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Fair Allocation of Energy and Power using Shapley Value to Reduce Deficit in Regions of Indian Grid

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Abstract

Objectives: The paper aims at reducing the power and energy deficit in various regions of India. **Methods:** A game theory based mathematical model performs the allocation called Shapley value, which does the fair allocation of power and energy in order to reduce the maximum deficit in a particular region. **Findings:** The simulation results confirm the distribution is fair enough in reducing the overall deficit percentage in all regions. **Applications:** The work can be integrated with the grid and further extensions to the next level are possible.

Keywords: Central Electricity Authority (CEA), Deficit, Energy, Game Theory, Power, Shapley Value (SV)

1. Introduction

From 18th century and in the last fifteen decades there is no change with the basic infrastructure of the electrical grid. It does not even satisfy the basic need of 21st century that is an "uninterrupted power" and "power for all" concept in developing countries. In India 300 million people does not have access to electric power. Another one-fourth million-get irregular power supply of about three to four hours a day. With the advancements in Information and Communication Technologies possible solution in the electrical sector is making the present grid to a smarter grid which can help to the present situations to improve. Indian has "one country; one grid system from December 2013. Indian grid system is categorised as Northern, Western, Southern, Eastern and North Eastern depending on its topology. These regions have different energy requirement and power demand. During the revenue year the electricity generated in the utility sector was 1,030.785 billion KWh with a shortage of 38.138 billion KWh which is a 3.6% deficit. The peak demand was 1,41,180 MW with a shortage of 7,006 MW which is a 4.7% deficit. This deficit will increase further due to the increase in population and drastic development in infrastructure. Figure 1 depicts the present Indian state of power with deficit figures.

Table 1. Energy and Power deficit for 2015

Region	Deficit %	
	Energy	Power
Northern	4.8	3.7
Western	0.3	1.0
Southern	2.1	2.7
Eastern	1.0	0.4
Northern Eastern	7.5	1.0

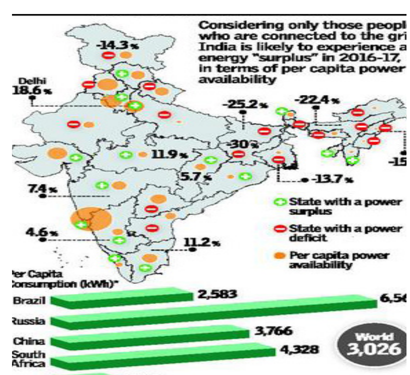

Figure 1. Power deficit status.

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This work focus with the deficit ranges in all five regions by using SV fair allocation. The overall percentage of Energy and Power deficit for the year 2015 is given in Table 1. For better understanding the paper is organized with the basics of game theory along with Shapley value in Section II, Section III with the Methodology, Section IV with Results and Discussions and section V with the Conclusions and Future scope of the work.

2. Concept of Game Theory

"Game theory" is the mathematical study of people reaction to different situations. The Section is explained with the theory behind game theory[1] along with the characteristics and properties of Shapley value, which is a part of game theory.

2.1 Basics of Game Theory

A competitive situation like candidates fighting an election, advertising and marketing is called a game, which represents a contest between two or more players. Theory of games is a choice of action by taking an account of all alternatives available to the other player rather than considering only the possible outcome. It is a contest between multiple players with a set of rules where each player is benefitted or satisfied sometimes which fails too. These competitive problems are mathematically based and are related to the Von Neumann criterion. This criterion deals with rationality where each player plays to minimize his maximum loss or to maximize his minimum gain. The mathematical games are popularly known as theory of games, which includes Shapley Value, which is the focus in this paper, and are used in the allocation of Energy and Power.

2.2 Characteristic of Game Theory

Games can be of both strategies[2] Two kinds of strategies are pure strategy and mixed strategy. Pure strategy means a player will know, what will be the other player's action in a defined situation where the objective is to maximize the gain. Mixed strategy means a player guesses an activity to an occasion in a probabilistic situation with the objective to maximize the expected gain. The highlighted characteristics are:

- **Chance of strategy:** If the players play by his skill then its game of strategy and if it's determined by his chance its game of chance.
- **Number of persons:** A game is said to be n - person if the number of players playing are 'n '. The player means a single or a group targeting an objective.
- **Number of activities:** There can be limited or unlimited activities depending on game.
- **Number of choices:** A finite game has limited number of activities each involving a finite number of alternatives otherwise the game is said to be infinite.
- **Information to players about the past game of other players**: The database can be completely, partly or may not be available.
- **Payoff:** A reward of satisfaction a player gets at the end of the play is a payoff. In a game if vi be the payoff to the player P_i, $1 \le i \le n$ in an n - person game.

Otherwise

If $\sum_{i=1}^{n} vi = 0$ Then the game is a zero sum game.

2.3 Properties of a Competitive Game

The properties of Game Theory are

(i) There are known number 'n' of players
(ii) Each player has finite number of activities
(iii) The rules are known to all players
(iv) The outcome of game is affected by choice of players
(v) The outcome of specific coalition by players is known in advance and numerically defined.

This paper includes mixed strategy with five players playing the game with a limited (two) activities and choices whereas all players know the outcome.

2.4 Concept of Shapley Value

Shapley value[3,4] is a cooperative concept in game theory. It is based on axioms and the unique solution conforms the axioms. It's a mechanism for assigning payoffs to players based on average of their contributions to possible coalitions. It's used in the allocation of costs in case of joint players. Shapley value don't guarantee fair outcomes. Shapley value is named after Lloyd Shapley of UCLA. It produces outcomes that have realistic features. The Shapley value is a mechanism for assigning payoffs to players based on an average of their contribution to possible coalitions.

A game which is having 'n' players has its characteristic function v (C)[5] which is the minimum total payoff that coalition 'C' can assure to its members.

Shapley value is an allocation of payoffs 'u_i' to each player i as defined by

$$\frac{(n-k)!\,(k-1)!}{n!\,[\,v(C)-v(C-\{i\}]\,]}$$

Where n ! means the product 1*2*…*n where the sum is taken for all the coalitions 'C' that have 'i ' as a player and in each term of the sum, k is the size of the coalition C.

The meaning is that each player should be given a payoff equivalent to the average of the input that he makes to each coalition[6] he belongs. Consider the size k of the coalition from 1 to n. A particular size coalition may occur with probability 1/n. Then (k -1) partners of 'i' coalition of size k can be chosen from (n - 1) players in the ways given.

$$\frac{(n-1)!}{[(n-1)-(k-1)]!\,(k-1)!}=\frac{(n-1)!}{[(n-k)!\,(k-1)]!}$$

This term makes the contribution that i makes to 'C'. The summary of Shapley value is a solution concept for a cooperative game where all coalitions to which an individual may belong are regarded equally likely and each individual is awarded the average of his contributions in raising the aggregate payoffs of all these coalitions.

3. Methodology

The Energy availability and Peak met varies from states to states because of the allocation of central sectors and bilateral and mutual Energy agreements between states. It is seen from the data that the allocation is not fair enough to all regions where some regions have a high deficit percentage whereas other have marginal deficit. The main objective of this paper is to reduce Energy and Power deficit allocation uniform to all regions. In order to make the deficit marginal to the extent, Shapley Value is used. The concept of Shapley Value can do the fair allocation within regions, thus reducing the overall deficit of Power and Energy.

For the simulation purpose "Energy supply position" in terms of requirement and availability and the "Peak supply position" in terms of peak demand and peak met are calculated as follows:

Evaluation of Energy Requirement - is the appraisal of the area - wise unrestricted ultimate demand and Energy requirement of each area is made utilizing the past data and pattern examination in consultation with the concerned state and finalized after detailed discussions for the forecast of the ultimate demand and Energy needed.

Evaluation of Peak Availability is done by assessing the peak availability of the units available for production in the various functions in different months after bearing in mind schedule maintenance.

Evaluation of Deficit/Surplus is the expected electricity deficit or surplus and is calculated as a variance between the net limitless predicted requirement and the net predicted availability in terms of Energy and peak demand.

In order to achieve the fair deficits in all regions randomly Shapley algorithm equation is used to the data table taken from Central Electricity Authority (CEA), Power ministry.

$$V(s)=\frac{(n-1)!}{\left[(n-1)-(k-1)\right]!\,(k-1)!}$$

The algorithm is coded in the software called Visual Studio Code which converges fast with a successful task completion. (that is the deficit is made uniform for all regions)

Table 2. Energy supply position - April 2015

Region	Energy (MU)		Deficit %	Shapley Value Allocation
	Requirement	Availability		
Northern	23626	22499	4.8	1.6
Western	27123	27044	0.3	0.996
Southern	24220	23702	2.1	1.37
Eastern	9747	9647	1.0	1.05
Northern Eastern	1038	960	7.5	2.006
All India	85754	83852	2.2	1.265

Table 3. Peak supply position – April 2015

Region	Power (MW)		Deficit %	Shapley Value Allocation
	Peak Demand	Peak met		
Northern	41540	40003	3.7	2.235
Western	43135	42690	1.0	1.26
Southern	37801	36786	2.7	1.334
Eastern	17368	17304	0.4	0.774
Northern Eastern	2220	2114	1.0	1.05
All India	136884	132119	3.5	1.85

4. Results and Discussions

The data table taken from CEA[7] is given as an input to the VISUAL STUDIO CODE and the simulations are carried out. Figures 2,3,4,5 are the input and output of the program used to control the deficit. The present and estimated values of deficit are as shown in the Table 2; Table 3 calculates the new deficit and achieves increased efficiency by normalizing the deficit values for better efficiency. The new deficit is the estimated values using a program based on 'Shapley Value'. This is calculated for both Energy and Power. The program takes the input as the present live data of the deficit and based on the game theory, it estimates and provides the fair allocation of these deficit values as more enhanced and efficient ones.

```
Present Deficit :-
                  -4.8
                  -0.3
                  -2.1
                  -1.0
                  -7.5
                  -2.2
```

Figure 2. Actual energy deficit.

```
New Deficit :-
                  -1.6
                  -0.996
                  -1.37
                  -1.05
                  -2.006
                  -1.265
```

Figure 3. Shapley value allotted energy deficit.

The targeted results are achieved and the values are shown.

```
Present Deficit :-
                  -3.7
                  -1.0
                  -2.7
                  -0.4
                  -4.8
                  -3.5
```

Figure 4. Actual power deficit.

```
New Deficit :-
                  -1.26
                  -1.05
                  -1.334
                  -0.778
                  -2.235
                  -1.85
```

Figure 5. Shapley Value allotted power deficit.

5. Conclusions and Future Work

This paper uses Shapley Value to reduce the deficits in Energy and Power in various regions of India. The deficits were non-uniform, some regions were having maximum deficits, and some others were having less. Shapley Value does a fair allocation on the availability and requirement of energy and with power demand and peak met. The basic equation of SV is coded in Visual Studio Code without much complexity. In future, the work can be extended for various areas in a specific region and also together so that the verified concept can be integrated for the future smart grid.

6. Acknowledgment

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