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# Reliable and Cost-Effective Supply Model using Multi Agent Smart Grid Controller

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***Abstract: The energy sector is moving towards renewable energy generation. Renewable energy generation is the key technology for a smart grid operation. These renewable producers' electricity generation capacity varies significantly with change in weather conditions and causes system unreliability. To improve acceptability of this intermittency either renewable generation should be such that it meets the load demand round the corner or there should be a successful coordination between renewable power generation and the grid, so that consumer gets a reliable and cost efficient power. This paper presents a computer-based model of a multi-agent Smart Grid Controller (SGC). The design objective is to provide reliable and cost optimized electricity to the consumers. The Smart Grid Controller continuously monitors the power availability and demand on hourly basis and switches between price-based demand fulfilment and priority-based demand fulfilment algorithm accordingly. Two case studies – Renewable with Grid Power (RwGP) and Renewable without Grid Power (RwoGP) are taken into consideration. The design is validated on the data of a township. The impact of normal and extreme weather conditions on renewable producer agent's operating capacity is simulated. System's performance is analysed on daily and monthly data. Results show that the model not only is reliable but also provides cost optimized solution to consumers as compared to only Grid supplied system.***

***Keywords: SGC, Python programming, Smart Grid Simulator***

## I. INTRODUCTION

In last decade, the power generation scenario has seen drastic changes in India [1]. The major reason for this change is sustained government efforts towards renewable power generation [2] and entry of private players. The gap between demand and power generation is reducing day by day but still there are frequent outages. Utilizing renewable energy resources along with the grid presents many challenges [3-6]. The traditional power distribution system is unable to integrate the renewable resources into the existing system effectively. Integration of renewable power resources need efficient algorithm in view of their unreliable nature since they depend on weather patterns, which can only be predicted with limited capabilities [7-12].

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To create a functional smart grid, it is necessary to predict the behaviour of the energy grid when certain parameters are changed. Simulation is fundamental to fulfil this requirement. Smart grid simulation is an essential prerequisite for evaluation and analysis before establishing a real-world grid.

This can be used to optimize the overall performance of the grid, specifically, when integrating renewable energy resources. Also, other tasks are required from the smart grid simulator such as optimization of distributed energy resource management, demand response, critical demand fulfilment, energy storage, simulating consumer demand, integration of communication and power network, etc.

The efficient operation of a smart grid requires effective integration of natural resources in multi agent system [13] as well as integration of user environment through bidirectional communication [14]. The algorithms proposed in smart grid operation should not only consider the problem of renewable energy source integration but should also consider the consumer needs [15] so that it brings significant saving to the user. So, for reliable [16] and effective working of a system, efficient algorithms are required [17].

This paper enhances the design of the smart grid controller by augmenting the dynamic switching capability to switch between priority based and price-based demand fulfilment

Smart grid controller's design reliability, sustainability and effectiveness is analysed using data of a township having 1000 houses, hospital, institution and commercial complex. By implementing two case studies, the performance of smart grid controller is compared with only grid-based system. The focus is on calculating the power flow in a microgrid and a power distribution grid. The former case includes a scenario where a microgrid supplies power to a township. The latter case includes a scenario where a microgrid is connected to grid i.e. grid connected mode. In this mode, microgrid can buy or sell excess power from or to the power utility grid. In both the cases a period of one day and one month have been simulated, observed and recorded at hourly intervals.

The proposed simulator can lower the energy bills of the consumers, is reliable as it is able to fulfil critical demand round the clock. The battery operation and maintenance cost are eliminated, thus is cost effective as compared to proposed smart grid simulator [18].

The paper is organized as follows: Section 2 discusses the smart grid controller framework. Section 3 provides the algorithm used in smart grid controller design. In Section 4 test case scenarios are discussed along with graphs and simulation results are presented based on the proposed approach. Section 5 concludes the paper.

## II. SMART GRID CONTROLLER FRAMEWORK

The proposed Multi Agent System (MAS) consists of several agents. These agents communicate, coordinate and cooperate with each other via a smart grid controller (SGC). Fig. 1 shows the architecture of proposed framework.

**1. Renewable Producers:**

Producer agents, which generates electricity using renewable resources

i) Wind Turbine Agent (WTAG): WTAG is installed at each wind turbine generator

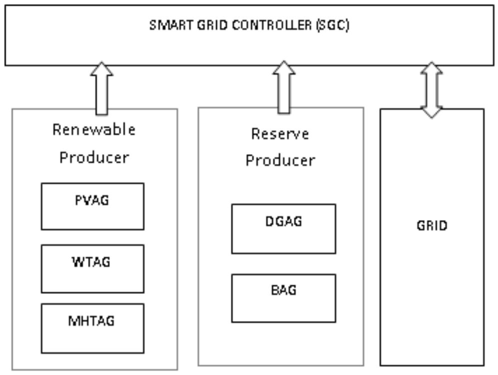


**Fig. 1. Smart Grid Controller**

ii) Photo-Voltaic Agent (PVAG): PVAG is installed at each photo-voltaic generator

iii) Micro-Hydro Turbine Agent (MHTAG): MHTAG is installed at each micro-hydro turbine generator

*2. Reserve Producers:*

Producer agents, which generates electricity only when there is power shortage

i) Battery Agent (BAG): BAG is installed at each battery centre. It acts as both consumer and producer.

ii) Diesel Generator Agent (DGAG): DGAG is installed at each diesel generator (DG)

*3. Grid:*

Producer that generates electricity from traditional sources (fossil fuel).

The proposed SGC design is modular and can work in both Micro grid and Grid connected scenarios.

### A. Renewable without Grid Power (RwoGP)

In this case, a micro grid supplies the locality/town under consideration where the electricity supply is from the renewable producers like solar photovoltaic, wind turbines, micro hydro turbines. This locality/town is not supplied by grid. Batteries are there which act as consumers i.e. are charged when power is surplus and are producers i.e. supply power when power is deficit. Here the available renewable producers and batteries fulfil the demand of hospital, commercial and institution along with residential demand. SGC keeps track of available power and demand round the clock on an hourly basis.

In the case when available power is not sufficient to meet minimum demand i.e. hospital, institution, commercial and other critical establishment like community hall, water pump, elevators etc., SGC turns on the diesel generators (DGs) as required to increase the available power so that demand of the critical loads can be fulfilled, though there will be an increase in the per unit price of electric power.

In the case when available power is enough to fulfil critical demand but short of fulfilling the full demand, SGC will supply power to different category consumers in order of priority. For example, it will first supply power to hospital, institution and commercial and in last to household consumers. Household consumer can also be divided into blocks/clusters and power cut can be planned in round-robin manner, so that each consumer can get some amount of power during the day.

In the case when available power is more than demand, SGC plays a major role in optimizing per unit price and improving system efficiency by utilizing more power from the available renewable resources in the ascending order of their per unit prices. Batteries will charge when demand is less.

### B. Renewable with Grid Power (RwGP)

In this case, the locality/town under consideration is grid connected. Power is available from both renewable resources and grid.

SGC tries to fulfil the demand through available renewable producers. The excess power generated by the renewable resources, is lend to the grid. In the case when demand is more, the grid fulfills it. In this way, excess power in terms of units given to grid is adjusted against the units drawn from grid.

Thus, there is no need of storing the surplus power in batteries and therefore the batteries installation, operation and maintenance cost can be eliminated.

## III. SMART GRID CONTROLLER ALGORITHMS

The smart grid design objective is to provide reliable and cost optimized electricity to the consumers. The smart grid controller continuously monitors the power availability and demand on hourly basis and switches between price-based demand fulfilment and priority-based demand fulfilment algorithm accordingly. When available power is more than demand, price price-based fulfilment method is applied to provide cost saving else priority-based demand fulfilment algorithm is applied to supply power to consumers based on their priority.

### A. Price based demand fulfillment

Price based demand algorithm is shown through flow chart in Fig. 2 and detailed steps are provided below:

*Step1:* Initiate the process for time t=1 and iterate the process every hour

*Step 2:* Fetch total demand (D) at time t

*Step3:* Fetch producer's information (producer id, per unit price, power available)

*Step4:* Sort producer list in ascending order of price (Fig. 4)

*Step 5:* Compute Total Available Power (TAP)

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*Step6:* Total available power is less than total demand, invoke priority-based demand fulfilment algorithm

*Step7:* Prepare Selected producer list from available producers using below steps

*Step8:* If selected producer capacity is less than demand then follow steps 9-11

*Step 9:* Add producer in selected producer list

*Step10:* Subtract supplied power from this producer from demand

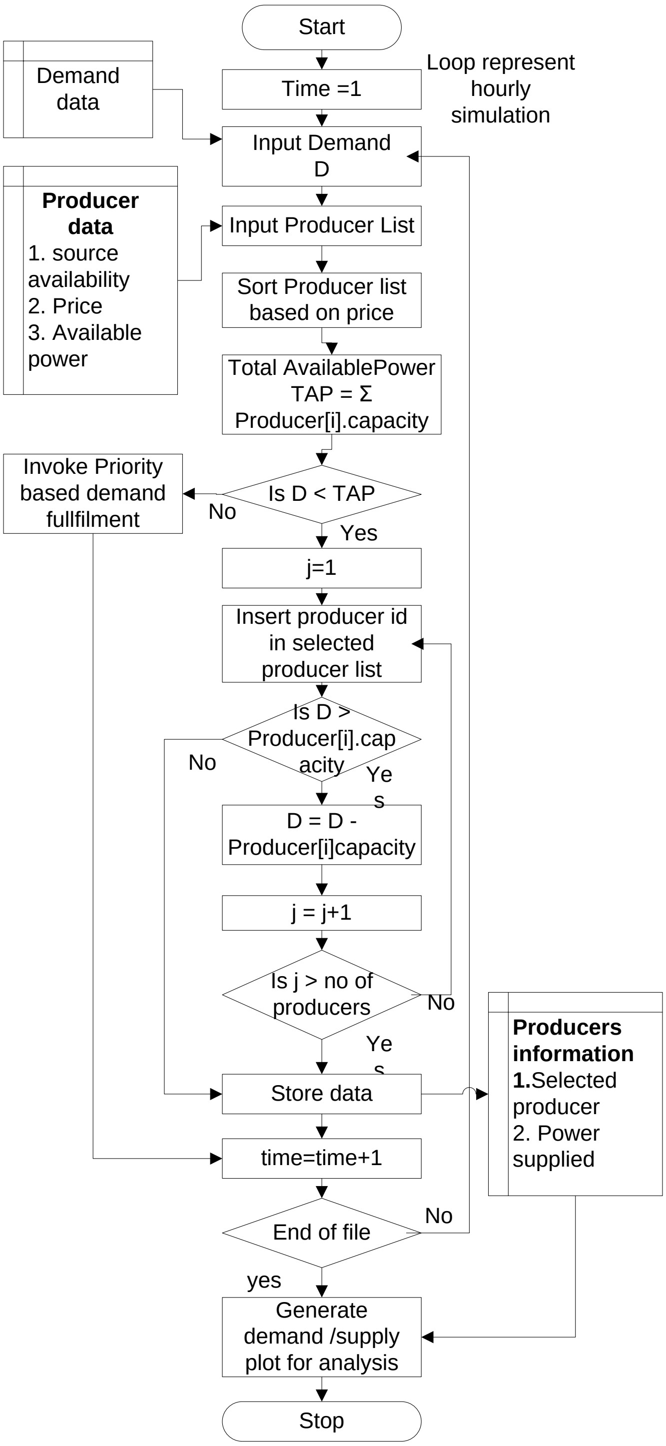


**Fig. 2. Price based demand fulfilment**

*Step11:* Repeat steps 9-10 till complete demand gets fulfilled

*Step12:* Store supplier list against time in file for analysis and plotting

*Step13:* Iterate steps 2-12 every hour

## B. Priority based demand fulfillment

Priority based demand algorithm is shown through flow chart in Fig. 3 and detailed steps are provided below:

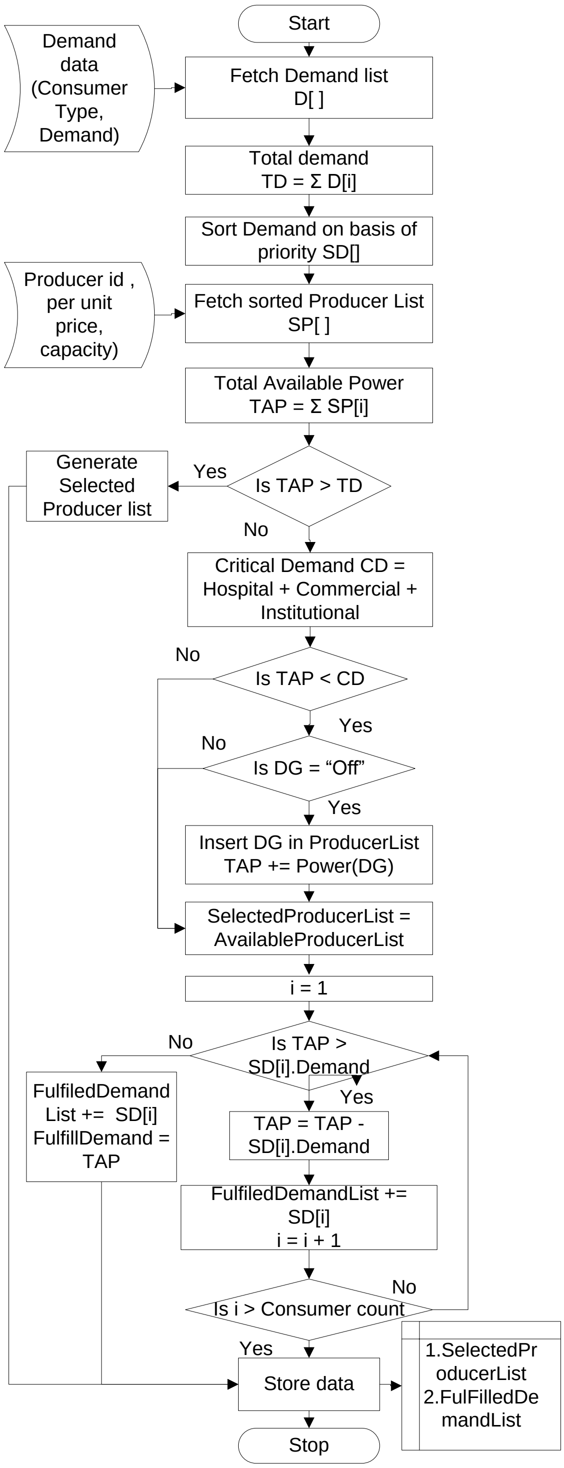


**Fig. 3. Priority based demand fulfilment**

*Step 1:* Fetch demand (D) of different consumer type like hospital, institution, commercial and private users. Compute total demand (TD)

$$TD = \Sigma D[i] \text{ ------- } (1)$$

*Step 2:* Sort demand based on priority. Here, Hospital demand will have highest priority followed by Institution, commercial and household

*Step 3:* Fetch sorted producer (SP) (Fig. 4) information (producer id, per unit price, available power) and compute total available power (TAP)

$$TAP = \Sigma SP[j] \text{ ------ } (2)$$

*Step 4:* If demand (TD) is less than total available Power (TAP) then generate selected producer list based on price-based fulfilment algorithm.

*Step 5:* If available power is less than demand then check whether critical (i.e. hospital, institutional and commercial) demand (CD) can be fulfilled by available power (TAP, if not then turn on DG and add it in producer list and TAP

$$TAP = TAP + DG\ Power \text{ ------ } (3)$$

*Step 6:* Prepare list of Consumer, whose demand can be fulfilled with total available power (TAP)

*Step 7:* Add selected consumers in a list for further analysis

### *C. Price based producer sorting*

The sorting algorithm is based on Python programming (Fig. 4)

*Step1:* Fetch producer's ID and add them in list

*Step2:* Fetch available power from these producers and append them in list against each producer

*Step3:* Fetch per unit price of each producer and append them against each producer

*Step4:* Generate key from per unit price list

*Step5:* Sort Producer list in ascending order of per unit price, using key generated in step4.

## IV. SMART GRID CONTROLLER DESIGN VALIDATION

### A. Smart Grid Simulator

The Smart Grid Controller framework proposed in this research work is validated through SGC simulator program using Python 3.0. The program simulates various real-world scenarios in micro grid system and grid connected system. It takes producer information (Producer ID , per unit price, capacity, and availability) and hourly demand as input and then simulates the real-world scenario by changing producer capacity/ availability with Python inbuilt random function for e.g. power available from WTAG is changed to some days to simulate windy /no -wind day.

Similarly, power from PVAG is changed to simulate rainy/cloudy day. It then applies the algorithms proposed in Section 3 to suggest the optimised list of producers (in case power available is more than demand) or consumers (in case demand is more than available power). Simulator also records the key operational parameters in a file and generates the graphs for performance analysis.

### B. Case Study

The case study considers a township located in India. It comprises of 1000 houses inhabited with modern amenities, institution, hospital, shopping complex. Typical household appliances include lighting, refrigerator, air conditioner/heater, geyser, television, washing machine, microwave etc. i.e. a max load of 5kVA to 10kVA.

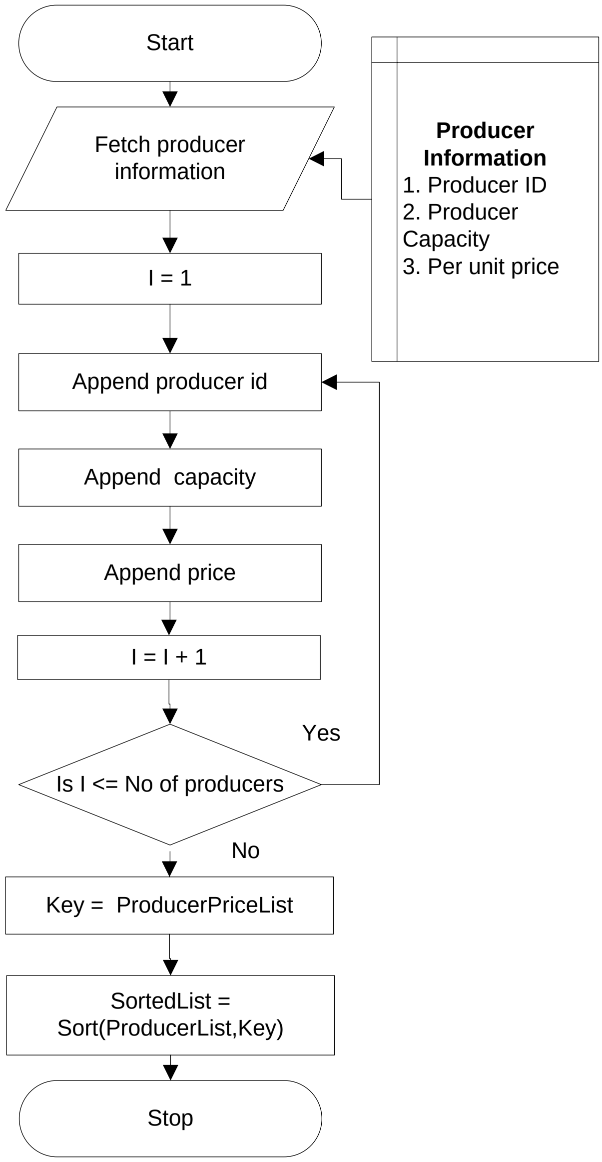


**Fig. 4. Price based producer sorting**

Data for various types of consumers is captured as follows

a) Commercial power consumption data for one hospital, one institutional complex and one shopping mall is taken from Electrical power Distribution Company of National Capital Region.

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b) Residential power consumption data is recorded at one of the Author's home within a community of 1000 houses located in metro city of National Capital Region. Data is recorded using EmonPi device (Fig. 5) [19].

c)

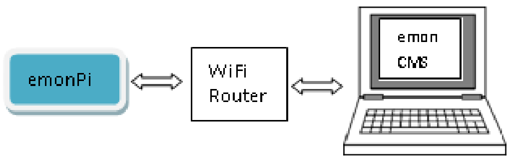


**Fig. 5. EmonPi Set up**

This data is extrapolated for 1000 houses by using Python's random function.

Following points are considered in deciding the Producer's capacity

a) There is a trade-off between power shortages and extra power therefore system's total capacity is fixed such that, critical demand should always be met, and extra power generation should be minimised.
b) The system should not be dependent on single renewable producer as the power generation capacity significantly varies with weather change.
c) BAG and DGAG producer capacity is taken less due to high maintenance cost of these producers.

Table I shows the Producer agents capacity considered for simulation.

**Table I. Producer Agent Capacity**

| Producer Agent | Producer Capacity (KW) |
|---|---|
| WTAG | 1000 |
| PVAG | 1100 |
| BAG | 250 |
| GRID | 2500 |
| MHTAG | 1000 |
| DGAG | 800 |

The power varies over the day and over various several days owing to changing weather patterns. This is emulated by introducing noise to signal for each producer using random module of Python.

- For one set of simulations, the randomization is done for 20% of values (80% operating capacity) which encompasses such instances of time when power producers are not very much affected by weather patterns (Table III).
- For other set of simulations, the randomization is done for 40% of tabular values (60% operating capacity) to encompass extreme weather patterns (Table IV).

Operating reserve is considered in SGC design to make it more robust and reliable.

- MHTAG constitute of four turbines; but SGC will utilize only three, leaving one for operating reserve.
- In case of WTAG, also one turbine is kept for operating reserve.
- To handle sudden demand fluctuation 110% of actual demand is considered in design. This extra 10% will work as cushion to handle those sudden fluctuations, as SGC will take some time in recompilation.

## V. RESULT AND DISCUSSION

The smart grid controller's performance is analysed in following cases:

1) Renewable without Grid Power (RwoGP)
2) Renewable with Grid Power (RwGP)

*1) Renewable without Grid Power (RwoGP):* The total demand and available power is analysed hourly in both normal and extreme weather condition. The demand and available power scenario for a typical day is shown in Fig. 6. and Fig. 7 in normal and extreme weather condition respectively.

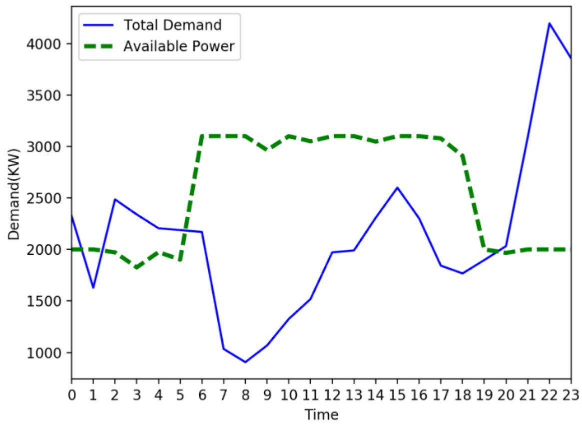


**Fig. 6. Demand and available power on a typical day**

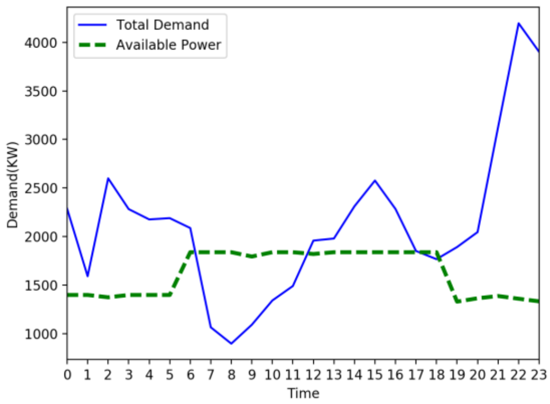


**Fig. 7. Demand and available power on a typical day in extreme weather condition**

SGC can fulfil critical demand round the clock with the effective use of Batteries and DGs in both weather conditions (Fig. 8 and 9 respectively). SGC is unable to meet total demand during night due to unavailability of PVAG. Surplus power during the day (Fig. 10) charges the batteries, which in turn is used in the night to fulfil sudden fluctuations in the demand

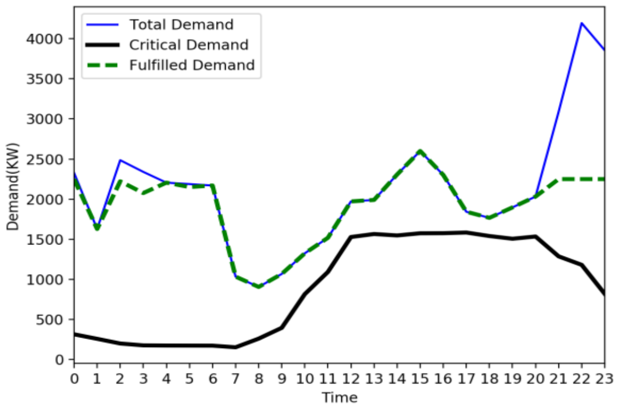


**Fig. 8. Demand fulfilment on a typical day**

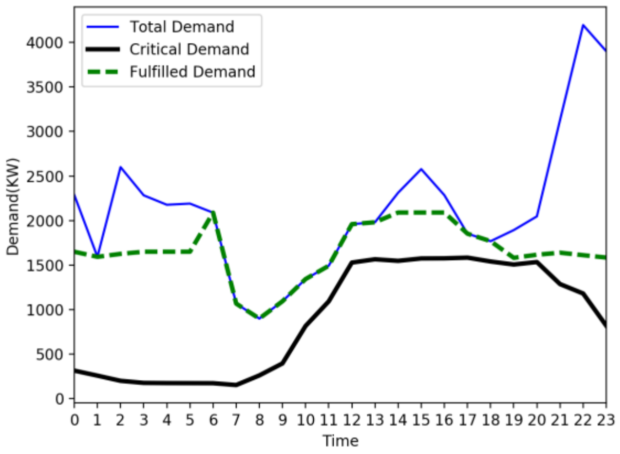


**Fig. 9. Demand fulfilment on a typical day in extreme weather condition**

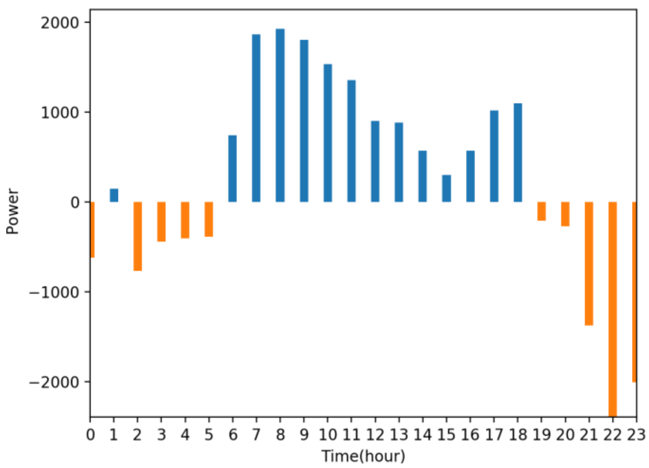


**Fig. 10. Surplus Power availability on a typical day**

To measure SGC's effectiveness, system's performance index is computed at different time zone during a day and at different operating capacity of producers.

Performance index is a measure of Smart Grid's operational effectiveness. It is an indication of Smart Grid's performance at a time and shows how much demand percentage Smart Grid can fulfil during peak hours.

*PI = Demand Fulfilled / Total Demand -----(4)*

Table II shows system's performance index when producers were operating at full capacity. Similarly, Table III and Table IV show system's performance at 80% and 40% of full capacity respectively.

As observed from above Tables (II-IV), system can fulfil critical demand even at 40% operating capacity. The system is also able to meet the total demand during the day but able to fulfil around 70% demand during evening and above 80% during night.

**Table II. Producer working at full (100%) capacity**

| Time Zone | Critical Demand (KW) | Total Demand (KW) | Power Available (KW) | PI (Critical Demand) | PI (Total Demand) |
|---|---|---|---|---|---|
| 00:00 - 05:00 | 1301 | 13202 | 13323 | 1 | 0.96 |
| 06:00 - 09:00 | 984 | 5161 | 13227 | 1 | 1 |
| 10:00 - 14:00 | 6550 | 9077 | 16637 | 1 | 1 |
| 15:00 - 18:00 | 6274 | 8505 | 13366 | 1 | 1 |
| 19:00 - 21:00 | 6327 | 14952 | 11060 | 1 | 0.71 |

**Table III. Producer working at normal (80%) capacity**

| Time Zone | Critical Demand (KW) | Total Demand (KW) | Power Available (KW) | PI (Critical Demand) | PI (Total Demand) |
|---|---|---|---|---|---|
| 00:00 - 05:00 | 1301 | 13242 | 12086 | 1 | 0.88 |
| 06:00 - 09:00 | 984 | 5167 | 11562 | 1 | 1 |
| 10:00 - 14:00 | 6550 | 9109 | 14546 | 1 | 1 |
| 15:00 - 18:00 | 6274 | 8497 | 11473 | 1 | 1 |
| 19:00 - 21:00 | 6327 | 14940 | 10235 | 1 | 0.67 |

**Table IV. Producer working at low (40%) capacity**

| Time Zone | Critical Demand (KW) | Total Demand (KW) | Power Available (KW) | PI (Critical Demand) | PI (Total Demand) |
|---|---|---|---|---|---|
| 00:00 - 05:00 | 1301 | 13071 | 9773 | 1.00 | 0.74 |
| 06:00 - 09:00 | 984 | 5149 | 8349 | 1.00 | 0.99 |
| 10:00 - 14:00 | 6550 | 9082 | 10334 | 1.00 | 0.97 |
| 15:00 - 18:00 | 6274 | 8520 | 8345 | 1.00 | 0.92 |
| 19:00 - 21:00 | 6327 | 15067 | 8250 | 1.00 | 0.55 |

2) *Renewable with Grid Power (RwGP):*

In this scenario, the power drawn from each producer agent is recorded for a month. To optimize per unit cost, SGC first utilizes the power drawn from renewable and balance demand is fulfilled from grid as shown in Fig. 11.

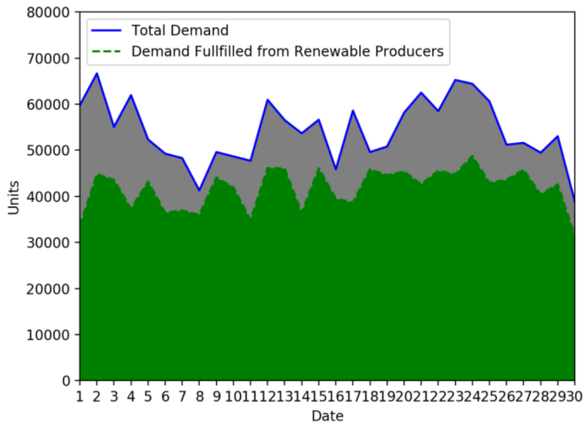


**Fig. 11. Power scenario during a month**

To analyze the cost optimization, daily cost is computed as below:

$$Optimized\ Cost\ (OC) = \Sigma D[i]*P[i] \text{ ----- } (5)$$

$$Grid\ Cost\ (GC) = TD*PG \text{ ---------------- } (6)$$

*Here*, D[i] is demand fulfilled by producer agent i, P[i]is price of producer agent i, TD is total demand and PG is grid price

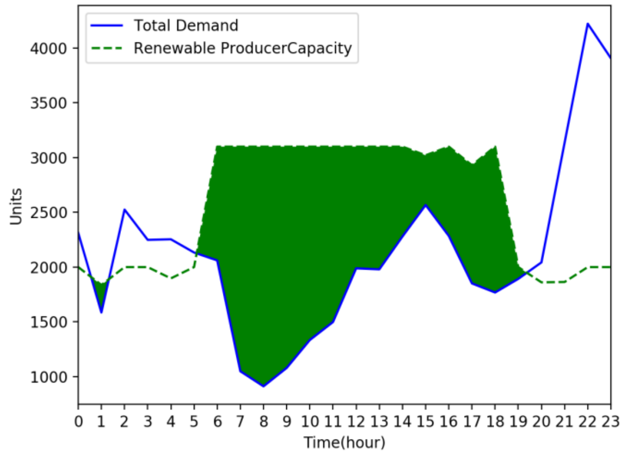


**Fig. 12. Power lend to grid on a typical day**

Daily saving is monitored for a month and presented in Table V. The data is computed when renewable producers are working at 80% of their full operating capacity. The proposed system can provide on an average 20% saving with respect to only grid-based system. As evident from shaded area in Fig. 12, surplus power is available from renewable agent during the day, which could be lent to grid. This surplus power from renewable can be compensated against the power drawn from grid (shaded area in Fig. 13) to achieve more saving.

The net power exchanged between grid and renewable sources for a month is shown in Fig. 14. Power lend to grid is shown by positive bars and power taken from grid is shown by negative bars.

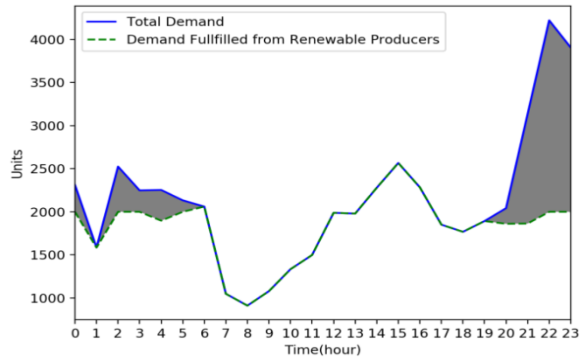


**Fig. 13. Power taken from grid on a typical day**

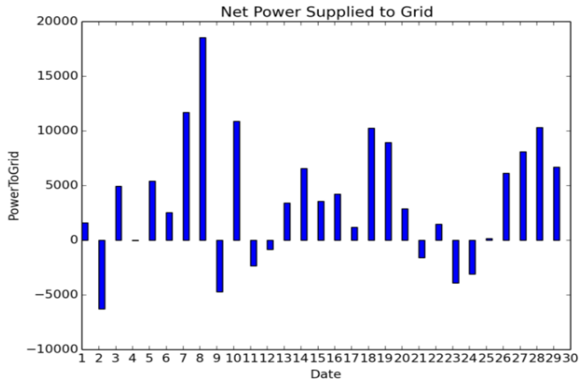


**Fig. 14. Power scenario during month**

## VI. CONCLUSION

The work proposes the solution for not only effective and seamless integration of natural producers in multi agent system but also considers the price conscious consumers perspective in the efficient operation of a smart grid controller. The simulator validates the effectiveness of the proposed Multi Agent based Smart Grid design using real world data. The system is sustainable as it can work effectively in both Renewable with Grid Power (RwGP) and Renewable without Grid Power (RwoGP) situations. The proposed simulator in this paper, not only is able to lower the energy bills of the consumers, but also is reliable as it is able to fulfil critical demand round the clock. The battery operation and maintenance cost are eliminated, thus is cost effective. Performance Index shows that even at 40% operating capacity, system can fulfil critical demand all the time and total demand during the day and around 70% demand at peak time in the evening. The results prove the feasibility of the system in Indian context and its ability to function successfully even in extreme weather conditions.

**Table V. Consumer Saving**

| Day | Cost with Grid (INR) | Cost with Renewable (INR) | Saving |
|---|---|---|---|
| 1 | 376554 | 314475 | 16% |
| 2 | 423823 | 350022 | 17% |
| 3 | 349269 | 281140 | 20% |

| | | | |
|---|---|---|---|
| 4 | 382935 | 313303 | 18% |
| 5 | 335027 | 264083 | 21% |
| 6 | 318810 | 251633 | 21% |
| 7 | 314902 | 248364 | 21% |
| 8 | 266617 | 203710 | 24% |
| 9 | 320427 | 250543 | 22% |
| 10 | 314748 | 247281 | 21% |
| 11 | 308378 | 243377 | 21% |
| 12 | 385326 | 316384 | 18% |
| 13 | 364614 | 292647 | 20% |
| 14 | 341385 | 274127 | 20% |
| 15 | 365059 | 293170 | 20% |
| 16 | 293049 | 231224 | 21% |
| 17 | 375376 | 307515 | 18% |
| 18 | 319384 | 247731 | 22% |
| 19 | 324175 | 256213 | 21% |
| 20 | 366292 | 296941 | 19% |
| 21 | 395817 | 321996 | 19% |
| 22 | 372107 | 301821 | 19% |
| 23 | 405438 | 335242 | 17% |
| 24 | 405753 | 331867 | 18% |
| 25 | 387310 | 316184 | 18% |
| 26 | 331642 | 262224 | 21% |
| 27 | 334899 | 262952 | 21% |
| 28 | 319487 | 250727 | 22% |
| 29 | 342640 | 274876 | 20% |
| 30 | 253151 | 197513 | 22% |

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