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Electrical Energy Conservation Model in Cricket Stadium, Maharashtra

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Abstract: ***Cricket is one of the most popular sport in India, being environmental friendly and energy-efficient sets an example for masses. This paper focuses on the optimization of energy management in a cricket stadium by using the Integer programming technique. Integer programming technique is used to maximize the energy conservation by the solar-powered stadium.***

Keywords: Optimization, Linear Programming, Integer Programming, Solar Panel, Energy Management, Cricket Stadium

1. INTRODUCTION

Electricity generation is one of the major causes of pollution. It is the process of generating electricity from available resources. Most of the electricity is produced using resources such as coal, nuclear, and other non-renewable resources. Producing energy from these resources has a huge impact on the environment.

Electricity can also be generated from resources like solar energy, Wind energy, geothermal energy, Biomass called Renewable resources. These resources replenish themselves without depleting the Earth's resources. They are also clean, safe and pollution generated from them is less as compared to non-renewable sources of energy. Using renewable resources instead of non-renewable resources will also help in reducing carbon footprint which is the need of the hour.

Solar energy is one such renewable resources. It is increasingly becoming a popular source of energy because of its never-ending supply and environment-friendly nature. It is radiation from the sun harnessed with the help of solar panels to generate electricity.

There are two types of solar energy

1. Active solar energy
2. Passive solar energy

Active solar energy involves the conversion of solar energy into usable heat via mechanical or electrical equipment such as fans and pumps. The heat that is collected is either immediately used or sored for later use. Passive solar energy utilizes the constituents of a structure to trap and accumulate heat energy from the sun. Both are useful, but passive solar energy is easy to produce as compared to active solar energy.

Solar panel consists of solar cells which are made up of semiconducting material that converts sunlight to electricity. During the manufacturing of solar cell mostly used material is silicon. The types of the solar panel are Conventional Silicon-based and Concentrating PV. Conventional Silicon-based is further divided into Monocrystalline technology, Polycrystalline technology, and Thin film technology

Each type has its advantages and disadvantages. Monocrystalline solar panel has a high-efficiency rate, lifespan is high as compared to others but it has higher costs as compared to others. Polycrystalline solar panel comes with low cost but it is sensitive to a higher temperature, it has a low-efficiency rate and lifespan is also short. Thin-film solar panel is flexible, lightweight, easy to produce, portable but with lower efficiency, short warranties. Thin-film solar panel has a short lifespan as compared to others. Concentrated PV Cell has a high rate of effectiveness due to solar tracker and cooling system.

Cricket being the most popular sport requires massive electricity for the stadium to run floodlights, cameras, giant television screens. On average, it has a monthly electricity bill of around Rs 5-10 lakh. Using solar energy to power the stadium can reduce the electricity bill and can increase the profit margin by being self-sufficient.

According to Maharashtra Energy Development Agency, Maharashtra has usually 4 to 6 kWh/m2 radiation in a day with 250-300 days of clear sun in a year. So, installing solar panels on the roof of the cricket stadium in Maharashtra in a good step. Considering it already has 820.8 kWp rooftop installation at the Cricket Club of India (CCI) and it is the world's largest atop a cricket stadium (1) (2).

Considering this as an example, we proceeded to take a reference stadium to install solar panel as VCA Stadium Jamtha of Vidarbha Cricket Association, situated on the edge of Nagpur city. The stadium contains 4 stands. The East and West stands are two-tier outdoor stands. The North stand include the Presidents Room, Secretary's Box, Security Central, Board rooms, and so on. The South stand incorporates the player's pavilion and rec centre, media room, and so on. Both North and South stands are three-tier stands (3).

2. LITERATURE REVIEW

Many researchers have used linear programming for Energy management. The following are reviews of some of them.

Francesco De Angelis (2013) in research paper 'Optimal Home Energy Management Under Dynamic Electrical and Thermal Constraints' explored the mixed-integer linear programming proposal, for obtaining an optimized usage of tasks power and management of renewable resources for thermal model dependent on heat-pump use. They had performed computer simulations using real data for confirming the productivity and robustness of the calculation (4).

Ziming Zhu (2012) suggested a mechanism for scheduling the optimized power for power-shift able appliances and optimized activity time for time-shift able appliances using integer linear programming considering the energy utilization trend of every appliance in research paper 'An Integer Linear Programming Based Optimization For Home Demand-Side Management In Smart Grid'. (5).

Juan WU (2012) in the paper 'Optimization Research of Generation Investment Based on Linear Programming Model' used linear programming model to find the optimal installed capacity of power plants and the final total cost as a reasoned choice for investment optimization. (6)

Satyajit Das (2017) in their paper ' Electrical Energy Conservation Model using Linear Programming' created a model using optimization technique which provided insight and comparison of how energy is saved along with cost just by replacing some of the frequently used electrical equipment. (7)

The objective Snežana Dragićević' (2009) considered in the research paper 'Application of Linear Programming In Energy Management' was to model and optimize an industrial steam-condensing framework by identifying energy sources which reduced general expenses for energy utilized all the while. In their study, they considered the cost of power and heat units generated externally as fixed and units generated internally as factors which were to be minimized (8)

3. LPP MODEL

In this paper, the objective considered is to maximize energy-savings by installing solar panels in the stadium under the given budget and area available. The size and cost of installation for each solar panel differ according to type, the material used, size, battery, etc. Here PV off-grid solar panels were considered and reference for values mentioned below were taken from Kenbrook solar (9).

Table 1: Energy-saving per unit usage and Installation cost, System generation, area comparison chart

Solar System	Energy Saving	Area (sq. meter)	Cost of Installation	System Generation (Units/year)
Solar Panel 1	1000	6	80000	1400
Solar Panel 2	2000	12	160000	2800
Solar Panel 3	3000	18	240000	4200
Solar Panel 4	5000	30	400000	7200

As mentioned earlier, the stadium has only two stands with complete roofs. So, the roof area available is 4000 m2. The budget allocated is Rs.60000000 for installation.

4.1 Linear Programming model:

For modelling linear programming problem (LPP) from practical problem following steps have to be considered: (10) (11) (12)

- First, select elements influencing goal as decision variables. Decision variables are mostly non-negative real number.
- Next, characterize the target by the utilizing linear relationship between the decision variables as objective function to be optimized which intend to be minimized (min) or maximized (max).
- Then characterize the constraints which are to be satisfied as a linear function of decision variables based on the resources available.

Such a model is called a linear programming problem (LPP) that has a linear objective function and linear equality or inequality constraints.

4.2 Integer Programming Problem (IPP):

IPP is a further extension of LPP where all the decision variables are integer. Based on the number & type of integers IIP can be further divided into 3 subtypes of IPP:

1. Pure IPP: Here all decision variables belong to integer set.
2. Mixed IPP: Here some of the decision variables are integers.
3. Binary IPP: Here decision variables are either 0 or 1.

MATHEMATICAL FORMULATION:

The general form of LPP is given as:

Let there be n number of decision variables say X_1, X_2, X_3... ..., X_n & m be the number of constraints on these n decision variables.

Then LPP can be represented as follows:

$$Opt.Z = C_1X_1 + C_2X_2 + \cdots + C_nX_n$$

Subject to,

$$a_{11}X_1 + a_{12}X_2 + \cdots + a_{1n}X_n \quad (\leq = \geq)\ b_1$$
$$a_{21}X_1 + a_{22}X_2 + \cdots + a_{2n}X_n \quad (\leq = \geq)\ b_2$$
$$\dots\dots\dots\dots\dots\dots\dots\dots$$
$$a_{i1}X_1 + a_{i2}X_2 + \cdots + a_{in}X_n \quad (\leq = \geq)\ b_i$$
$$\dots\dots\dots\dots\dots\dots\dots\dots$$
$$a_{n1}X_1 + a_{n2}X_2 + \cdots + a_{nn}X_n\ (\leq = \geq)\ b_m$$
$$X_j \geq 0\ \forall\ j = 1,2, \dots \dots n$$

where, $X_j, j = 1,2, \dots n$ are n decision varibles

Z is objective function

$C_1, C_2 \dots C_n$ are cost coefficients

a_{ij}'s are technical coefficients decided from the situation of decision making

$b_1, b_2, \dots b_m$ are RHS contants referred to as availability of resources

In industry LHS represents supply are RHS as demand

In our case, we have to maximize the energy savings which will be Z

X_1: No of Solar Panel 1
X_2: No of Solar Panel 2
X_3: No of Solar Panel 3
X_4: No of Solar Panel 3
c_i: Energy Saved by i^{th} panel
a_{1i}: Area of i^{th} panel
a_{2i}: Cost of Installation of i^{th} panel

b_1: Area of rooftop
b_2: Budget allocated

Objective Function:

$$Max\ Z = 1000X_1 + 2000X_2 + 3000X_3 + 5000X_4$$

Subject to:

$$6X_1 + 12X_2 + 18X_3 + 30X_4 \leq 4000$$

$$80000X_1 + 160000X_2 + 240000X_3 + 400000X_4 \leq 60000000$$

Values can be represented tabular format as

Table 2: Tabular form of LPP

Solar Panel System	Energy Saved	Area	Cost of Installation
X_1	1000	6	80000
X_2	2000	12	160000
X_3	3000	18	240000
X_4	5000	30	400000
	= (Maximize)	<=	<=
RHS	Z	4000	60000000

4. ANALYSIS

The analysis was done in Python using a package called PuLP. The Pulp package is authored by J.S. Roy and S.A. Mitchell. (13) The solution obtained is given below:

```
Problem:
MAXIMIZE
1000*x_1 + 2000*x_2 + 3000*x_3 + 5000*x_4 + 0
SUBJECT TO
_C1: 6 x_1 + 12 x_2 + 18 x_3 + 30 x_4 <= 4000

_C2: 80000 x_1 + 160000 x_2 + 240000 x_3 + 400000 x_4 <= 60000000

VARIABLES
0 <= x_1 Integer
0 <= x_2 Integer
0 <= x_3 Integer
0 <= x_4 Integer

Optimal
X_1= 1.0 X_2= 0.0 X_3= 0.0 X_4= 133.0 Z= 666000.0
```

```
name   shadow price       slack
 _C1           -0.0         4.0
 _C2           -0.0   6720000.0
```

The optimum result can be found by installing **1** solar panel of **1000W** and **133** solar panels of **5000W.** The maximum energy saved per year is **666000W** after installation of solar panels by utilizing **Rs. 53,280,000.00 (1*80,000 + 133 *400,000)** out of budget of **Rs. 60,000,000.00.** This installation of solar panels helps to generate **959,000 units/year** i.e 1000w will generate around 1400 units/year and 133 panels of 5000w will generate around 7200 units/ year /panel which is 957600 units/ year

We can calculate the recovery period by using the following formula,

$$Recovery\ Period = \frac{Budget * 1000\ (in\ watts)}{Energy\ Saving * 365 * 24 * 5.6\ /KWh}$$

Budget = Rs. 53,280,000.00
Energy Savings = 666000W
Therefore, Recovery Period = 1.63 years. This means after 1.63 years, the system will yield profit. Also, this system will save around **Rs. 3,26,71,296.00** per year.

The sensitivity of the solution can be obtained using slack and shadow pricing. Given below is the slack and shadow price observed for the solution

The slack variable for constraint 1 i.e. area is 4 m^2 which we can decrease the b_1, Area of rooftop by 4 m^2 objective function won't be affected as we have an unused area of 4 m^2 Similarly, budget of Rs. 6,720,000 is still left hence the budget can be reduced till Rs 53,280,000 and the objective function won't affected. Since the shadow price for every constraint is 0, they are a binding constraint i.e., an increase of availability doesn't increase energy saved.

5. Conclusion

The integer programming problem is used in this paper for the installation of solar panels to maximize energy generation. The maximum energy could be generated by installing 133 solar panels of 5000W and 1 solar panel of 1000W. This saves 666000W energy per year with the total installation cost Rs. 53,280,000. The energy conserved will recover the cost of installation by the end of 1.63 years and will start to yield profit after that. The installation of the solar panel in the stadium makes it energy-efficient and environmental-friendly by reducing carbon footprints. This model was developed by taking VCA Stadium Jamtha as reference stadium. Similar models can be constructed for other stadium given rooftop area, budget for installation are available. Also, it was considered that the current roof can withhold the weight of the solar system to be installed else the cost of replacement of the roof should be reduced from the budget.

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