only	**22**	1821	83	1821	83	1816	83
B	AC Gen + Le Acid	29	763	26	770	27	460	16
C	AC Gen + Li-1	24	706	29	707	29	389	16
D	AC Gen + Le Acid + PV	29	678	23	739	25	402	14
E	AC Gen + Li-1 + PV	24	590	25	589	25	328	14
F	DC Gen only	**22**	1512	69	1512	69	1508	69
G	DC Gen + Le Acid	29	700	24	706	24	460	16
H	DC Gen + Li-1	24	677	28	678	28	402	17
I	DC Gen + Le Acid + PV	29	615	21	674	23	402	14
J	DC Gen + Li-1 + PV	24	538	22	570	24	328	14

Table 3.14: Simulation Results for 4-hour grid case for Outdoor BTS; Lead Acid battery used is 600Ah whereas Li-1 battery used is 150Ah; PV used is 1.6 kW

The following inferences can be drawn from results:

- The overall costs (except the cases where only the generator powers the site) are significantly lower in outdoor case as compared to the costs in the indoor site.

- When the site runs just on the generator (AC or DC), the costs per unit of electricity are much higher than what they are for the same case under the indoor BTS site, as the generator is large (15 kVA) as compared to the load and consequently runs at a lower load, leading to inefficiency and higher costs. Using a 15kVA DG is not very meaningful in this context; however for uniformity sake, it was used. There is a strong case for smaller size generator to be used. In fact this is the case, even when batteries are used, for the load is still small, leading to the generator being run on lower efficiency. Therefore the best-case unit costs of electricity here is ₹14 for bursty grid case and ₹21 to 25 for cases 1 and 2. The comparable figures for indoor case, when generator was used with higher efficiency was ₹16 to 18 for case 1 (night grid) and case 2 (night grid).

- In the absence of batteries, DC DG has a lower cost per unit than an AC DG

- The addition of battery brings down the costs heavily, by 60 to 75%; and as expected, more with AC generator as compared to DC generator.

- Use of solar PV reduces costs further by 10 to 15%; less as compared to that for indoor cases.

- When solar PV is added, it eliminates the DG when there are multiple bursts (Case 3)

Now let us present results when different Lithium batteries (with different technology and sizes) are used in the 4-hour grid case in Table 3.15.

	4 hours grid	No of units	Case 1		Case 2		Case 3	
		(kWh)	Cost/ day ₹	Cost/ unit ₹	Cost/day ₹	Cost/unit ₹	Cost/day ₹	Cost/unit₹
K	AC Gen + Li-1	24	744	31	729	30	744	31
L	AC Gen + Li-1 + PV	24	534	22	633	26	520	22
M	AC Gen + Li-2 +PV	24	539	22	572	24	308	13
N	AC Gen + Li-3	24	592	25	594	25	593	25
O	AC Gen + Li-3 + PV	24	426	18	509	21	382	16
P	DC Gen+ Li-1	24	664	28	653	27	664	28
Q	DC Gen+ Li-1 +PV	24	490	20	573	24	482	20
R	DC Gen+ Li-2 + PV	24	515	21	553	23	308	13

Table 3.15: Simulation Results for 4 Hour Grid Cases for Indoor BTS with 100Ah Li-1 or 150Ah Li-2 or 150Ah Li-3 Batteries; PV used is 1.6kW

The results are in line with that for 150 Ah Li-1 battery in Table 3.14. However as is evident from rows K and L, the reduction in size for Li-1 battery is not advisable. Li-2 battery with PV gives new low for cost per unit of electricity, as shown in rows M and R. Surprisingly, Li-3 battery does not give as good a result as for indoor case; one may have to optimise its size for usage.

We now move on to present simulation results for outdoor BTS for 8 hour grid in Table 3.16.

	8 hours Grid	No of units (kWh)	Case 4		Case 5		Case 6		Case 7	
			Cost / day ₹	Cost/unit ₹	Cost / day ₹	Cost/unit ₹	Cost / day ₹	Cost/unit ₹	Cost / day ₹	Cost/unit ₹
A	AC Gen only	**22**	1487	68	1487	68	1480	67	1483	67
B	AC Gen + Le Acid	29	715	25	712	25	418	14	422	15
C	AC Gen + Li-1	24	587	24	589	25	349	15	351	15
D	AC Gen+Le Acid+ PV	29	337	12	386	13	357	12	358	12
E	AC Gen + Li-1 + PV	24	448	19	564	24	301	13	301	13
F	DC Gen only	**22**	1241	56	1241	56	1233	56	1237	56
G	DC Gen + Le Acid	29	652	22	650	22	418	14	422	15
H	DC Gen + Li-1	24	568	24	569	24	349	15	351	15
I	DC Gen+ Le Acid+ PV	29	337	12	386	13	357	12	358	12
J	DC Gen + Li-1 + PV	24	438	18	541	23	301	13	301	13

Table 3.16: Simulation Results for 8-hour grid case for Outdoor BTS; Lead Acid battery used is 600Ah whereas Li-1 battery used is 150Ah; PV used is 1.6 kW

The results again show that use of generator alone gives very high energy costs per day and very high per unit energy costs; this is due to large size of generator, making it run at poor efficiency. The costs are lower for DC generator, but high nonetheless. The rest of the results are in line with that for outdoor BTS with four hour-grid. Use of any kind of battery drastically reduces costs, as generator now runs at higher efficiency. But PV here helps far more significantly, especially with large Lead Acid battery, as shown in rows D and I, bringing down the per unit costs to ₹12 and day energy cost to as low as ₹337. The inclusion of PV with Li-1 battery does not give as good a result in case 4 (see row E and J), as the size of the battery is small; but for the burst cases (case 6 and 7), the Li battery performs as well. Li battery with PV for case 5 performs poorly as sunlight hours overlaps with the grid-availability hours.

We now present in Table 3.17, the results of simulations carried out using Lithium batteries with different sizes and technologies.

	8 hours grid	No of units	Case 4		Case 5		Case 6		Case 7	
		(kWh)	Cost / day ₹	Cost/unit ₹	Cost / day ₹	Cost/unit ₹	Cost / day ₹	Cost/unit ₹	Cost / day ₹	Cost/unit ₹
K	AC Gen + Li-1	24	628	26	626	26	324	14	513	21
L	AC Gen+Li-1+ PV	24	435	18	592	25	274	11	423	18
M	AC Gen+Li-2+PV	24	419	17	543	23	277	12	278	12
N	AC Gen + Li-3	24	508	21	508	21	244	10	392	16
O	AC Gen+ Li-3+PV	24	351	15	435	18	213	9	213	9
P	DC Gen + Li-1	24	568	24	567	24	324	14	484	20
Q	DC Gen+ Li-1+PV	24	409	17	530	22	274	11	406	17
R	DC Gen+ Li-2+PV	24	409	17	519	22	277	12	278	12

Table 3.17: Simulation Results for 8 Hour Grid Cases for Indoor BTS with 100Ah Li-1 or 150Ah Li-2 or 150Ah Li-3 Batteries; PV used is 1.6kW

The results in rows K and L for Li-1 battery of smaller size shows worse performance as compared to results presented in Table 3.13 in rows C and E for cases 4, 5 and 7; but for cases 6 (one hour eight burst), the smaller battery behaves better, bringing down the per unit energy costs to ₹11 when PV is present. In fact use of 150Ah Li-3 battery goes a step further (Row O) and along with PV brings down the per unit costs of electricity to ₹9 and total electricity costs in a day to as low as ₹213 for outdoor

BTS in bursty cases (case 6 and 7). Most likely, the generator is never turned on. The results with Li-2 battery are not as encouraging.

The overall conclusions for Outdoor BTS is therefore as follows:

1. A smaller generator should be used.

2. With proper sizing and selection of battery and solar PV, it should be possible to virtually eliminate generator, if grid is available for 8 to 10 hours in a bursty manner.

3. PV would make a huge difference when grid-availability is poor.

3.3.2.3 Retro-Fitted Indoor Shelters

We next take up retrofitted Indoor BTS. As air-conditioner is used in this situation, the solar PV size chosen for simulation is again 4.8 kW. But the air-conditioner is turned on only when ambient temperature is 40°C; further a chiller is used to house the battery. The total power consumption is therefore higher than that for the Outdoor case, but less than that for the conventional Indoor case and varies between 38 and 44 units a day, depending on type of battery used (amounting to battery losses). Table 3.18 presents the results for 4-hour grid.

	4 hour grid	No of units (kWh)	Case 1		Case 2		Case 3	
			Cost / day ₹	Cost/unit ₹	Cost / day ₹	Cost/unit ₹	Cost / day ₹	Cost/unit ₹
A	AC Gen only	**38**	**1969**	52	1927	51	1953	51
B	AC Gen + Le Acid	44	**1210**	28	1077	24	885	20
C	AC Gen + Li-1	40	**988**	25	936	23	865	22
D	AC Gen + Le Acid + PV	44	**760**	17	828	19	491	11
E	AC Gen + Li-1 + PV	40	**534**	13	683	17	534	13
F	DC Gen only	**38**	**1619**	43	1599	42	1610	42
G	DC Gen + Le Acid	44	**1119**	25	989	22	852	19
H	DC Gen + Li-1	40	**954**	24	899	22	843	21
I	DC Gen + Le Acid + PV	44	**702**	16	762	17	491	11
J	DC Gen + Li-1 + PV	40	**614**	15	656	16	531	13

Table 3.18: Simulation Results for 4-hour grid case for Retrofitted BTS; Lead Acid battery used is 600Ah whereas Li-1 battery used is 150Ah; PV used is 4.8 kW; PV used for configuration E for case 2 is however only 4.4kW

The simulation results are very similar to that for Outdoor BTS. The inferences are as follows:

- The cost per unit of energy is very high as shown in rows A and F when AC and DC generators alone are used; the generators work at very low efficiency due to low loading. Smaller generators would ceratinly help. In the absence of a battery, a DC DG is more cost effective than an AC DG.

- The induction of battery reduces costs by 40 to 60% for AC generators and 40 to 50% for DC generator. The induction of solar PV further reduces costs by about 40% for case 1 (night grid) but by lesser amount of about 30% for case 2 (when grid availability overlaps with sunlight); for case the bursty case (case 3), the PV reduces again by 40%.

- For the AC Generator or DC Generator along with Lead Acid and PV (rows D and I) the energy costs come down to ₹491 per day or ₹11 per unit. The Li battery has higher costs.

We now present in Table 3.19 simulation results for Retrofitted BTS for Lithium batteries of different sizes and technologies:

	4 hour grid	No of units (kWh)	Case 1		Case 2		Case 3	
			Cost / day ₹	Cost/unit ₹	Cost/ day ₹	Cost/unit ₹	Cost/ day ₹	Cost/unit ₹
K	AC Gen + Li-1	40	**1079**	27	977	24	1014	25
L	AC Gen + Li-1+ PV	40	**672**	17	801	20	612	15
M	AC Gen + Li-2+ PV	40	**617**	15	669	17	516	13
N	AC Gen + Li-3	40	**872**	22	779	19	805	20
O	AC Gen + Li-3+ PV	40	**508**	13	593	15	462	12
P	DC Gen + Li-1	40	**979**	24	881	22	925	23
Q	DC Gen + Li-1 + PV	40	**612**	15	716	18	572	14
R	DC Gen + Li-2 + PV	40	**593**	15	650	16	650	16

Table 3.19: Simulation Results for 4 Hour Grid Cases for Retrofitted BTS with 100Ah Li-1 or 150Ah Li-2 or 150Ah Li-3 Batteries; PV used is 4.8kW; PV used for configuration L, M, Q, R for case 2 is however only 4.4kW

It is obvious that smaller Li-1 battery (rows K and L) does not reduce costs. However Li-3 battery with PV (row O) does bring down the energy costs per day and per unit energy cost to match that for Lead Acid battery case presented in row D and I in Table 3.18. In fact the actual energy cost per day for Li-3 battery with PV (row O) for case 3 is only ₹462, a bit lower than that for Lead Acid (₹491) presented above, even though per unit energy cost for Li-3 battery is higher (₹12 rather than ₹11); this is because the total energy consumed per day is lower for Li-3 battery, because of high battery efficiencies. The conclusion is that with appropriate choice of technology and sizes, the two kinds of batteries could be made to behave equal to the other in terms of energy costs. But the PV helps in all cases.

We now present the simulation results of 8 hour grid in Table 3.20.

	8 hours grid	No of units (kWh)	Case 4		Case 5		Case 6		Case 7	
			Cost / day ₹	Cost/ unit ₹	Cost / day ₹	Cost/ unit ₹	Cost / day ₹	Cost/ unit ₹	Cost / day ₹	Cost/ unit ₹
A	AC Gen only	**38**	1639	43	1584	42	1594	42	1614	42
B	AC Gen + Le Acid	44	1118	25	875	20	626	14	637	14
C	AC Gen + Li-1	40	986	25	850	21	695	17	882	22
D	AC Gen + Le Acid+ PV	44	415	9	485	11	442	10	445	10
E	AC Gen + Li-1+ PV	40	572	14	742	19	434	11	563	14
F	DC Gen only	**38**	1351	36	1322	35	1324	35	1338	35
G	DC Gen + Le Acid	44	1036	24	811	18	626	14	637	14
H	DC Gen + Li-1	40	952	24	822	21	692	17	856	21
I	DC Gen + Le Acid + PV	44	415	9	485	11	442	10	445	10
J	DC Gen + Li-1 + PV	40	562	14	717	18	434	11	558	14

Table 3.20: Simulation Results for 8-hour grid case for Retrofitted BTS; Lead Acid battery used is 600Ah whereas Li-1 battery used is 150Ah; PV used is 4.8kW

The general conclusions are not too different form that we have seen earlier. The important point to note is that for Lead Acid plus PV (rows D and I), the unit energy costs can be as low as ₹9 to ₹10. It appears that use of DG is completely eliminated in such cases. For Li-1 + PV (row E and J), the costs are higher; the costs increases considerably for day-grid, when grid-availability and sunlight overlaps.

Finally we present in Table 3.21, the results of simulations for 8 hour grid Retrofitted BTS, when different sizes and technologies of batteries are used.

	8 hours grid	No of units (kWh)	Case 4		Case 5		Case 6		Case 7	
			Cost / day ₹	Cost/unit ₹	Cost / day ₹	Cost/unit ₹	Cost / day ₹	Cost/unit ₹	Cost / day ₹	Cost/unit ₹
K	AC Gen + Li-1	40	1074	27	934	23	744	19	894	22
L	AC Gen + Li-1+ PV	40	610	15	739	18	409	10	582	15
M	AC Gen + Li-2+ PV	40	549	14	727	18	417	10	545	14
N	AC Gen + Li-3	40	879	22	750	19	602	15	713	18
O	AC Gen + Li-3+ PV	40	517	13	592	15	333	8	462	12
P	DC Gen + Li-1	40	984	25	849	21	724	18	839	21
Q	DC Gen + Li-1 + PV	40	565	14	678	17	409	10	557	14
R	DC Gen + Li-2 + PV	40	539	13	702	18	417	10	540	14

TABLE 3.21: SIMULATION RESULTS FOR 8 HOUR GRID CASES FOR RETROFITTED BTS WITH 100Ah LI-1 OR 150AH LI-2 OR 150Ah LI-3 BATTERIES; PV USED IS 4.8kW

The results are on predicted lines. 100Ah Li-1 battery does not help. Li-3 battery with PV (row O) gives lowest costs; in fact, for this case of one-hour bursty grid (case 6), the energy costs for the day goes down to ₹333 and per unit energy costs reaches a new low at ₹8, fairly close to that of the grid.

The overall conclusions for Retrofitted Indoor BTS are therefore similar to that for Outdoor BTS and is as follows:

1. Use of generator smaller than 15 KVA needs to be explored.

With proper sizing and selection of battery and solar PV it should be possible to virtually eliminate generator, if grid is available for 8 to 10 hours in a busrty manner. Large size Lead Acid and small size Li-3 battery give lowest costs and are comparable to each other.

2. PV would make a huge difference when grid-availability is poor.

3.3.3 Optimization

We now present some other interesting results that on the one hand demonstrate the power of the simulator and on the other hand, demonstrate the importance of optimization. We take a conventional indoor cell site where sources are present as in configuration D, defined in Section 3.2.7, implying an AC Generator, 600Ah Lead Acid battery and 4.8 KW solar PV. We first examine variation of cost per unit of electricity used by the site as number of hours of grid availability is varied. The results are shown in Fig. 3.8 for three cases, one where the grid-power is available in one hour bursts (for example for a 12 hour grid-availability, the grid power is available every alternate hour and for 16 hour grid availability, the grid power in available for an hour at a time followed by half an hour of grid-failure). The other case is where the grid-availability is for 2 hour bursts, implying that grid is available at a time for two hours followed by an absence of grid and then again two hour grid-availability and so on; the third case is for four hour bursts. The results show that cost per unit is same for all three cases if grid-availability is for 8 hours a day or more. The per unit cost falls rapidly as grid-power availability increases from 0 to 12 hours in all three cases, and then falls slowly, reaching ₹8 per unit for 24 hours grid-power availability. The reason it is higher than ₹5 is because of the presence of the generator and battery, which lie idle now. Even while remaining idle, the capital costs and interest costs of generator and battery would continue to contribute to the per unit power-costs at the site.

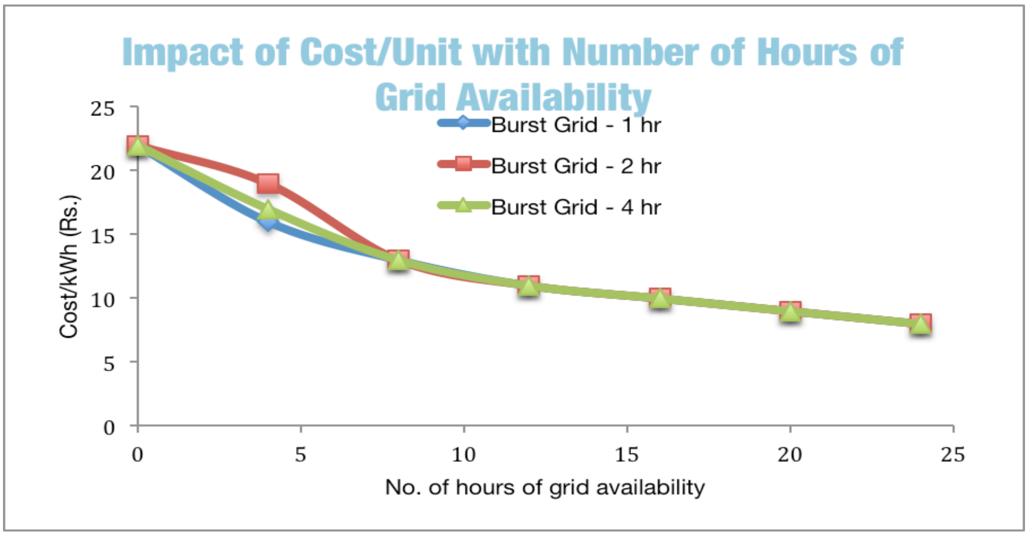


FIG. 3.8: COST PER UNIT OF ELECTRICITY FOR INDOOR BTS SITE AS GRID-AVAILABILITY VARIES FORM 0 HOURS TO 24 HOURS IN A DAY IN BURSTS OF ONE AND TWO HOURS

We now take the same site with the same configuration, but vary the battery capacity to examine the variation of per unit energy costs, while the PV size remains at 4.8 kW; the grid is now assumed to be available for 8 hours in a day in 2 hour and 4 hour bursts. Fig. 3.9 presents the results. The cost per unit of electricity in 4 hour burst grid decreases as battery capacity reaches 600Ah, after which it saturates. The 2-hour burst however shows interesting results. The unit cost of electricity decreases till the battery decreases to 500 Ah and then increases again as battery size is increased further, implying that 500 Ah battery will be optimal in such a situation.

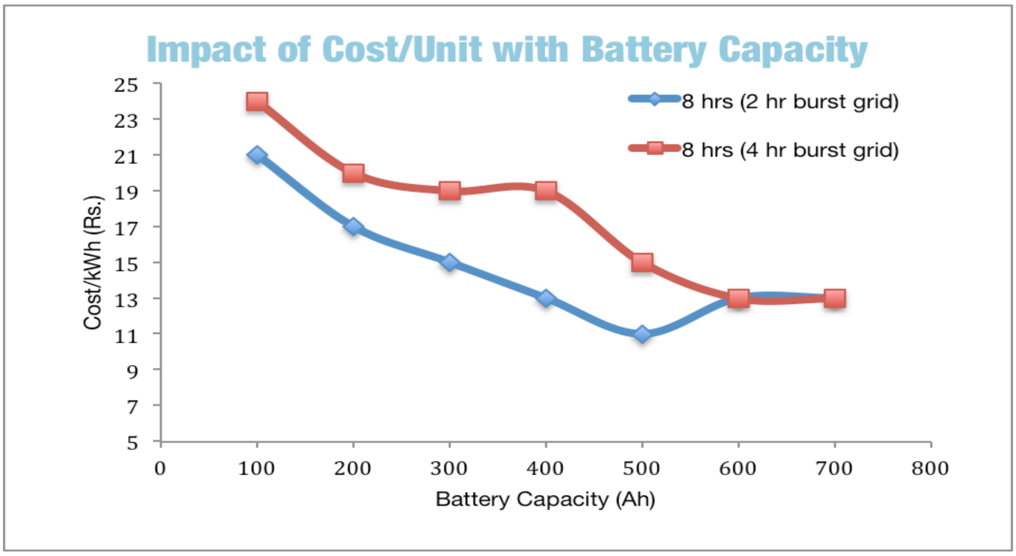


FIG. 3.9: COST PER UNIT OF ELECTRICITY USED BY AN INDOOR BTS SITE AS BATTERY CAPACITY VARIES

We now keep the battery capacity constant at 600 Ah and grid-availability to 8 hours and vary the size of PV used. Fig. 3.10 presents the results for grid with 2 hours and 4 hour bursts. Surprisingly, 2 hour bursts gives lower per unit cost and decreases somewhat rapidly as solar PV size increases to 5.5 kW and then decreases much less rapidly. For the four hours burst case, the cost per unit falls rapidly as PV size becomes 4.8 kW and then decreases more slowly.

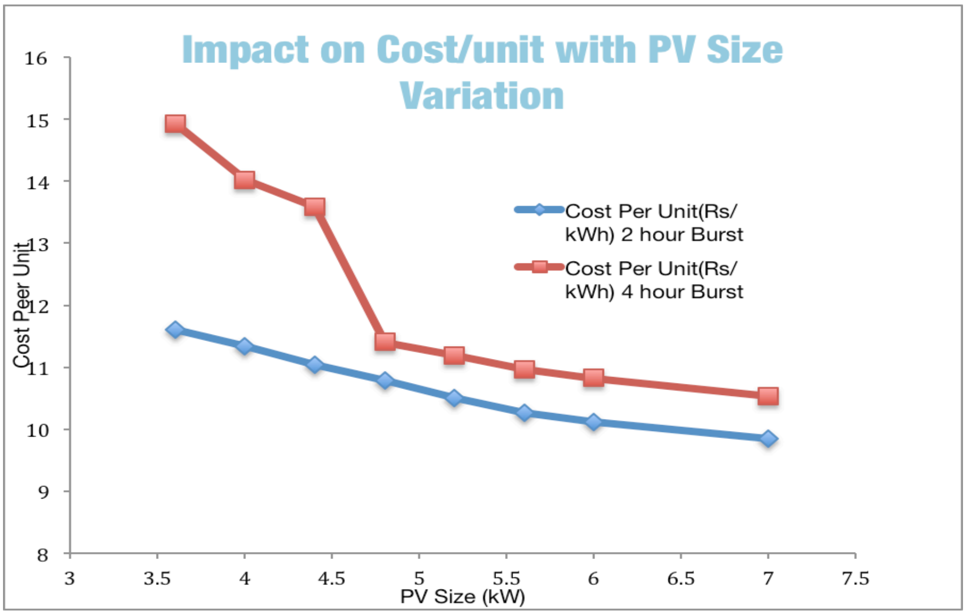


FIG. 310:COST PER UNIT OF ELECTRICITY USED BY AN INDOOR BTS SITE AS SOLAR PV IS VARIED

3.4 Conclusion

We have presented here simulation results for 3 x 378 cases of BTS sites so far and analyzed them for their energy costs. It is obvious that each site is unique and should be optimized independently. Yet some general conclusions emerge, which a BTS site designer needs to keep in mind. They include:

1. Even with minimal grid availability, it should be possible to use a proper combination of diesel generator, battery and PV to bring down the energy costs close to ₹10 per unit, in fact less than this number if the grid availability is bursty.

2. The use of diesel generator contributes maximum to the energy costs of a BTS site, especially when it is used with low loading percentage and therefore used with poor efficiency. The capital expense of the generator and the maintenance adds to the costs. It is best to have a situation, where DG is not turned on at all. It is shown here that with even 8 hours of grid availability, **it is possible to avoid using DG most of the time, when solar PV and battery are used diligently**. The DG should be used on rare rainy days when sunlight availability is poor as well as grid-availability becomes very erratic. It is better to have a DC DG, if one has purchase a new one; however if one already has an AC generator, one can use it diligently.

3. **Solar PV is critical to bring down the costs**.

4. Fortunately there are a large variety of batteries available today. Using a **healthy battery will be critical** to saving energy costs. Use of larger size (say 600 Ah) Lead Acid batteries or smaller size (say 150 Ah) Li-3 or Li-1 battery of the kind specified in Table 3.3 appears to give excellent results.

But before we move on to the recommendations, let us pause and examine another issue. So far, we have looked at cases, where the grid-availability was very poor, and limited to at most 8 hour grid-availability per day. What if the grid-availability is larger, say 12 hour or 16 hours a day? We therefore carry out some simulation for 12 hour and 16-hour grid availability cases for some limited combinations of sources. We take up configuration D, E and O defined in section 3.2.7. All these three configurations include AC Generator and PV; in addition, case D has 600Ah Lead Acid battery, case E has 150Ah Li-1 battery and case O has 150Ah of Li-3 battery. The 12-hour and 16 hour grid availability cases are defined in Table 3.22. The results for simulation for configurations D, E and O for these grid-availability cases is presented in table 3.23.

Case	Grid Availability (hrs)	Grid availability timings
8	12	12 midnight – 12 noon
9	12	0-2AM; 4AM-6AM; 8AM-10AM; 12noon-2PM; 4PM-6PM; 8PM-10PM
10	16	0-2PM; 3PM-5PM; 6PM-8PM; 9PM-11PM; 12noon-2PM; 3PM-5PM; 6PM-8PM; 9PM-11PM
11	16	8 PM–12noon

TABLE 3.22: GRID-AVAILABILITY CASES

			Case 8 (12 hrs)		Case 9 (12 hrs)		Case 10 (16 hrs)		Case 11 (16 hrs)	
		No.of uts/day	**Cost/day**	**Cost/ut**	**Cost/day**	**Cost/ut**	**Cost/day**	**Cost/ut**	**Cost/day**	**Cost/ut**
	Conventional (Indoor) BTS									
D	**AC Gen + Le Acid + PV**	**55**	517	9	523	10	452	8	422	8
E	**AC Gen + Li-1 + PV**	**55**	740	13	611	11	455	8	596	11
O	**AC Gen + Li-3 + PV**	**55**	602	11	548	10	366	7	502	9
	Outdoor BTS									
D	**AC Gen + Le Acid + PV**	**29**	315	11	314	11	272	9	256	9
E	**AC Gen + Li-1 + PV**	**24**	440	18	278	12	256	11	249	10
O	**AC Gen + Li-3 + PV**	**24**	345	14	199	8	184	8	179	7
	Retrofitted BTS									
D	**AC Gen + Le Acid + PV**	**44**	391	9	404	9	354	8	325	7
E	**AC Gen + Li-1 + PV**	**40**	515	13	364	9	336	8	321	8
O	**AC Gen + Li-3 + PV**	**40**	420	11	281	7	265	7	252	6

TABLE 3.23: SIMULATION RESULTS FOR DIFFERENT BTS FOR CONFIGURATIONS HAVING AC GENERATOR, PV AND 600AH LEAD ACID, 150AH LI-1 AND 150AH LI-3 BATTERIES

The results show that for these source configurations, the energy costs per day goes down to ₹6 to ₹9 per unit for 16 hour grid availability (cases 10 and 11) for all types of base stations; the results are very close to the grid-costs. Even for 12-hour grid (cases 8 and 9) the costs are between ₹7 to ₹10 mostly, only marginally higher than that for grid. Li-1 (row E) gives the worst results, especially for Outdoor BTS.

These results confirm the general conclusions listed above. Proper combination of diesel generator, well-maintained battery along with solar PV panel can bring down the BTS site energy costs close to that of grid-costs. For this generator has to be made almost redundant and used only on some very specific days.

Before we end this section, some general comments and cautions are listed.

1. It is important that the battery management system measures the state of charge of battery correctly so that battery charging – discharging takes place well; this is critical to reduced energy costs.

2. While capital expenses for diesel generator, battery and solar PV has been included in these computations, the CAPEX for air-conditioner, battery-chiller, shelter and Integrated Power Convertor Unit (IPU) has not been included. The IPU is a critical element and its efficiency will influence the total energy costs; equally important is its CAPEX. A proper IPU, which combines grid-power, different type of batteries as well as solar PV is still to be designed. The unit should also enable remote management.

Section 4: Recommendations

This report has analyzed the different energy-costs involved in the functioning of BTS sites by the means of a simulation tool. 3 x 378 simulations for different BTS site scenarios were carried and results were analyzed here. While there may be a large number of other specific scenarios, the results and analysis presented in the report are sufficiently encompassing and some general recommendations emerge from these simulations. There will always be specific cases (which in fact could be simulated quickly by using the tool presented here), for which the optimal design of energy systems could be different and some of the recommendations given here would not be applicable. But for most BTS sites in India, these recommendations would be very useful.

The recommendations are broadly focused on three areas, namely Research & Development, Adaptation & Adoption and Policy Measures. The recommendations in each section are discussed as those that require immediate focus, the ones with mid-term and the ones with long-term outlook.

4.1 Research & Development

Constant research to find solution to problems specific to India is required. Some of the R&D required would be in the technology front while some others would require coming up with innovations to customize the existing technologies to solve issues, which are unique to our country. The immediate R&D agenda would include the following:

- Encourage innovation in BTS equipment to reduce total energy consumption.
- Power Electronics for IPU including subsystems for measurement of State of Charge for batteries, Charge controllers, AC-DC, DC-DC and DC-AC convertors and Systems for Remote management of sites and all its equipment.
- Developing DC Diesel Generators and AC Diesel Generators with governors, which enable an AC DG to have higher efficiency even at lower loads.
- Designing of Solar air conditioners and solar chillers.

The Long term R&D would involve:

- Development of New Battery Technology, where the storage costs could be under ₹5 per unit of energy would be a game changer. This requires sustained and substantial research.
- Designing solar panels, which are damage-resistant; the outdoor panels should not be easily damageable by stones.

4.2 Adaptation

While Research & Development are essential to come up with solutions for any existing challenge, innovative use of technology to facilitate the adoption is essential for reducing immediate OPEX contribution of BTS sites. Switching to a newly developed technology involves substantial investments to be made. In India there are over 300,000 BTS sites, where deployment has already taken place. It is not possible to redo the site afresh. One has to enable incremental investments bringing in incremental reduction in energy costs. Most of the suggestions here can be implemented in short-term:

- Promote replacement of old equipment with energy efficient BTS equipment by giving incentives to the telecom companies. This is particularly important for rural areas, where the funding can be done through USOF.
- Require each operator to monitor and report the total energy consumption for all their BTS sites and also report the contribution made by each source to the total energy consumption.
- Mandate moving of BTS sites to renewable energy progressively. The aim should be to get 50% of total BTS site energy for each operator from renewables in five years; may be 10% each year. Incentives and dis-incentives need to be designed to enable this.
- Retrofitting Indoor BTS shelters could be attractive to reduce energy costs with incremental investments.
- Encourage addition of solar panels in a modular manner at the existing BTS sites.

4.3 Policy Measures

Policy Measures a go a long way in influencing directions. If BTS sites have to reduce their energy consumption and energy costs per unit, it is imperative that policies are designed to enable this. Here we list some of the immediate policy measures, which will get us to move quickly in the direction:

- Bank-loans for the purchase of Solar PV Panels for BTS sites should be classified as priority sector loans by RBI. This is critical as Solar PV panels have a long life-time and interest rate plays a major role in determining cost per unit of electricity produced by these panels. If subsidy is to be provided for renewable energy, subsidized long-term interest may be the best mechanism.
- Introduce time of the day metering for electricity consumed at BTS sites. This will incentivize electricity board to continue to supply electricity to the sites, even during peak-hours. For Operators, it will incentivize using renewables, at least during peak-hours.
- Telecom Operators who use renewable sources for powering their sites (even partially) should be provided with incentives. These incentives could be reduction in the license fee or funds provided to the operators from USOF.

The policy measures that need to be taken up in medium term are as follows:

- If the Operator generates more renewable energy than consumed by the BTS site, they should be able to feed the surplus to the grid and draw from the grid at some other time. In a sense, grid would be the storage for renewables. However, as the volume increases, time of the day metering needs to be taken into account for both feeding and drawing.
- The telecom companies should be able to feed power to a grid at one place and be able to extract it from another place. Currently this is possible for only large amounts of power; it should be made possible to feed and extract smaller amounts of power.

4.4 In the end

We close the report not just with recommendations. The report has been based on quantitative study and analysis of energy consumed at a BTS site and its costs. Very recently, we were introduced to batteries (One Lead Acid and another Lithium Polymer), which were of much higher performance than the ones used in study in the report. Even though we cannot certify the claims of battery manufacturers yet, we present in Table 4.1 the key specifications of the two batteries and Table 4.2, we present the results of simulation for a conventional Indoor shelter, where these batteries have been used 4.8KW solar PV panels, but with no generator. The grid power is assumed as per cases 4, 6, 7, 8, 9, 10 and 11 as defined in Table 4.2. The results do show that the costs are touching ₹6 to 7 per unit. Of course, these numbers are obtained when generator is not used at all, taking away the fixed costs of generator. There may be some rainy days in a year when grid failure is severe; absence of generator would cause a problem then. One has to figure out alternate way of wheeling in power without keeping a generator for such rare days, which adds nearly ₹2 per unit to the cost of electricity. The challenges are indeed enormous, but the potential gains are equally strong.

Battery type	Capacity (Ah)	Discharge %	Cycles	CAPEX	Efficiency %	Charging Rate
HP Lead Acid	600	40	3000	5500	95	0.3C
HP Li Ion	150	90	6000	45000	99	C

TABLE 4.1: SPECIFICATIONS OF TWO VERY HIGH PERFORMANCE BATTERIES

	AC Gen + High performance Le Acid + PV			AC Gen + HP Li+ PV	
	No. of uts	**Cost/day**	**Cost/ut**	**Cost/day**	**Cost/ut**
Case 4	**55**	**711**	**13**	**768**	**14**
Case 6	**55**	**419**	**8**	**538**	**10**
Case 7	**55**	**417**	**8**	**707**	**13**
Case 8	**55**	**390**	**7**	**717**	**13**
Case 9	**55**	**392**	**7**	**491**	**9**
Case 10	**55**	**364**	**7**	**444**	**8**
Case 11	**55**	**353**	**6**	**585**	**11**

TABLE 4.2: SIMULATION RESULTS FOR CONVENTIONAL INDOOR BTS WITH AN AC GENERATOR, 4.8KW PV AND EITHER HIGH PERFORMANCE LEAD ACID OR LI ION BATTERY AS SPECIFIED IN TABLE 4.

References:

1. TELECOM REGULATORY AUTHORITY OF INDIA (TRAI) WEBSITE: http://www.trai.gov.in/WriteReadData/WhatsNew/Documents/PR-TSD-May2012.pdf. Retrieved on 22/9/2012.
2. TELECOM REGULATORY AUTHORITY OF INDIA, Consultation Paper On Green Telecommunications. 3rd February, 2011, page 2, points 3 and 4, page 16 http://www.ccaoi.in/UI/links/fwresearch/conceltation%20paper%203.pdf. Retrieved on 22/9/2012.
3. The True Cost of providing energy for the Telecom Towers in India: White paper by Intelligent Energy
4. Green Telecom: The Way Ahead, Report by AT Kearney
5. Telecommunication Power System: Energy saving renewable sources and environment monitoring, Report by Carmine Lubritto, University of Naples, Italy
6. Dirty Talking? Case of telecom to shift from diesel to renewable, Report by Green Peace Organization
7. Page 5 of Green Telecom: The Way Ahead by AT Kearney
8. Data from Amara Raja Batteries Ltd.