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Operational Analysis of Institutional Energy System for Developing a Micro-grid

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Abstract— In most of the institutional buildings solar photovoltaic (PV) systems are used for fulfilling the local energy requirement. In this work, a typical institution with solar PV and battery energy storage is selected for analyzing the system's operation to fulfil the institutional energy demand. To operate this energy system as a micro-grid, distributed generator is selected for fulfilling the institutional load demand in coordination with PV, battery and during the grid outage time. The operation of distributed generator has improved the system performance and coordinated the contribution among local energy resources e.g. PV energy and battery throughput. In this work, relative analysis of the institutional energy system with and without distributed generator has been analyzed for annual load profile. It has been observed; the distributed generator is not only useful for supplying the energy to the essential load but also during the grid outage conditions. The analysis shows that if, the grid outage continues for longer period then distributed generator can provide the power to the institutional load and operate as a micro-grid. It has been observed, the battery energy throughput as well as effective utilization of local energy resources can be improved by installing distributed generator. The presented analysis is going to be useful for operating the institutional energy system as a micro-grid with different energy and power management strategies.

Keywords— Battery Energy Throughput, Institutional Hybrid Energy System, Micro-grid, Solar Photovoltaic System

1. Introduction

The penetration of photovoltaic system in the energy network is increasing exponentially. In the distributed network, most of the solar photovoltaic system are going to be building integrated. The photovoltaic system with energy storage can play major role for demand-side management. To overcome the grid outage conditions specially in the weak grid region, PV system with energy storage may require an additional distributed generator. And such system can be operated as a micro-grid with appropriate power and energy management strategies [1]. Therefore, it is very important to select appropriate capacity of distributed generators to meet the load demand especially during the grid outages. In a study [2], techno-economic sizing of an off-grid renewable energy system has been carried out for supplying electricity to the rural



community in Sri Lanka however, sizing with grid-connected system is not elaborated with energy pricing. The power conditioning devices of the distributed energy sources can be used to operate the hybrid energy system as a micro-grid (grid connected as well as islanded modes) and can help in regulating the frequency and voltage [3]. The PV system integrated with battery energy storage as well distributed generator can be used as an active generator for operating the entire system as a micro-grid. Such system requires to maintain power quality, reliability and to optimize the energy supply according to the load's characteristics [4]. The electrical energy pricing as well as techno-economic characteristics of the distributed generators have significant impact on the operation of the grid connected energy system [5], and it also affects the battery energy throughput. The grid outage period can significantly impact the operation of PV system and energy storage if appropriate distributed generators are not selected. In the literature, impact of grid outage period on operation of PV system with energy storage is not significantly addressed, and also the analysis of battery energy throughput [6]. The distributed generator can play important role specially during grid outage time, and also improving the battery energy throughput. It has been observed that such analysis has not been sufficiently reported with consideration of real operational results of the institutional hybrid system [7-8].

The main aim of this paper is to analyse operation of the institutional energy system with PV and battery energy storage especially during the grid outage time to fulfil the essential load demand. To improve the performance of the institutional energy system, the role of a distributed generator has been analysed for supplying the power to the load and for improving the battery energy throughput. And, also the importance of energy management strategies for improving the local resources utilization, and how such system can be operated as micro-grid during the grid connected as well as in the islanded mode [10].

In this paper, The Energy and Resources Institute (TERI)'s Retreat Building located at TERI-Gram Gurgaon, India (latitude 28.45 and longitude 77.02) has been considered as an institutional energy system. The TERI-Retreat building energy system has PV capacity of 12.8 kWp, battery (lead-acid) energy storage capacity 48V/ 600Ah and it has been used for providing the electricity to essential loads as well as the main grid to supply the total load demand [11-12]. The block diagram of the existing energy system at TERI-Retreat building has shown in Fig. 1.

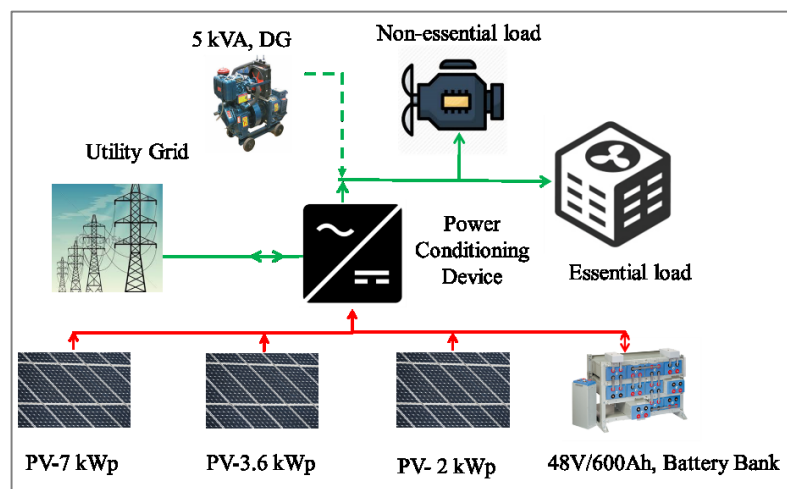


Fig. 1. Block Diagram of existing system at TERI's Retreat Building

In this paper, the operational results of the TERI's Retreat Building energy system has been presented in the section 2. The role of distributed generator during grid outage period with relative performance analysis has been reported in the Section 3. The conclusive results with role of distributed generator for operating the institutional energy system as micro-grid has been presented in the Section 4.

2. Operation Analysis of TERI's Retreat Building Energy System

The schematic of the TERI-Retreat Building energy system is shown in Fig. 1. In this institutional building, electrical load has been divided into the essential and non-essential categories and the total annual load profiles have been presented in Fig. 2. It has been observed that there has been 20% load variation in the daily load profile with reference to the monthly average load profile. The detail analysis of the load profiles has been reported in the ref [11-12]. The PV output profile and load profile has been also reported in the Fig. 2.

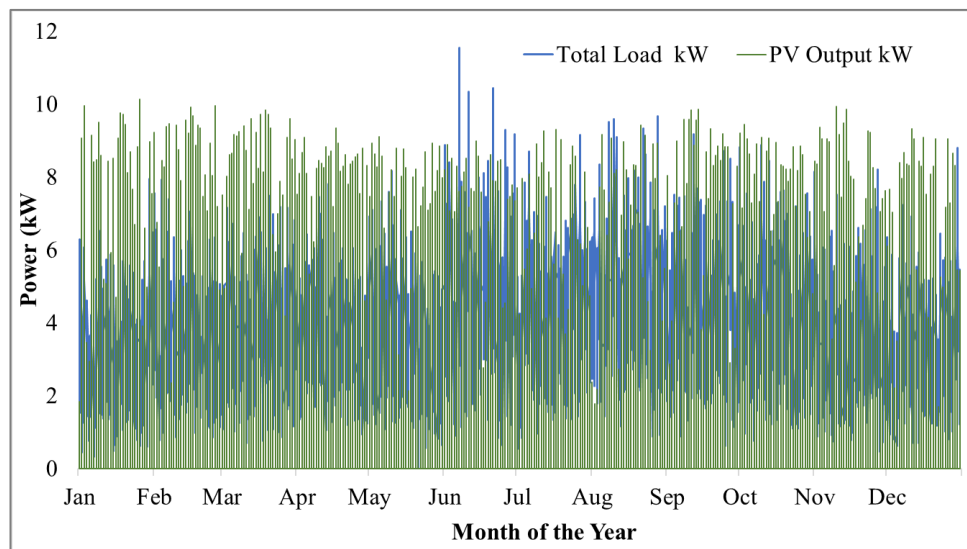


Fig. 2. Annual Profile of the PV Production and the Total Load

It has been observed that the annual energy supply contribution from the grid and the PV for fulfilling the TERI's Retreat building load are 47% and 53% respectively. In the analysis, two hours grid outage has been considered, and especially during this period the role of battery energy storage, for supplying the energy to the essential loads, has been analysed. The monthly average contributions from the PV, grid and the battery energy throughput with monthly average load have been reported in Fig. 3. The analysis has clearly indicated the need of backup power or other distributed energy sources if the grid outage is going to be for longer duration, and it may result in the blackout situation at the institution.

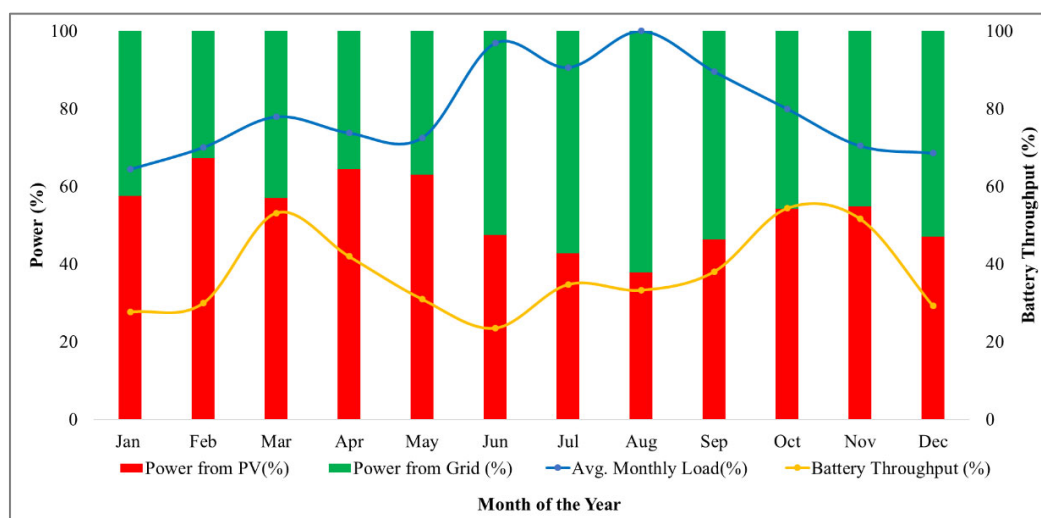


Fig. 3. Monthly contribution from energy sources to the load and battery throughput

The battery operating conditions have been considered with state-of-charge (SoC) from 100% to depth-of-discharge (DoD) of 60%. The lifetime energy throughput of 1 kWh battery has been taken 840 kWh with roundtrip efficiency of 80%.

In the month May (e.g. summer season period), the PV has contributed 63% for fulfilling this monthly load and the remaining 37% has been supplied by the grid with battery throughput of 30%. In the winter season period (e.g. month Dec), the contribution of PV has been 47% and the grid has supplied 53% with battery throughput 29%. The annual average battery throughput has been 37%. The operational results show that if the grid outage is going to increase, then the existing system may not be able to fulfil even the essential load demand. Therefore, it is needed to include a controllable distributed generator not only to avoid the blackout situation, but also to increase the battery throughput for more effective utilization of the PV output; and also, to operate the system as micro-grid during islanded and grid connected mode.

3. Performance Analysis of TERI's Retreat Building Energy System with Distributed Generator

It has been observed that without controllable distributed generator, the TERI's Retreat building energy system has main operational problems during longer grid outage time, and also on the battery energy throughput for storing the excess PV energy (i.e. 3.68%) with appropriate energy management strategies.

In this work, for overcoming the above-mentioned issues, the controllable distributed generator (DG) is introduced without increasing the battery energy storage capacity. The DG can also be operated as controllable source for dispatching the required power as per instantaneous requirement of the institution load with grid constraints as well as during grid outage period [10].

The energy system at TERI's Retreat Building Facility is upgraded by including a DG, whereas the PV and battery capacities are the same as shown in the Fig.1. The schematic of the system with DG has been presented in Fig. 1. Performance of the energy system with DG has been analyzed with the same operating conditions as described in Section 2 and the same typical two months (i.e. May and December) have been selected for analyzing the system operation.

3.1 System Operation Analysis for the Month May

As described in the Section 2, month May has been selected to represent the summer season. During this month May, the contributions from the PV, grid, DG and battery with load have been given in Figure 4 and 5. It has been observed that the monthly average energy contributions to the load from the PV, grid and DG's have been 62.3%, 32.3% and 1.4% respectively; and the DG has operated for 40 hours in the May month. It has been noticed that with DG, the grid contribution has been reduced and the battery throughput has increased to 61%. A typical day 17th of May has been selected to analyse the hourly system operation and observed that especially during the grid outage time, the DG and battery have been contributing effectively and also DG has provided energy to the battery for operating it in the desired conditions. The operational results for 17th May has been given in Fig. 6. On the day 17 of May, the PV, Grid and DG's have contributed 61%, 22% and 17% respectively and the DG has operated three times in a day especially during grid outage periods. The battery energy throughput on this day of 17th May has been 87%.

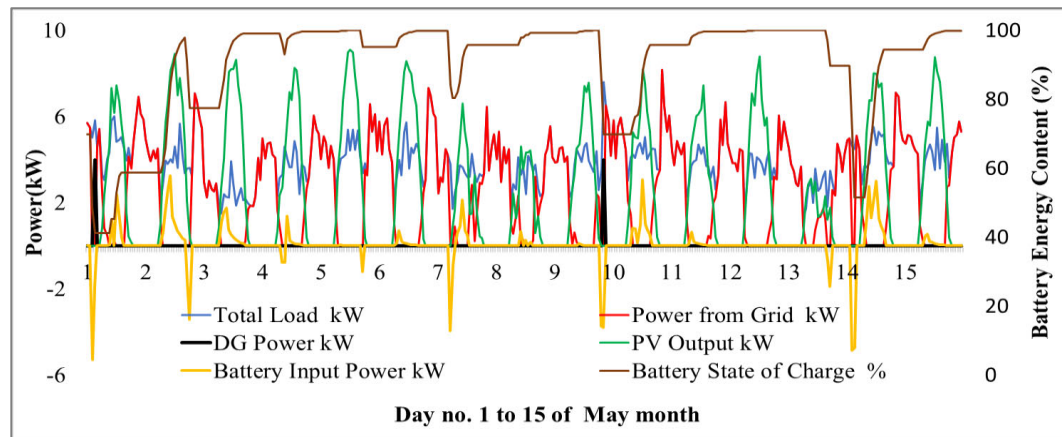


Fig. 4. Energy Contribution from Different Sources of day no. 1-15 of May

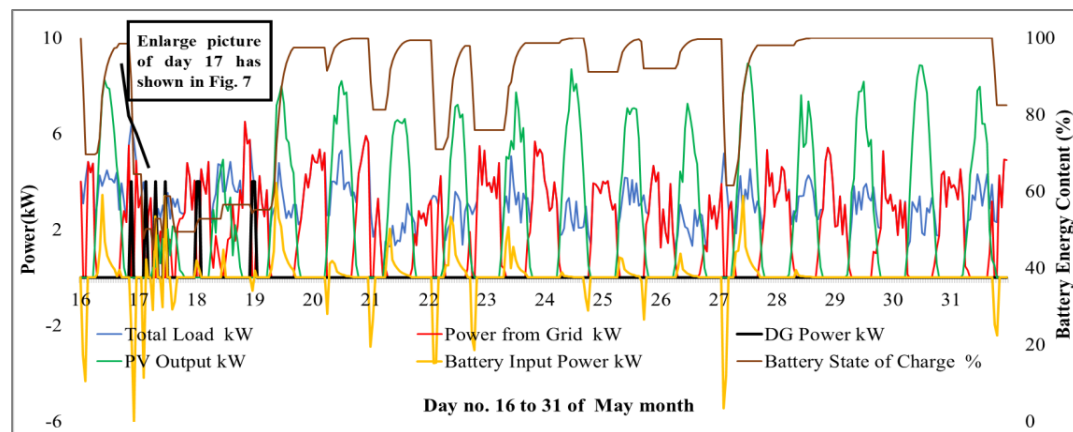


Fig. 5. Energy Contribution from Different Sources for day no. 16-31 of May

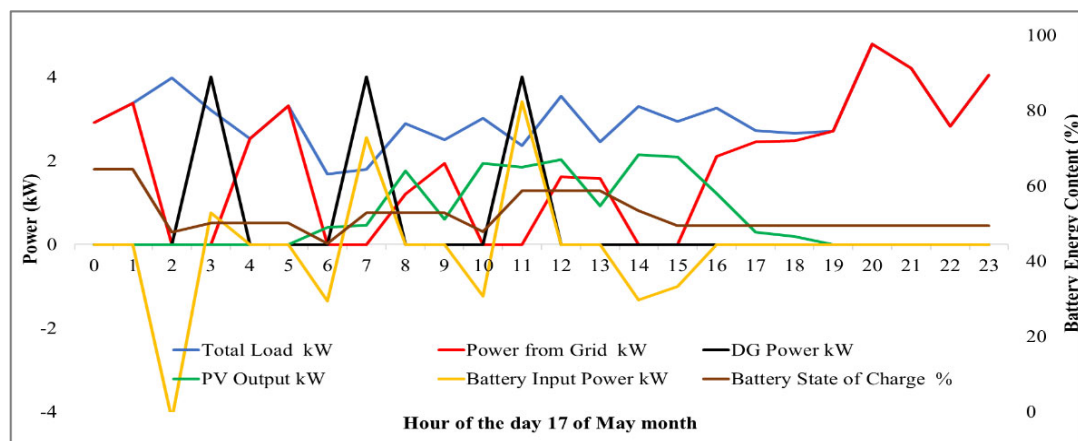


Fig. 6. Energy Contribution from Different Sources on the day no. 17 of May

3.2 System Operation Analysis for the Month December

As described in the Section 2, month December has been selected to represent the winter season. During December month, the contributions from the PV, grid, DG and battery with load have been given in Figure 7 and 8. It has been observed that the monthly average energy contributions to the load from the PV, grid and DG's have been 50.30%, 48.90% and 0.90 % respectively; and the DG has operated for 20 hours in the December month. It has been noticed that with DG, the grid contribution has been reduced and the battery throughput has increased to 73%. as been given in Fig. 7.

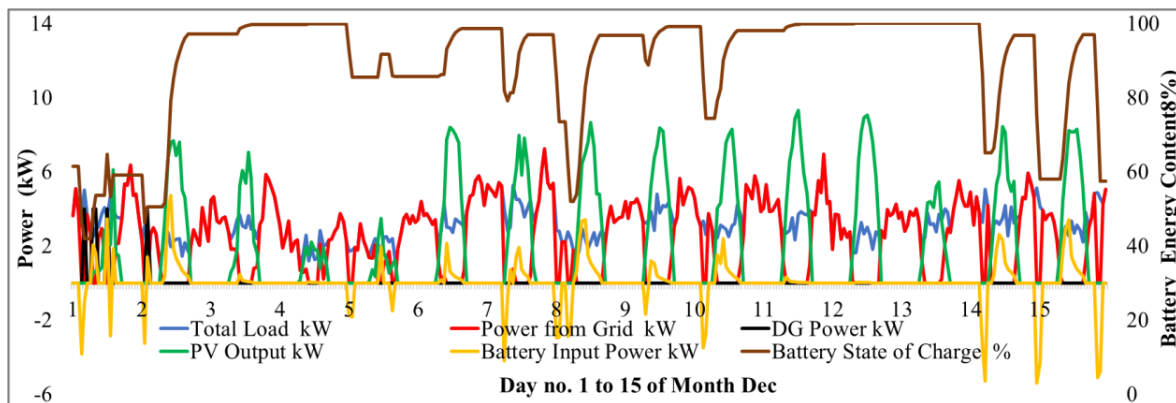


Fig. 7. Energy Contribution from Different Sources for 1-15 days of Month December

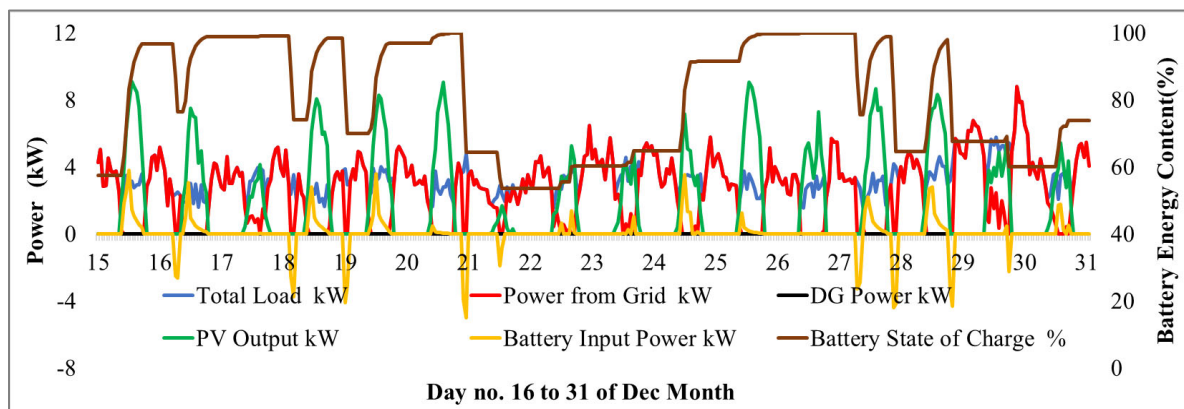


Fig. 8. Energy Contribution from Different Sources for 16-31 days of Month December

It has been observed from Fig. 7 and Fig. 8, that DG operates only 20 hrs in the month of December and its contribution is estimated 0.9% to the load demand. Except on day 1 and 2, DG doesn't operate on the remaining days of the month as PV along with battery have enough power to provide back up during outage condition. On the day 1, when grid outages occurred and PV doesn't produce enough power and battery's SoC also reached below 50% level, then DG starts operating and meet the instantaneous load demand and as well as charge the battery. DG actively participate and provide back-up power to the entire system's load until grid and PV restored back.

It has been observed from Fig. 7, that battery's SoC has reached to the lowest level of 42% (i.e. 2% above the DoD) on the day 1 and its SoC is recovered by the power contribution from DG and PV. Almost each day in December month, battery's charging and discharging have taken place which indicates, battery is actively participating to meet the load demand during grid outages conditions and therefore its throughput has increased from 29% (i.e. existing system) to 73% (i.e. upgraded system) in the December month. It has been noticed that PV has contributed 12% more as compare to the December month to meet the TERI's retreat building demand which results 16% less energy is purchased from the grid in the May month.

3.3 Annual Operational Analysis of TERI's Retreat Building Energy System with DG

The average annual contribution from PV, Grid, DG and battery are analyzed to meet the TERI's Retreat building load demand. Based on the obtained results, from existing case scenario and upgraded energy system at TERI's Retreat Centre, the annual battery throughput has increased from 37% to 72%, and excess power generation has reduced to 1.67% from 3.68% of the total load and system is able to meet total load demand during outage conditions.

It has been estimated that annual average power contribution from PV, Grid and DG, to meet the load demand are 53%, 45% and 2% respectively and annual average battery throughput is 72%. It has been observed that DG operates in each month of the year and its monthly contribution varies in between 1 to 4%. In comparison to the existing energy system at TERI's Retreat building, battery throughput is more than 60% for each month of the year which indicates a significant increase in the battery's charging and discharging process.

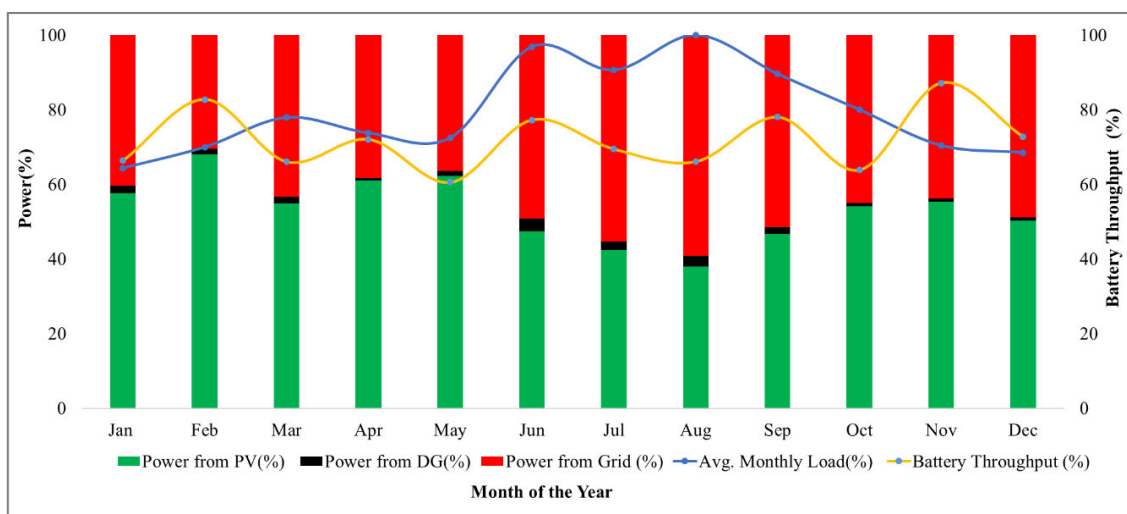


Fig. 9. Monthly contribution from energy sources to the load and battery throughput with DG

It has been observed that even after considering 2 hours random outages throughout the year, 5% more TERI's Retreat Building Load has been fulfilled as compare to existing system. During the year, it has been noted that annual excess power production has reduced to 1.67 % as more PV power is used to charge the battery and therefore increase its throughput. It has been seen from Fig. 3 & 9, in the existing case battery's SoC was always above 60% and average annual throughput was 37% whereas in the upgraded energy system battery's SoC reached to minimum battery level (i.e. 40%) and average annual throughput increased to 72%.

4. Conclusions

In this work, TERI's Retreat Building Energy System as a typical institution is selected for analyzing the system operation to fulfil institutional energy demand. To operate this energy system as a micro-grid, distributed generator is also selected for fulfilling the institutional load demand in coordination with the PV, battery and during the grid outage time. The TERI's Retreat Building Energy System without DG has annual energy supply from the grid and PV for fulfilling the load demand are 47% and 53% respectively with battery energy throughput of 37%. But with the DG, performance of the system with same operating conditions of the grid outage and battery has been improved with PV contribution 53.2%, Grid contribution 45.20%, battery throughput 72%. In this work, DG has main priority to provide power supply to the load during grid outage, but it also ensures the battery charging if, SoC reached below than 50% and other sources are not able to supply the required energy to the load. It concludes that, the upgraded energy system with DG can be performed better compare to the existing energy system and it can also operate as a micro-grid.

Future work is further continuing and focusing on maximizing the local PV production and optimizing the battery energy storage, with appropriate energy management strategy. Energy system performance will be analysed with Time-of-Use Tariff to get maximum economic benefits from battery energy storage. Other distributed energy sources (e.g. biomass gasifier) will be also explored to integrate with the energy system at TERI's Retreat building for providing controllable dispatch power to the micro-grid.

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