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Research Article

A Qualitative Analysis of an Intelligent Use of Demand and Generation in the Microgrid

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Abstract

There are reliable solutions for overcoming the mismanagements and inefficiencies in the microgrid, which have been discussed, in the following proposed study. It focuses on the utilization of Renewable Energy Sources (RES) for operating the microgrid in a smart way such that the supply demand ratio is balanced profiting both the utility user and the end user. Power sources are scheduled as per requirement based on their availability and per unit cost. Centralized Multi Agent System (MAS) technique is adopted in which a central controller controls the operation of the whole microgrid system. Load agents attached to the system are of two types, i.e., critical load and non-critical load. The power to the critical load is to be maintained as a result of which in case of any emergency situation the power supplied to the non-critical load is shed off in order to make the critical load running. Different techniques are utilized for load management. Demand Side Management (DSM) is one of those techniques in which the load shifts from peak to off-peak hours and vice versa. Further, on the simulation of the proposed study has been performed in MATLAB/Simulink software and its hardware implementation has been done as well. The output results achieved indicates the supply to the load agents depending upon the availability of the power sources.

Keywords: Renewable Energy Sources (RES), Distributed Generator (DG), Energy Storage System (ESS), Demand Side Management (DSM), Multi Agent System (MAS).

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1. Introduction

Power can be generated by utilizing fossil fuel sources and Renewable Energy Sources (RES). Owing to the adverse effects of fossil fuel including increased stress on transmission and distribution system and high carbon emissions, there has been a shift from the fossil fuel resources to RES. RES are the best remedy to tackle the increasing energy demand and can play a vital rote in fullfilling the energy deficit gap between the energy demand and supply (Ifat *et al.*, 2020). Further, their use can make power generation more reliable, economical and environment friendly. The integration of different types of RES can be made possible through the use of microgrid. Microgrid can be described as a modern type of power system that contains a combination of RES, Distributed Generators (DG), Energy Storage System (ESS) and different loads with a controlled infrastructure. It further establishes a flexible flow of power between different consumers with improved power quality and reliable power flow through power electronic components that act as an interface between the RES and DG.

For energy management in the operation of a microgrid, DSM is one of the major techniques used. The major impact zones of DSM include load management and load reduction. In the DSM technique, the load is transferred from peak hours to off peak hours as a result of which the reliability and efficiency of operation is increased, and secondly the cost and peak hours are minimized. The load priority and user choices are also taken into account in the whole process. Moreover, different loads are used and their corresponding preference is adjusted according to the load priority. Through SPDT relays each type of load is connected and the consumption of power according to the specified limit is ensured. The loads are classified into shiftable and non-shiftable loads, where the shiftable load can be varied according to the availability of power sources. The main advantage of this system is that the users achieve profit in the electricity bills (Anjana & Angel, 2017).

DSM is both utility and customer driven. Its techniques are used to process changes faster in order to avoid the unwanted impact on customer processes. A smart network is built for the implementation of DSM in distribution network, which is further implemented on two microgrids with the help of a test distribution feeder and is utilized by JAVA Agent Development Framework (JADE). Because of uncertain variations in the accessibility of RES, the supply demand relation is unstable. Therefore, through intelligent microgrid network the arrangement of reliable electricity is accomplished resulting in the balance of supply to demand ratio according to the regulation of the utility user. For adjusting the supply to demand ratio and for the execution of DSM strategies, Demand Response (DR) technique is used. DR programs are defined in microgrids to achieve flexibility in the load management operation. Accordingly, the non-critical load is shifted to the most prefferable time span as a result of which the end users having high priority value achieve a decrease in the operating cost of adjustable loads. For scheduling power sources, the following optimization model is appropriate which precisely predicts the behavior of the battery State of Charge (SoC) and also estimates the energy consumed from the power sources (Nunna & Dolla, 2013; Luna et al., 2017; Azeroual et al., 2020).

Similarly, DSM strategies can be used to encouarge the end users to change their load priorties according to the utility demand by offering them different incentives which can be helpful in reducing the net energy consumption. Therefore, this method can promote price-based DSM for the residential sector and can also serve as an efficient tool for the implementation of DSM schemes at a larger level (Venizelou *et al.*, 2020).

Load shifting is one of the major approaches of DSM. The objective of the calculations performed in the proposed study is to achieve the final load curve close to the objective load curve for the achievement of the DSM requirements. It adopts heuristics-based algorithm which models load demand patterns according to customer demands and handles extensive number of different controllable devices. Moreover, simulations are performed on a smart grid with customers from different zones including residential area customers, industrial area customers and commercial area customers. In a residential area, there are high number of devices for control, but the overall decrement in operating cost is not according to the required criterion. Also, the consumption rate of a residential area is less when compared to that of a commercial area. While in an industrial area, there are less devices but the consumption rate is high and consumption period is long (Logenthiran *et al.*, 2012).

By focusing on load management strategy of microgrid in islanded mode, load-shedding algorithm is utilized. The idea of Intelligent Load Shedder (ILS) module is implemented in which circuit breaker, microcontroller and certain measurement devices are connected in series with low priority loads to detect the specified point. The low priority loads can be removed from the system in order to maintain the high priority loads only. Moreover, a Static Transfer Switch (STS) connected in the system is used for sending and receiving data from microcontroller and also for communicating with the ILS. When the load in the islanding mode cannot be maintained sufficiently, load-shedding algorithm through ILS balances the system such that the load can be controlled in satisfactory operation limit utilizing the local DG. The combined control of the ILS, microcontroller, and STS shows an intelligent load management algorithm. Inductive, capacitive, and real loads, assumed to be linear, are connected in parallel with each DG to distinguish the inductive, capacitive and real power components. After that through their comparison, a decision is made that whether the system can sufficiently meet the load requirement or not (Kennedy *et al.*, 2012).

Due to the unpredictable output variations of wind turbine, solar power and load demands, energy management in microgrid faces challenges. In order to overcome the challenges, a Price Based Demand Response (PBDR) is adopted by RES to adjust loads. A dispatchable DG also coordinates with PBDR to achieve economic targets and maintain power balance. The strategy of two-stage coordination is based on two operations. In the first stage, DR is scheduled 24 hours ahead of next day following the mechanism that when price is lower, demand is assumed to increase. This strategy is done in order to achieve the maximum profit through optimization of the next 24 hours ahead. In the second stage, an accurate output of hourly scheduling of non-dispatchable DG is predicted by weather predictions and also more hourly predictions are completed by measurement of analytical approaches. As a result, the dispatchable DG output is complemented with PBDR decisions to maximize the overall profit (Zhang *et al.*, 2017).

For the operation of microgrid to be optimal, a robust approach is adopted that performs the operation of energy sources and Direct Load Control (DLC) as a result of which output variations of RES are addressed. This scheduling is done through two-stage framework, which involves an hour-ahead charging/discharging of energy sources and quarter-hour ahead scheduling of DLC. This is done in order to ensure the profit maximization of the microgrid where maintenance cost of ES and operation are also considered. Moreover, the stochastic behavior of wind power and solar power is taken through unpredictability where uncertainty variables represent the worst-case scenario in order to achieve the final results successfully for all uncertain conditions (Zhang *et al.*, 2016).

In the studies performed, the operation of microgrid depends upon a single central controller in which a centralized scheduling model is implemented. In its normal operation, the microgrid can work both in grid connected as well as in islanded mode, without any interruption of power supply to the loads. While in grid-connected mode, the microgrid schedules local resources as well as supplies power to the main grid in order to reduce the cost of its operation. In case of any main grid interruptions, the microgrid starts its operation in the islanded mode as a result of which it supplies power to the local loads connected and also ensures flexibility in its operation. In order to deal with the forecast error that causes perturbations in the load and generation forecasts, a robust optimization model like the Benders decomposition method is adopted (Khodaei, 2014).

Other way for the smart control and operation of a microgrid in both islanded and grid connected mode is the MAS strategy. In MAS, each significant part associated with the microgrid is used as an autonomous intelligent agent that can control the adjacent components, as well as communicate with other agents. The MAS comprises of three techniques for controlling the agents in microgrid and in dealing with every other single agent: centralized, decentralized and hybrid co-ordination. In fully centralized coordination, the main controller performs all the control functions while in fully decentralized coordination, each unit of the microgrid is controlled by a local controller. Moreover, either circuit breakers and relays or AC-to-AC power electronic interfacing can control the loads. ESS plays a main role in integrating RES, which is combined with non-dispatchable units i.e. solar energy, for providing overall stability and improving power quality (Longenthiran *et al.*, 2015; Olivaries *et al.*, 2014; Sen & Baysal, 2018). However, the main problem of adopting the decentralized approach is that with the failure of any control agent, the whole microgrid system can collapse. In the decentralized system, the communication of microgrid agents is restricted to their neighbors only and therefore, its adoption is not a universal solution (Bharath, 2019).

In this proposed study the RES are integrated and then selected as per their priority depending on their time of availability. The main objectives of the study focuses on the integration of RES in line to the microgrid, utilization of proper DSM strategy for reliability of the power system and minimization of the operating cost by the management of sources and loads according to their preferred time of use. A microcontroller is used which acts as a central controller in the microgrid. Switching devices are connected with the load agents as well as with the power sources. The priority of the loads and power sources is adjusted through the microcontroller. Viewing the novelty of the proposed study, it utilizes energy management techniques through DSM, classifying the loads on the basis of critical and non-critical load. Hence, by adopting centralized MAS technique, the controller utilizes the RES as well as controls the critical and non-critical loads.

This paper is classified as follow: Section 2 describes the formulation of the proposed study. Section 3 explains the simulation strategy. Section 4 deals with the hardware implementation and validation. The hardware model mathematical calculations are explained in section 5. Section 6 outlines the simulation results and section 7 shows and explains the hardware results. Section 8 concludes the paper.

2. Formulation of the Proposed Study

Figure 1 shows an overview of the proposed study. The main theme of the proposed system is to utilize RES according to their availability for the operation of load in a smart way based on

DSM and centralized MAS technique. RES are selected for power generation in the microgrid by keeping in view their efficiency, environment friendliness, economic benefits and effectiveness, as compared to conventional energy sources. The microgrid comprises of RES, DG, ESS and load agents. The load agents are classified into critical and non-critical loads. Supply to the critical load must be maintained at all costs. Moreover, the supply to the load agents is given according to DSM techniques.

The microgrid central controller plays a leading role in the operation of the microgrid by operating according to centralized control technique. All the power sources available are taken into consideration by the central controller of the microgrid. When the RES i.e., wind or solar are present along with DG, the power is supplied to the load agents (critical and non-critical) as well as to the utility grid through DG. If the RES are not present, then DG source is taken into consideration, which supplies power to the load agents (critical and non-critical), but no power is supplied to the utility grid. Further, if the power sources are not available, then a backup battery is utilized which supplies power to the critical load only while the non-critical load is shed off.

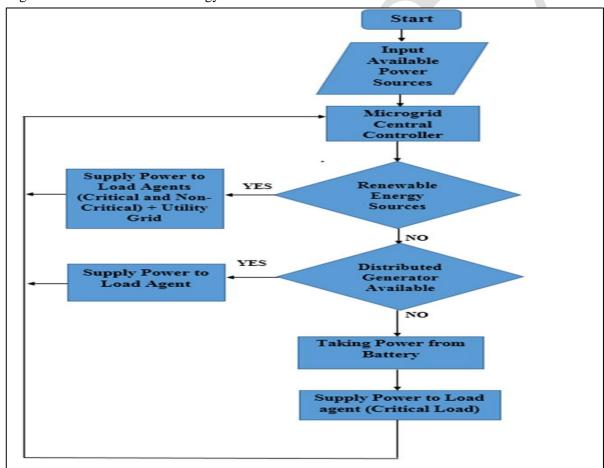


Figure 1: Real time control strategy flow chart

3. Simulation Strategy

The simulation of the proposed system in the study has been carried out on MATLAB Simulink. RES i.e. wind source and solar source have been taken along with DG and backup

battery. Switching devices i.e. circuit breakers have been connected with sources as well as load. Each power source is converted into DC by using rectifiers and then the DC output has been further given to a central microcontroller. Hence, the following power sources have been implemented along with the specific simulation strategy explained as under;

3.1. Wind Source

The wind source model uses Doubly Fid Induction Generator (DFIG) wind turbine, which keeps the output voltages at a fixed value, regardless of the wind turbine speed. It also provides supply to the grid through both of its rotor and stator.

In the wind model as shown in the figure 2 the frequency is set to 50 Hz. The DFIG wind turbine is set at 800V and then attached to bus1. After that a transformer is used which steps up the voltage to 18KV and then the voltage is passed through the transmission line of 10 km line. The transmission line is attached to another bus and then further attached to a transformer that steps down 18KV to 11KV. Moreover, a resistive load is further attached to the wind source and the output voltage is observed.

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Figure 2. Wind simulation model

3.2. Solar Source

Figure 3 shows the solar simulation model. The PV module voltage depends upon the irradiance and temperature. The irradiance is set to 1000w/m^2 and temperature is set at 25 degree. The voltage and current of the PV module along with the MPPT parameters are given as an input to MPPT controller that uses observe and perturb algorithm in order to track maximum point of the power. As a result, we get a constant value with certain delay for conversion into pulses. The pulses are given to the gate of the IGBT in the converter and the gate of the converter is open or closed according to number of pulses. Then the output of the converter is given to IGBT of the inverter, also we used the carrier and reference signal block,

the function of these two signals is to compare the carrier signal with the reference signal and provide a PWM to gate of the IGBT. The inverter is used to convert the DC voltages into AC voltages and gives a square wave signal.

Further, on, a battery of 7Ah is connected with the solar source. The solar source not only operates the load but also charges the battery. The initial SoC of the battery is set at 70% and battery voltage is set at 12V. Then a bus selector is connected with the battery to check its state of charge as well as battery voltage. A resistive load is also connected to observe the output voltage along the load.

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Figure 3: Solar simulation model

3.3. Distributed Generator

A 3-phase programmable voltage source is used a DG source as shown in figure 4.

A Conn1
Conn1
Conn3

Figure 4: Distributed Generator (DG) simulation model

3.4. Integration Strategy

For integration of power sources, the solar source, DG source, backup battery and wind source are converted into subsystems. A 3-phase Sinusoidal Pulse Width Modulation (SPWM) inverter is also used. With each source circuit breakers are connected for switching purpose. The outputs of circuit breakers are connected with the 3-phase SPWM inverter that converts DC voltage into AC voltage and operates the load. To achieve the integration of the sources, preference is given to each source and this is done through a central microcontroller as shown in figure 5. The outputs of the controller are used to control (Switch ON and OFF) the breakers. Output terminal of the controller i.e. y1 is connected with the wind circuit breaker, y2 with the DG load circuit breaker, y3 with the DG utility grid breaker and y4 is connected with the solar circuit breaker. Moreover, as two load agents are used i.e. critical and non-critical, y5 and y6 are connected with the critical load breakers and y7 along with y8 and y9 are connected with the non-critical load circuit breakers. y10 and y11 are connected with the battery circuit breakers. Further, on two scopes are used for checking the output of the load along with the sources and load inverter.

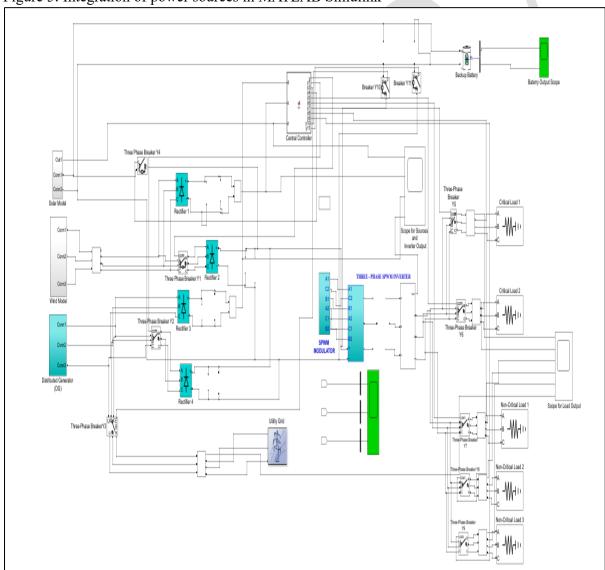


Figure 5: Integration of power sources in MATLAB Simulink

4. Hardware Validation Strategy

In the hardware part of the proposed study as shown in figure 6 three power sources Solar, DG and backup battery are used. Two batteries are utilized, one battery is used with the solar source and the other battery is used as a backup source which is kept charged through the DG. The output of Solar source is in DC, which is further passed through Buck Boost converter in order to charge the battery connected with the solar source. The output voltage is then passed through the voltage divider circuit, as a result of which 5V is achieved that is fed as an input to the microcontroller.

Similarly, the 220V AC voltage from DG is first stepped down to 12V AC and then converted to 12V DC through rectifier. The 12V DC is then passed through the voltage divider circuit and is reduced to 5V DC and given to the microcontroller as an input. Moreover, the voltage from backup battery is also in DC, which is passed through the voltage divider circuit to get 5V DC and then supplied to the microcontroller.

Further on, the positive and negative terminals of the sources are given to the relays. A central microcontroller i.e., Arduino UNO is used to give preference to the power sources accordingly. ULN2003A IC is used with the microcontroller to step up the voltage from 5V to 12V and for operating the relays.

The voltage of the power source to which priority is given, further passes through the relays which then gets tripped. Further on, the voltage passes through the inverter, and then goes through the center tapped transformer where it is stepped up to 220V AC, in order to operate the load agents. Moreover, load agents are classified into critical and non-critical loads, where the supply to the critical load must be maintained at all cost.

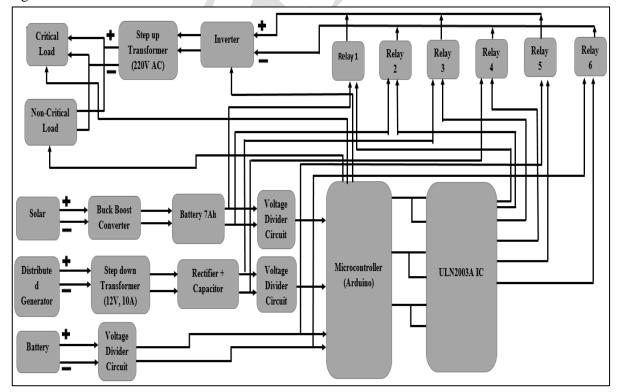


Figure 6: Hardware architecture model

5. Hardware Model Mathematical Calculations

5.1. Buck Boost Converter

Buck Boost converter can be defined as a DC to DC converter whose output voltage is higher than or less than the input voltage with the voltage magnitude depending upon the duty cycle. A single inductor and fly back circuit is also used. If the voltage is higher than the required battery charging voltage, it acts as a Buck converter which steps down the voltage to the battery charging level and vice versa.

5.1.1. For Buck Mode

a. When there is a Gate Signal

In this state, the power of the switch Q1 is turned ON and the power of the switch S2 is turned OFF. Therefore, for the Gate to source Voltage;

$$Vgs=Vg-V....$$
 (5.1)

Where;

Vgs= Gate to Source Voltage, Vg= Gate Voltage and Vs= Source Voltage

As in this state Vg=5V and Vs=0V. So by putting the required values in equation (5.1):

$$Vgs=5V-0V$$
 $Vgs=5V$

As Vgs>0, the switch Q1 will be ON and the inductor will be charged linearly by the voltage as a result of which it will store the charge in the form of a magnetic field.

b. When Gate Signal is Zero

In this state the power of the both switches Q1 and Q2 will be turned OFF. Moreover Vg=0 and Vs=0. So by considering equation (5.1).

As Vgs=0V, the switches will be OFF and the inductor will discharge due to which power will be supplied to load.

5.1.2. For Boost Mode

a. When there is a Gate Signal

In this state both the switches Q1 and Q2 are ON due to which Vg= 5V and Vs= 12V. So by considering equation (5.1):

$$Vgs=Vg-Vs$$

 $Vgs=5V-12V$
 $Vgs=-7V$

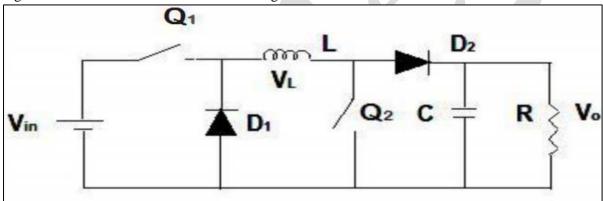
As Vgs<0, the switch Q2 will remain ON and the output capacitor will supply power to the load and the input voltage will be charging the inductor.

b. When there is no Gate Signal

In this state the switch Q2 is OFF and the switch Q1 is ON due to which Vg=0V and Vs=12V. So by considering equation (5.1):

As Vgs<0, the switch Q1 will remain ON and the inductor at start will be discharging but then it changes its polarity due to the input voltage and supplying power to load.

Figure 7: Buck Boost converter schematic diagram



Source: Chandran & Chandran, 2015

5.2. Rectified Capacitor Value

As we used a step down transformer of 220V to 12V so;

Turns Ratio, n= 18.33:1

Now for the primary and secondary peak voltage;

Vp (primary) =
$$220 \times \sqrt{2}$$
=311.13
Vp (secondary) = $n \times Vp$
Vp (secondary = 0.055×311.13
Vp (secondary = $17.11V$

In order to determine the rectified voltage;

Suppose Peak-to-Peak ripple voltage;

$$Vr(pp) = 0.15V$$

So, by using the equation for Peak-to-Peak ripple voltage;

$$Vr(pp) = (1/fRC) Vp (rectified)(5.3)$$

Now, by putting values in the above equation (5.3);

C=
$$(1/(100 \times 220 \times 0.15))$$
 15.7
C= 4760μ F

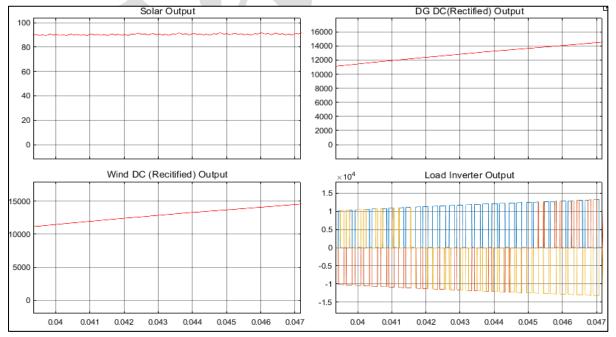
6. Simulation Results

By checking the stability of power sources, we integrated them. The simulation results are shown in the form of graphs where in each graph x axis indicates the time period, while y axis indicates the voltage level that changes with respect to the time.

6.1. When Power Sources are Available

Figure 8 shows the output voltage levels of the sources and the inverter along with time when all the power sources are sufficiently available. In this case the power is supplied to the load agents (critical and non- critical) as well as to the utility grid.

Figure 8: Sources and inverter output voltage when all power sources are available



The figure 9 shows the output voltage of load when operated through available RES. Power is

supplied to the critical and non-critical load of the microgrid. The major objective is to utilize the renewable energy sources, as their cost per unit is less. In this case, DG source supplies power to the utility grid as it is sufficiently available.

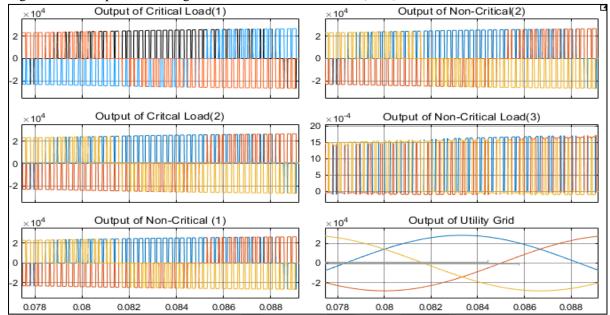


Figure 9: Load operated through Renewable Power Sources (RES)

6.2. When RES are not Sufficiently Available

Figure 10 shows the output voltage of RES and the inverter when the output voltage of the solar source is negligible while the output voltage of the wind source is also not sufficiently available. Therefore, the DG whose output voltage is sufficiently available is utilized and it will operate the load agent.

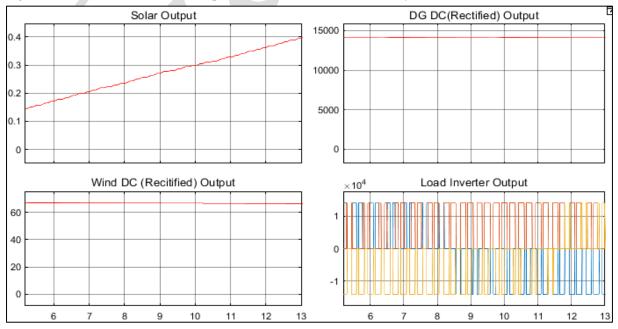


Figure 10: Sources and inverter output when RES are not sufficiently available

When DG source is utilized for operation, power will be supplied to both the critical load and non-critical load. Moreover, power will not be supplied to the utility grid in this case as shown in figure 11.

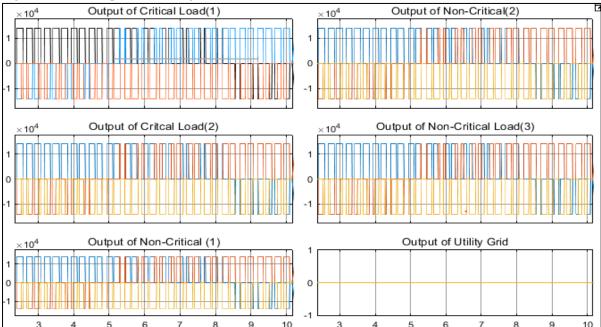


Figure 11: Load operated through DG

6.3. When Power Sources are not Sufficiently Available

In the third case as shown in figure 12 the output voltage level of the power sources including solar source, wind source and DG is not sufficient to operate the load. Hence, a battery is used as a backup source.

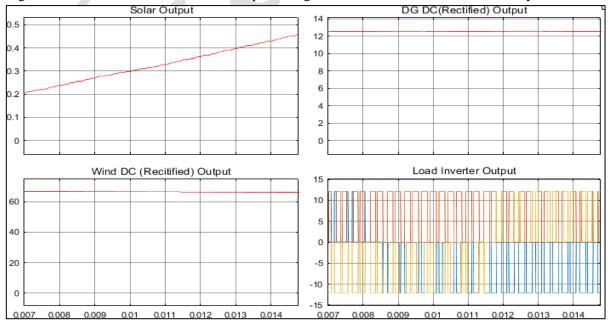


Figure 12: Power sources and inverter output voltage when all sources are not sufficiently available

In this case, the critical load will be operated only, while power will not be supplied to the non-critical load as well as to the utility grid, as shown in figure 13.

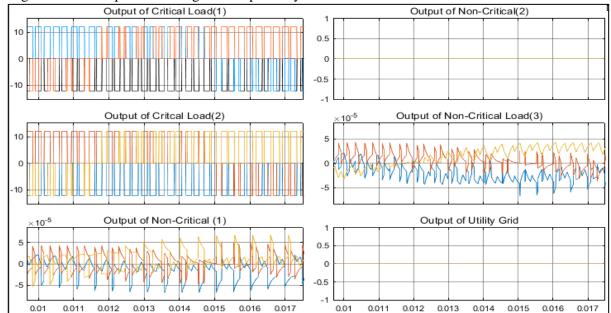


Figure 13: Load operated through back up battery

7. Hardware Results

For hardware implementation, three power sources including solar source, DG and backup battery source are utilized in order to operate the load agents. The hardware prototype is given in figure 14.



Figure 14: Hardware prototype

a. When Power Sources are Available

In this case, when all power sources are utilized, both the critical loads and non-critical loads are operated. Moreover, the sources are given priority through the microcontroller where first preference is given to the solar source.

b. When Solar Source and Backup Battery are Available

In this case when the solar source and backup battery are available both the critical and non-critical will be operated.

c. When DG and Backup Battery are Available

In this case, power will be supplied by DG to both the critical loads and non-critical loads.

d. When Backup Battery is Available

In this case, no power sources are available and a battery is used as a backup source. The backup battery will supply power to the critical load while the non-critical load will not be operated.

Description	Load Agents	State
When all power sources are available	Critical Load	ON
	Non-Critical Load	ON
When solar source and backup battery are available	Critical Load	ON
	Non-Critical Load	ON
When DG and backup battery are available	Critical Load	ON
	Non-Critical Load	ON
When backup battery is available	Critical Load	ON
	Non-Critical Load	OFF

8. Conclusion

Microgrid plays an important role in power generation and distribution. Microgrid can be used to meet the electricity needs of increasing human population and to maintain the continuity of supply at the consumer terminals. In the proposed study, power is generated and distributed among different loads in a smart way. DSM is one of the major techniques used to distribute power among load agents connected with the microgrid. The DSM implementation in the microgrid relies upon the two-path correspondence between the utility user and the end user. Its major impact areas are load management and load reduction.

According to the proposed strategy in the paper, power is generated from RES along with the DG source and backup battery source. The sources as well as load agents are given preference through a central microcontroller. Load agents are operated by the power sources depending upon their availability. The load is transferred from peak hours to off peak hours due to which reliability and efficiency of operation is increased, and secondly the cost and peak hours are minimized. The load agents are classified into critical loads and non-critical loads. Critical load operation should be maintained while the non-critical load operation can be interrupted.

Moreover, the results of the proposed study are software simulation as well as hardware validation. The results obtained show that when RES are available, power is supplied to both the load agents (critical and non-critical load) as well as to the utility grid. When RES are not available, backup battery acts as a power source to operate the critical load only.

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