# Intelligent Dynamic Grid Forecasting Algorithm for a Grid-Connected Solar PV Based Microgrid

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***Abstract*—This paper outlines the enhancement in performance characteristics of microgrids operating in rural and semi-urban regions with the inclusion of intermittent grid to the existing solar PV microgrid installations. The paper presents an Intelligent Dynamic Grid Forecasting Algorithm (IDGFA) that predicts day-ahead requirement of power from the utility grid, providing for load scheduling for the grid operator. This results in dynamic and strategic resource allocation in real time and enables maximum load servicing by the microgrids. The IDGFA runs at 7:00 a.m. every day wherein day-ahead shortages are tracked based on hourly State Of Charge (SOC) estimates made for a 48 hour duration. The SOC estimates are made with inexpensive, accurate, hourly solar PV forecasts made available for the same period. The instance and duration of grid requirement are intelligently predicted by minimizing the shortages for next day, leading to maximizing load servicing efficiency for a particular PV size. This proves to be an inexpensive option for enhanced load servicing as alternatively, oversizing PV systems for the same purpose leads to much higher capital costs and excessive wastage of energy. Rural microgrid with intermittent grid connectivity that are examined in this paper are for conditions in central India and it is observed that the system efficiency is above 97% in all cases. The excess energy contributed by the intermittent grid is also found to be negligible.**

***Index Terms*—microgrid, energy storage, adaptive algorithm, power grid, solar energy, forecasting, energy management**

## I. INTRODUCTION

The global energy demand has risen considerably due to industrialization and population growth. Traditionally, this energy demand is usually met by fossil fuels, which include coal, oil and natural gas. However, increased green house gas emissions have caused a radical change in policy to switch over to renewable energy. Due to these evolving landscapes, the global energy contributed by renewables has increased from 800 GW to 1560 GW [1]. Yet, 17% of the world's population have no access to electricity [2].

This inequality between energy generation and demand is severe in developing countries like India where 21.3% of the total population have no access to electricity as per World Bank's Global electrification database. Furthermore, 75 million Indian rural households do not have access to electricity, while only 5.8 million Indian urban households lack such access. This growing disparity between the urban and rural populace is unsustainable and is characterized by the lack of access to energy [3].

This need for energy inclusion has led to multiple installations of microgrids which are localized energy generation units with energy storage and Distributed Energy Resources (DERs) like solar PV, biogas and wind in order to serve a community [4]. India offers 300 clear sunny days a year that allows a potential solar energy incidence of 5000 trillion kWh.

This makes conditions favourable for solar PV microgrid initiatives like *Mera Gao Power* and *The Energy and Resources Institutes* (TERI) solar microgrid in Odisha to provide electricity access to villages [5] [6]. However, solar is intermittent in nature due to variable weather conditions, which is usually resolved by using energy storage solutions. Such a purely storage sizing dominated solution is expected to cost at least as much per watt installed as solar PV installations which makes them economically unfit for decentralized rural installations [7]. Another solution of oversizing of PV to maximize load servicing is not economical and hence not viable for a rural scenario.

An alternative strategy to such solutions, is the inclusion of the intermittent grid to the existing solar PV microgrid with storage unit. This ensures dynamic allocation of energy from solar PV and the utility grid within economic constraints. As a result of this, the load servicing capabilities are higher than conventional off-grid installations. Since grid power in rural India is sporadic in nature, there is a need for intelligent energy generation forecasting systems to facilitate the availability - demand balance, by providing the grid operator with day ahead grid power requirement forecast for convenient load scheduling.

This paper proposes an intelligent dynamic grid-forecasting algorithm that predicts the day-ahead power requirement from the utility grid thus offering opportunities for the grid operator to pre-plan energy dispatch. The intelligent and dynamic aspects of the algorithm reduces the shortages that occur in real time by utilizing solar PV forecasts and load requirement estimates, thus resulting in maximizing load servicing in an intermittent grid tied solar PV microgrid. The intelligent algorithm developed in this paper proves to be a reliable solution in rural and semi-urban scenarios where lack of continuous energy access is a major drawback, further ensuring economic viability with very minimal constraints.

## II. RELATED WORK

*Rajesh et al* [8] have proposed a system to reduce the intermittency of utility grid by supplementing it with renewable DERs in a rural Indian scenario. The Microgrid Control Centre

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uses intelligence to optimise load servicing based on renewable energy forecasts. The architecture proposed does not include a storage bank for load servicing, but the authors have proposed its significance as a future work. *Bacha et al* [9] have highlighted that off-grid PV microgrid installations suffer from intermittency in generation and have recommended the need to integrate such microgrids to energy storage solutions and the utility grid. This integration requires energy management to maximise load servicing. In the system proposed in our paper, the inclusion of intermittent grid working in tandem with solar PV connected to a storage bank ensures maximal load servicing. Our system relies on 48 hour solar PV forecasts and SOC estimations of the storage bank which facilitate optimal power utilisation from the utility grid.

*Jha et al* [10] have discussed integrating isolated microgrids to the national grid. It is gathered that the economic benefit of national grid utilisation for servicing load is a better option than load servicing by isolated microgrids. This may lead to the cease of isolated microgrid operations on grid expansion, thus calling for the necessity to integrate. *Kuwahata et al* [11] have proposed the role of microgrids in accelerating the energy access in developing countries. The integration of grid expansion with the renewable energy sources provides for a reliable and economic alternative. In our paper, load servicing is done by integration of renewable energy sources with utility grid, which is typically intermittent in nature in rural areas. Operating rural microgrids in grid-connected mode with day-ahead scheduling of resources ensures reliable and accelerated availability-demand balance with negligible dissipation of excess energy.

## III. Problem Statement

Solar PV microgrids are designed to meet a predefined load servicing efficiency. Such systems tend to operate in rural and semi-urban regions of India. Many of these systems are located at the tail end of the existing grid network. Hence, intermittent access to utility grids is available. Load servicing based on prioritization of loads, depending on their criticality would be efficient during periods of energy shortage. To reduce energy shortage, PV sizes can be increased, although, this will result in very high capital cost. With the usage of inexpensive solar PV forecast, accurate load requirement predictions and hence day-ahead shortage predictions can be made. In this paper, these shortages are used by the IDGFA to estimate the day ahead grid requirement for maximizing load servicing with negligible additional capital cost.

## IV. Methodology

### A. System Architecture

The physical connection of the system architecture is as shown in Figure 1. The loads to be serviced in the microgrid are fixed and prioritized based on their criticality as Critical Loads (CL) and Non-Critical Loads (NCL). The microgrid consist of solar PV which is connected to a storage bank. The storage services loads based on fixed State Of Charge (SOC) thresholds that are pre-set based on criticality of the load. The system implemented in the paper, aspects maximizing load servicing with the inclusion of intermittent grid in a stand alone PV microgrid. The storage bank is cut off from servicing the load when grid is available. Therefore the load is not served simultaneously from both the storage bank and the grid. The control room performs this switching of load servicing by grid or storage bank ensuring mutual independence.

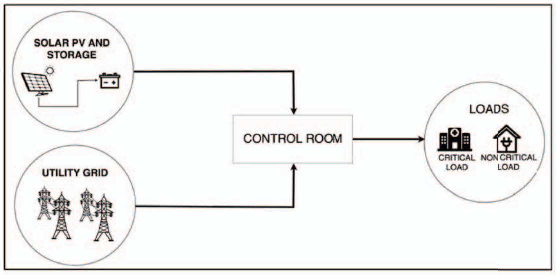


Fig. 1: Architecture of grid-connected solar PV based microgrid

### B. System Design

Yearly data for the power generated by various solar PV on an hourly basis with fixed loads are obtained from HOMER for a village, Deogarh in the state of Madya Pradesh, India. These values are used for prediction purposes. The choice of Valve Regulated Lead-Acid (VRLA) batteries in the storage bank is made as they exhibit superior performance and longevity for their cost. Table 1 shows the design specifications of the system proposed and implemented in this paper.

TABLE I: SYSTEM DESIGN SPECIFICATION

| PVSize (kW) | Storage Bank | | Loads (kW) | |
|---|---|---|---|---|
| | Size (kWh) | Parameters | CL | NCL |
| 16 to 25 | 96 | Vision 6FM200D 12V 200Ah (2.4kWh) | 1 | 3 |

### C. System Operation

*1) System Run Time Operation:* During run time, SOC of the storage bank is tracked hourly based on the PV inputs and load serviced. The amount of charge in the storage bank is its SOC. It is expressed as a percentage of the total capacity of the battery as shown in equation 1.

$$SOC = ((ChargePresent)/TotalCapacity) * 100 \quad (1)$$

The availability of grid is checked for. If grid is available, it services the total system load (Lt=CL+NCL). The SOC remains unaltered by the influence of the grid due to the mutual independence of grid and storage bank in the architecture. SOC during instances of grid availability is calculated as shown in equation 2.

$$SOC[i] = SOC[i-1] + PV[i] \quad (2)$$

where $i$ is current hour

When grid is unavailable, appropriate loads are serviced based on prioritization of load criticality and pre-set SOC thresholds. CL and NCL are serviced till SOC is greater than 30%, only CL is serviced from 30% to 10% SOC and load servicing is shut down below 10% SOC. The pseudo code for

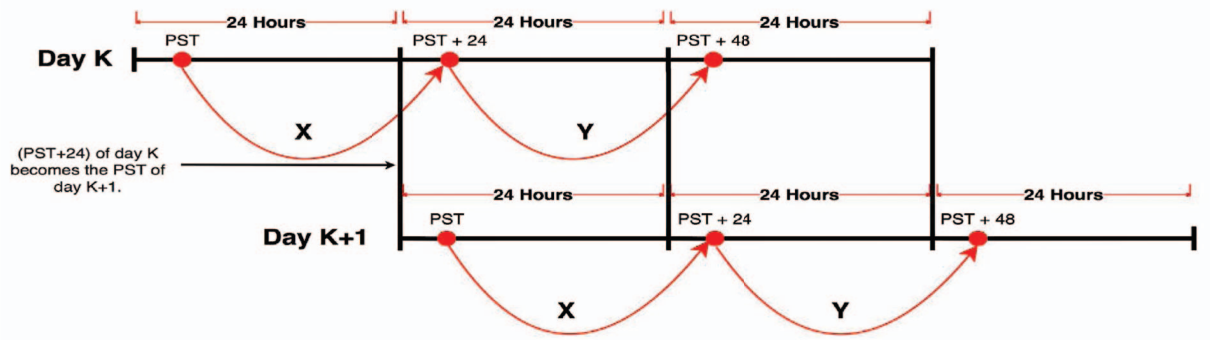
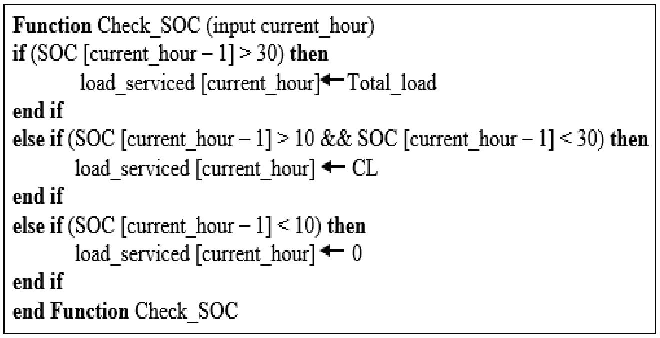


Fig. 2: Operational flow of IDGFA



```
Function Check_SOC (input current_hour)
if (SOC [current_hour – 1] > 30) then
        load_serviced [current_hour] ← Total_load
end if
else if (SOC [current_hour – 1] > 10 && SOC [current_hour – 1] < 30) then
        load_serviced [current_hour] ← CL
end if
else if (SOC [current_hour – 1] < 10) then
        load_serviced [current_hour] ← 0
end if
end Function Check_SOC
```

Fig. 3: Pseudo code for hourly load determination

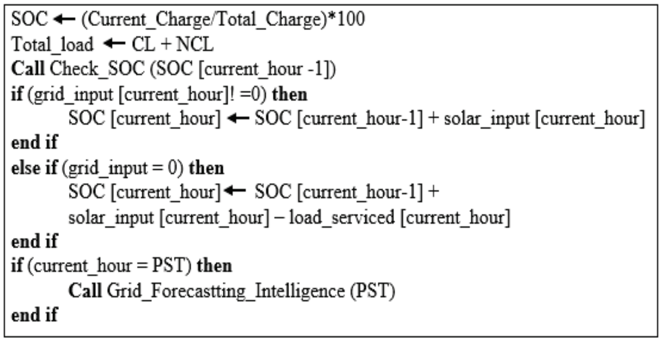
determining hourly load servicing based on prioritization is shown in Figure 3.

The SOC calculation at these hourly instances when grid is unavailable is done using equation 3.

$$SOC[i] = SOC[i-1] + PV[i] - LoadServiced[i] \tag{3}$$

where $i$ is current hour

The system runs Intelligent Dynamic Grid Forecasting Algorithm at 7:00 a.m., which is called the Prediction Start Time (PST) to find the grid energy required for the next day as explained in *Section IV-C*. The system is flexibly designed such that the PST can be fixed as any particular hourly instance of the day throughout the year. The pseudo code for the system’s run time operation is shown in Figure 4.



```
SOC ← (Current_Charge/Total_Charge)*100
Total_load ← CL + NCL
Call Check_SOC (SOC [current_hour -1])
if (grid_input [current_hour]! =0) then
        SOC [current_hour] ← SOC [current_hour-1] + solar_input [current_hour]
end if
else if (grid_input = 0) then
        SOC [current_hour] ← SOC [current_hour-1] +
        solar_input [current_hour] – load_serviced [current_hour]
end if
if (current_hour = PST) then
        Call Grid_Forecastting_Intelligence (PST)
end if
```

Fig. 4: Pseudo code for run time operation

*2) Intelligent Dynamic Grid Forecasting Algorithm:* An intelligent dynamic grid-forecasting algorithm is developed which predicts day-ahead grid requirement for maximum load servicing. It determines the instance and duration of grid requirement for the next day. Figure 2 represents the operational flow of the IDGFA with respect to time.

The IDGFA runs at PST every day for the next 48 hours, i.e. from PST to PST+48. The prediction consist of two continuous intervals, namely:

- **Interval X:** The prediction interval corresponding to first 24 hours, i.e. from PST to PST+24.
- **Interval Y:** The prediction interval corresponding to next 24 hours, i.e. from PST+25 to PST+48.

The operational time flow of the IDGFA is explained below:

- On any day K, at PST, the IDGFA runs.
- Day-ahead prediction of power requirement from grid is done at PST of day K by estimating shortage in the interval Y as explained in next *Section*.
- PST+24 of day K becomes the PST of day K+1.

*a) Grid Requirement Forecasting:* The IDGFA at PST forecasts the power required from the grid by the microgrid for the next day, for maximizing load servicing, by intelligently calculating/estimating the shortages based on hourly SOC estimations which in turn determine hourly load servicing. The hourly SOC estimations are done by obtaining solar PV predicted values for the next 48 hours. The hourly solar PV forecasts in interval X has an accuracy of ±10% and in interval Y has an accuracy of ±20%[12].

*i. Calculation of day ahead shortage*: At PST+1, real time SOC and hourly solar PV forecast for next 48 hours are obtained. Real time SOC is used to calculate the expected SOC based on predicted solar PV. Load patterns are simulated based on previous hour’s SOC and SOC thresholds explained in *Section IV-C*. The SOC estimations are calculated as shown in equation 4.

$$\begin{aligned} SOC_{Estimate}[i] = SOC_{Estimate}[i-1] + PV_{pred[i]} \\ - Load\ Requirement_{pred}[i] \end{aligned} \tag{4}$$

where $i$ is current hour

At PST the total unmet loads in the interval Y using the SOC estimations as explained above are calculated as shown in equation 5. These unmet loads in Y are calculated as shortage ($S_y$) as shown in equation 6.

$$UnmetLoad[i] = Lt - LoadRequirement_{pred}[i] \tag{5}$$

$$Sy = \sum_{i\,=\,PST+25}^{PST+48} UnmetLoad[i] \tag{6}$$

where $i$ is current hour

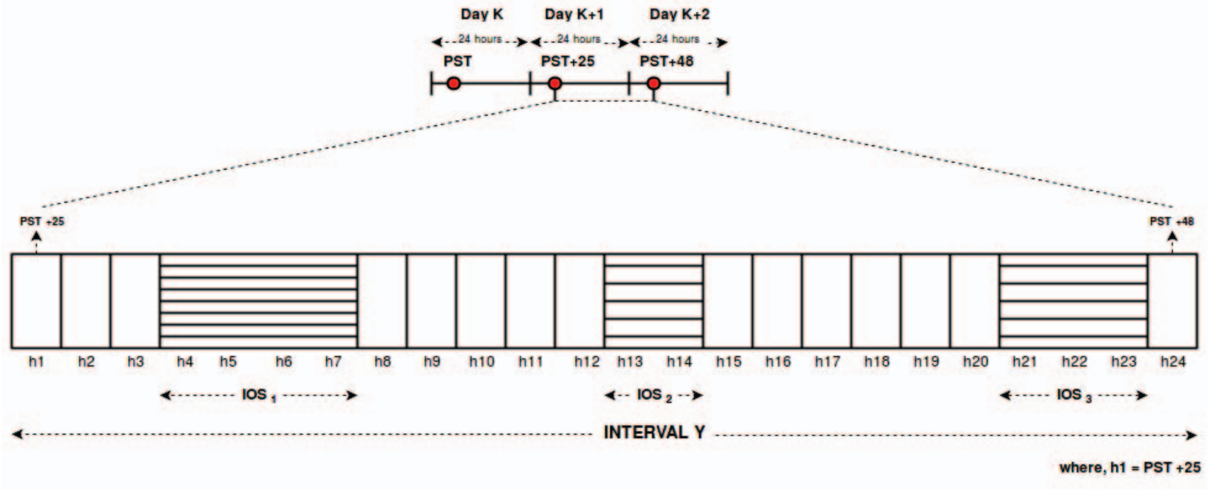
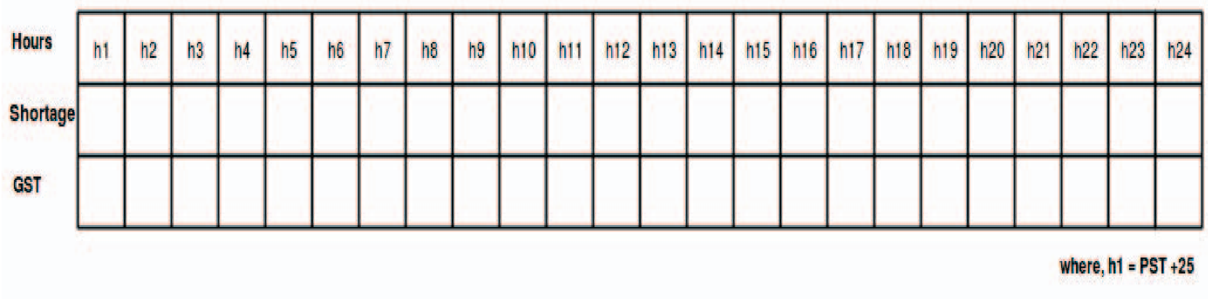


Fig. 5: Intervals Of Shortage

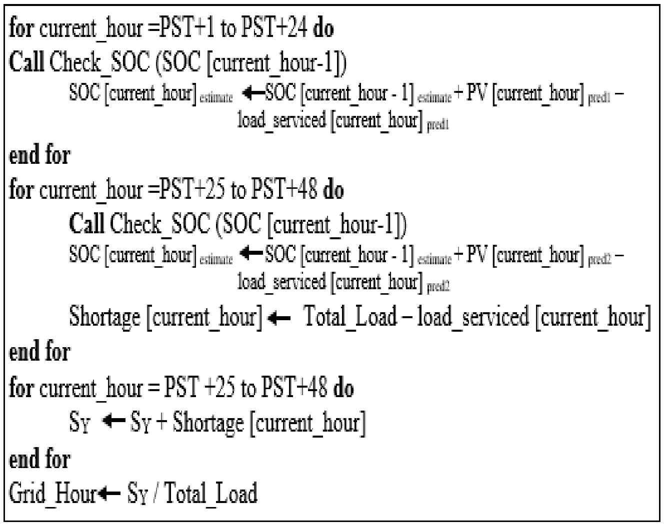


| Hours | h1 | h2 | h3 | h4 | h5 | h6 | h7 | h8 | h9 | h10 | h11 | h12 | h13 | h14 | h15 | h16 | h17 | h18 | h19 | h20 | h21 | h22 | h23 | h24 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Shortage | | | | | | | | | | | | | | | | | | | | | | | | |
| GST | | | | | | | | | | | | | | | | | | | | | | | | |

where, h1 = PST +25

Fig. 6: Template for determining IDGST in Y

*ii. Calculation of grid power requirement*: The number of hours of grid requirement is calculated as shown in equation 7 using the day-ahead shortage calculated in equation 6. The pseudo code for grid power requirement is shown in Figure 7.



```
for current_hour =PST+1 to PST+24 do
Call Check_SOC (SOC [current_hour-1])
        $SOC[current\_hour]_{estimate} \leftarrow SOC[current\_hour - 1]_{estimate} + PV[current\_hour]_{pred1} -$
                      $load\_serviced[current\_hour]_{pred1}$
end for
for current_hour =PST+25 to PST+48 do
        Call Check_SOC (SOC [current_hour-1])
        $SOC[current\_hour]_{estimate} \leftarrow SOC[current\_hour - 1]_{estimate} + PV[current\_hour]_{pred2} -$
                      $load\_serviced[current\_hour]_{pred2}$
        $Shortage[current\_hour] \leftarrow Total\_Load - load\_serviced[current\_hour]$
end for
for current_hour = PST +25 to PST+48 do
        $S_Y \leftarrow S_Y + Shortage[current\_hour]$
end for
$Grid\_Hour \leftarrow S_Y / Total\_Load$
```

Fig. 7: Pseudo code for Grid Power Requirement

$$NumberofGridHoursrequired(GH) = Round\{(Sy/Lt)\} \tag{7}$$

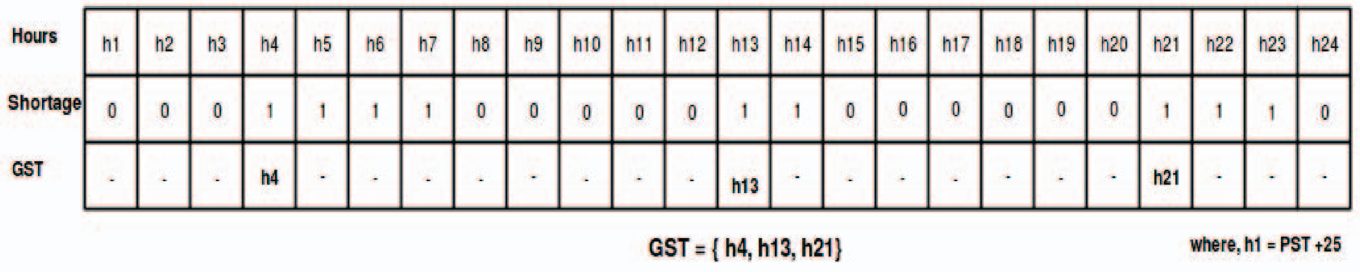
*b) Dynamic Grid Start Time (DGST):* DGST is the hour from which grid becomes available in a day for number of grid hours (GH), calculated in equation 7, in real time. On day K, when the IDGFA runs at PST, the shortages that occur at every hour in interval Y are tracked. Each continuous period of shortage occurrences is identified as an Interval Of Shortage $IOS_n$, where n = 1,2,3,,12. Figure 5 illustrates an example where $IOS_1$ shows continuous occurrence of shortage in hours h4 through h7, $IOS_2$ indicates continuous occurrence of shortage in hours h13 through h14 while $IOS_3$ portrays continuous occurrence of shortage in hours h21 through h23.

*i. Calculation of DGST:* The IDGFA at PST, determines the DGST in the interval Y by using the Template shown in Figure 6. At any day K, at PST, for interval Y, a two stage hourly template is formed.

- **Stage 1 -** Determining if there is a shortage estimated in each hour using equation 5. If there is a shortage occurrence, the corresponding shortage is marked as "1", else a "0".
- **Stage 2 -** Determining $IOS_n$ in interval Y as explained in *Section IV-C*. Then, the Grid Start Times (GSTs) are determined as those hourly instances that denote the start of an IOS. The pseudo code for finding the GSTs is shown in Figure 9.

Figure 8 illustrates an example of Template formation where the shortages and the GSTs in interval Y of a day K are shown. It can be seen that hours h4 through h7, h13 through h14 and h21 through h23 have continuous shortage occurrences. The start time of these corresponding IOS's - h4, h13 and h21 are the GSTs determined.

By fixing each of the GST's determined as the DGST, $S_y$ for each GST in the interval Y is calculated as shown in equation 6 and the final DGST is forecasted as the one for which $S_y$



| Hours | h1 | h2 | h3 | h4 | h5 | h6 | h7 | h8 | h9 | h10 | h11 | h12 | h13 | h14 | h15 | h16 | h17 | h18 | h19 | h20 | h21 | h22 | h23 | h24 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Shortage | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 0 |
| GST | - | - | - | h4 | - | - | - | - | - | - | - | - | h13 | - | - | - | - | - | - | - | h21 | - | - | - |

GST = { h4, h13, h21}

where, h1 = PST +25

Fig. 8: Template Formation in interval Y - Example

```
for current_hour = PST+25 to PST+48 do
    if (Unmet Load [current_hour] > 0) then
        Shortage [current_hour] ⬅1
    end if
    else if (Unmet Load [current_hour] = 0)
        Shortage [current_hour] ⬅0
    end if
end
for current_hour = PST+25 to PST+48 do
    if (Shortage [current_hour] > 0) then
        IOS [flag] ⬅current_hour
        current_hour++
    end if
    while (Shortage [current_hour] > 0 && current_hour < = PST+48) then
        current_hour++
    end
    flag ++
end
```

Fig. 9: Pseudo code for determining GSTs in the interval Y

is minimum, thus enhancing load servicing efficiency. The pseudo code for determining the DGST is shown in Figure 10. The predicted DGST and the GH are updated to the grid operator at PST enabling day-ahead grid forecast.

```
for n = 0 to flag do
    Grid_Start_Time ← IOS[n]
    Grid_End_Time ← Grid_Hour + Grid_Start_Time -1
    for current_hour = PST+25 to PST + 48 do
        if (current_hour = = Grid_Start_Time) then
            while (current_hour < = Grid_End_Time) do
                load_serviced [current_hour]$_{pred2}$ ←Total_load
                SOC [current_hour]$_{estimate}$ ← SOC [current_hour - 1]$_{estimate}$ + PV [current_hour]$_{pred2}$
                current_hour ++
            end
        end if
        else
            Call Check_SOC (SOC [current_hour-1])
            SOC [current_hour]$_{estimate}$ ← SOC [current_hour - 1]$_{estimate}$ + PV [current_hour]$_{pred2}$ –
                load_serviced [current_hour]$_{pred2}$
            Shortage [current_hour] ← Total_Load – load_serviced [current_hour]
        end if
        $S_y$ [n] = Sy[n] + Shortage [current_hour]
    end for
end for
DGST ← Call Min_Shortage_GridStartTime ($S_y$)
```

Fig. 10: Pseudo code for determining Dynamic Grid Start Time

### D. *Simulation Results and Performance Analysis*

*1) Comparison of Load Servicing Performance:* Load servicing is defined as the percentage of the total system load that is serviced. The load servicing efficiency for PV microgrid for sizes from 16 kW to 25 kW were observed to vary from 76% to 92%. With the inclusion of intermittent grid to the existing systems, the load servicing efficiency was found to be greater than 97% for sizes from 16 to 25 kW, as seen in Figure 11. Our system assumes fixed load (Lt=4 kW) and the total loads to be serviced per year is 35,040 kW.

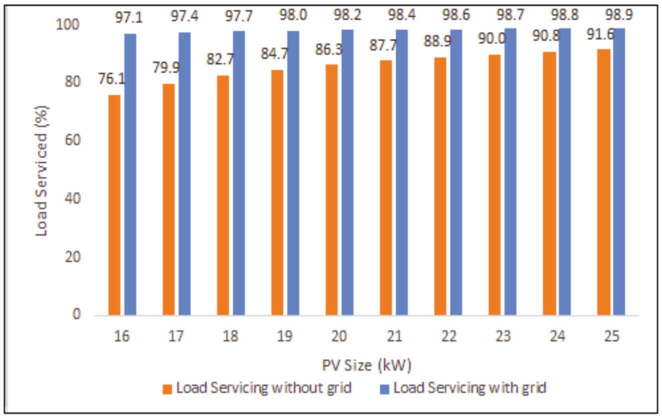


Fig. 11: Load servicing efficiency of both systems

In a rural microgrid installation in central India, there is generational difference in solar PV due to seasonal variations. The load serviced by the PV standalone system during winter and monsoon seasons is lesser than the amount of load serviced during summer season as expected. This fall in load servicing is compensated by the percentage of load serviced by the intermittent grid by up to 30% of the total load served as shown in Figure 12. As a result, the intermittent grid system has a consistently high load servicing performance greater than 97%.

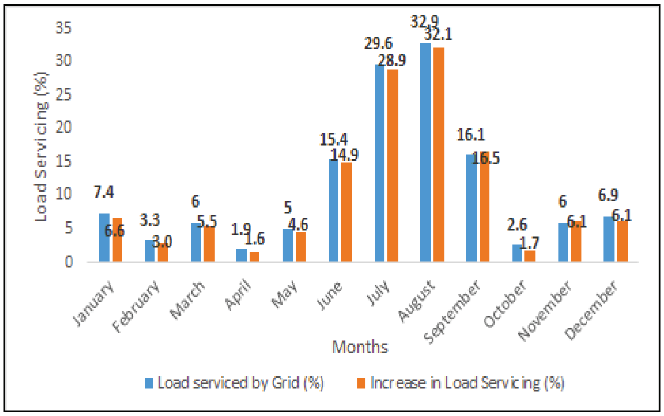


Fig. 12: Load servicing efficiency of both systems

*2) Effect of IDGFA on Excess Energy:* It is observed from Figure 13 that the percentage increase in load servicing after the inclusion of intermittent grid is almost entirely contributed by the grid. Thus, grid energy contributes minimally to the excess energy in the system as depicted in Figure 14.

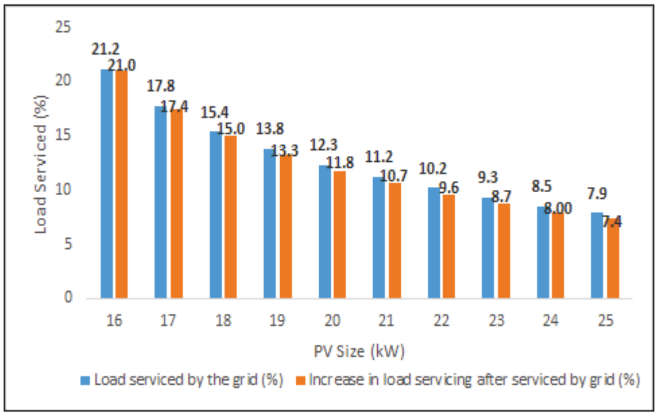


Fig. 13: Energy contributed by grid in percentage increase of load servicing

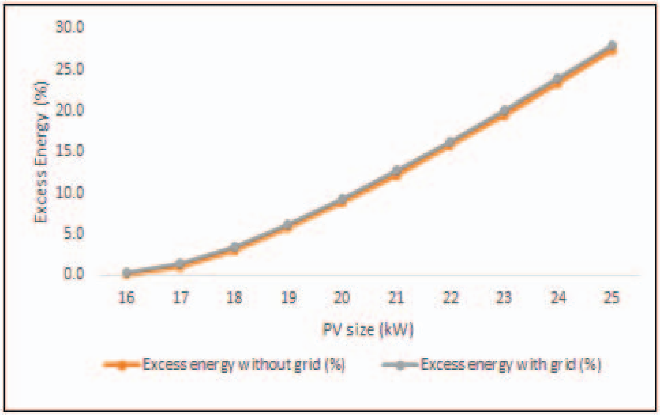


Fig. 14: Excess energy generated in both systems

*3) Efficiency of Grid Servicing for different PV sizes:* The energy obtained from the grid is used for load servicing and a part of it constitutes to excess energy. The grid efficiency shown in Table II depicts the percentage of energy available from the grid that is used to service the load.

TABLE II: CALCULATION OF GRID EFFICIENCY

| $PV$ | $LoadNG$ | $LoadWG$ | $LoadDiff(x)$ | $ExcessNG$ | $ExcessWG$ | $ExcessDiff(y)$ | $x+k=y$ | $GridEfficiency$ |
|---|---|---|---|---|---|---|---|---|
| 16 | 25063 | 34041 | 8978 | 52.6 | 95.3 | 42.7 | 9020.7 | 99.5 |
| 17 | 26669 | 34119 | 7450 | 375.1 | 494.1 | 119.0 | 7569.0 | 98.4 |
| 18 | 28010 | 34242 | 6232 | 1066.0 | 1211.0 | 145.0 | 6377.0 | 97.7 |
| 19 | 28979 | 34350 | 5371 | 2017.0 | 2184.0 | 167.0 | 5538.0 | 97.0 |
| 20 | 29685 | 34404 | 4719 | 3108.5 | 3278.5 | 170.0 | 4889.0 | 96.5 |
| 21 | 30254 | 34491 | 4237 | 4287.5 | 4445.5 | 158.0 | 4395.0 | 96.4 |
| 22 | 30737 | 34536 | 3799 | 5529.1 | 5711.1 | 182.0 | 3981.0 | 95.4 |
| 23 | 31158 | 34575 | 3417 | 6829.4 | 7034.4 | 205.0 | 3622.0 | 94.3 |
| 24 | 31524 | 34611 | 3087 | 8201.7 | 8388.7 | 187.0 | 3274.0 | 94.3 |
| 25 | 31818 | 34622 | 2844 | 9602.0 | 9780.0 | 178.0 | 3022.0 | 94.1 |

where *NG* is No Grid and *WG* is With Grid.

The theoretical efficiency of the grid-connected PV microgid system is 100% and the practical efficiency was found to be between 99% and 93.5% for various PV sizes as shown in Figure 15.

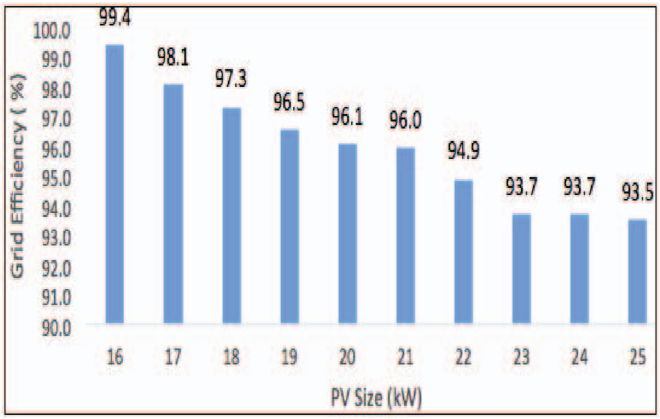


Fig. 15: Variation of grid servicing efficiency across various PV sizes

*4) Comparison of Dynamic Grid Start Time with Fixed Grid Start Time:* This paper presents an Intelligent Dynamic Grid Forecasting Algorithm for a grid-connected solar PV based microgrid, which forecasts the grid requirement dynamically. The duration and interval of grid requirement are forecasted in a day-ahead basis. This was found to be more efficient for load servicing than obtaining energy from the grid at a pre-defined, fixed time interval of the day throughout the year as shown in Figure 16.

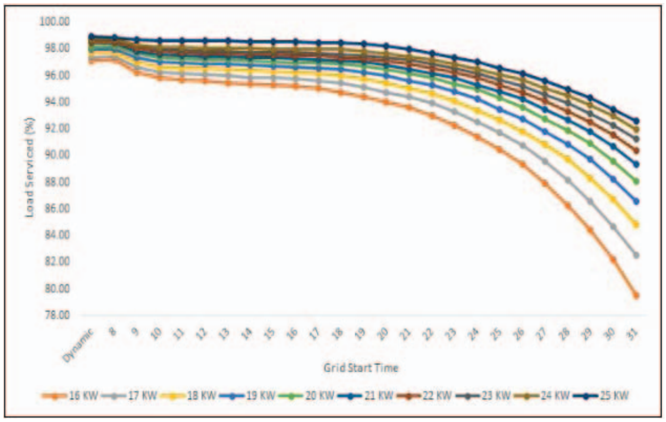


Fig. 16: Load servicing efficiency for grid-connected PV microgrid for various PV sizes

Load servicing efficiencies by grid interconnected PV based microgrid systems for various PV sizes with fixed grid start times from PST+1 (at 8:00 a.m.) to PST+24 (at 7:00 a.m. the next day) for pre-forecasted intervals on a day-ahead basis versus load servicing efficiency based on the IDGFA is proposed in this paper. It can be inferred that the DGST gives maximum load servicing efficiency of 97.1% and 98.9% for PV sizes 16 kW and 25 kW respectively, indicating an increase in load servicing efficiency for any PV size.

## V. CONCLUSION

Typically solar PV microgrid installations in rural and semi-urban India are done in order to provide them with access to energy where lack of it is a major drawback. To enhance load-servicing capabilities of off-grid solar PV microgrid installations in such scenarios, inclusion of intermittent grid to such systems is found to be a viable solution with no added capital cost. The simulated load servicing efficiency in such a system is always found to be greater than 97%. The IDGFA also ensures that negligible amount of energy obtained from the utility grid contributes to the excess energy of the total system, thus ensuring optimization of the grid usage. The added advantage of day ahead forecasting of grid power requirement provides the grid operator for day ahead load dispatch planning of the utility grid.

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## REFERENCES

[1] C Lins, L E.Williamson, S Leitner, S Teske, ”The First Decade: 2004-2014 10 Years of Renewable Energy Progress”, [Online], Available:www.ren21.net/Portals/0/documents/activities/Topical/%20 Reports/REN21_10yr.pdf

[2] International Energy Agency, WEO 2015 Electricity access database, [Online], Available:http://www.worldenergyoutlook.org/resources/energydevelopment/ energyaccesdatabase/

[3] S B Agnihotri and P C Maithani, ”CONTOURS OF INEQUALITY: What Census 2011 tells about Indias energy poverty”, Centre for Science and Environment, [Online], Available: www.cseindia.org/docs/aad2015/Contours-of-inequality2015.pdf

[4] Energy.gov, ”How Microgrids work”, [Online] Available: http://www.energy.gov/articles/how-microgrids- work

[5] V. Vel, K. Meghana, R. Ramesh, H. Sekar and V. Vijayaraghavan, ”Flexible D-agent architecture for DER operation in a rural Indian microgrid,” Global Humanitarian Technology Conference (GHTC), 2015 IEEE, Seattle, WA, 2015, pp. 26-32.
doi: 10.1109/GHTC.2015.7343950

[6] Debajit Palit, ”Empowering the poor: An OASYS story from Dhenkanal District, Odisha, India”, [Online], Available: http://energy-access.gnesd.org/cases/44- empowering-the- poor-an- oasys-story-from-dhenkanal-district- odisha-india.html

[7] Schalk Cloete, ”The Renewable Energy Reality Check”, [Online], Available:http://www.theenergycollective.com/schalk-cloete/228151/renewable- energy-reality- check

[8] R. Rajesh, S. Vijayakumar, M. Srinivasan and V. Vijayaraghavan, &quot;An avant garde argumentation of quality-of- service via low-cost cloud-based smart microgrid solution: A rural India perspective,&quot; Environmental Energy and Structural Monitoring Systems (EESMS), 2013 IEEE Workshop on, Trento, 2013, pp. 1-6.

[9] S. Bacha, D. Picault, B. Burger, I. Etxeberria-Otadui and J. Martins, &quot;Photovoltaics in Microgrids: An Overview of Grid Integration and Energy Management Aspects,&quot;in IEEE Industrial Electronics Magazine, vol. 9, no. 1, pp. 33-46, March 2015.

[10] S. K. Jha, P. Stoa and K. Uhlen, &quot;Socio-economic impact of a rural microgrid,&quot; 2016 4th International Conference on the Development in the in Renewable Energy Technology (ICDRET), Dhaka, 2016, pp. 1-4.

[11] R. Kuwahata, N. Martensen, T. Ackermann and S. Teske, &quot;The role of microgrids in accelerating energy access,&quot; 2012 3rd IEEE PES Innovative Smart Grid Technologies Europe (ISGT Europe), Berlin, 2012, pp. 1-9.

[12] A. S. Ganesan, B. Govindarajan, R. Ramesh, V. Vel and V. Vijayaraghavan, &quot; Dynamic and intelligent load servicing strategy for a stand-alone solar PV-based microgrid,&quot; Global Humanitarian Technology Conference (GHTC), 2015 IEEE, Seattle, WA, 2015, pp. 348-353.