



Priority-based low voltage DC microgrid system for rural electrification

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ABSTRACT

This paper discusses the current state of DC distribution system, how it can be beneficial to isolate solar-based Micro-Grid (MG) system in a rural area, and how the priority-based approach can help the MGs to operate in cost-effective and reliable ways. DC distribution system holds many advantages over AC systems in such area, where the load demand is not so high and the electricity supply through grid extension is not feasible. Direct load control-based approach can ensure a continuous supply of power to the loads with various priorities. In this paper, an experimental analysis of the DC MGs has been presented with the help of priority based algorithms. A cost-effective SCADA system is developed to interface with the remaining parts of the system, so that the MGs can be monitor and control to get the desired performance. The main objective of this study is to identify a cost-effective and practical energy management system for the rural area, where expensive and advanced technology is not suitable. From this study, it is concluded that the proposed combination of algorithm and SCADA system increase the system's reliability and power consistency significantly.

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1. Introduction

Renewable Energy Resources (RES) based MGs are found to be a promising technology to provide the electricity to the rural area, where extension of the national grid is infeasible (Shrestha et al., 2019a,c). Despite these efforts, these systems are not reliable and efficient in many ways (Shrestha et al., 2020b). These systems lack the proper monitoring and energy management system. Most of the loads used in rural areas are lighting loads, which are DC loads with AC–DC power converters (AEP, 2018/19). With the development in power electronics technologies and renewable DC power generators like solar, permanent magnet generators, biofuel cells etc., development and implementation of DC distribution system is increasing day by day (Iyer et al., 2015; Prabhala et al., 2018). In the past, most of the electrical loads used to run on AC, but with the increase in the development of semiconductor technologies, the load type used is being shifted to DC. However, the power grids still provide AC supply, resulting all of these devices to have inbuilt power converters that convert AC to the required DC. It makes the devices costlier and inefficient. For

the DC distribution system, the individual devices do not require power converters, which plays an important role in the reduction of device size, system cost and performances etc. (Prabhala et al., 2018). Also, the coordination between the distributed generators (DGs) within the MGs is found to be easier in DC system than AC because of synchronization and power flow direction issues (Shrestha et al., 2019b; Tran et al., 2019).

In the present context, the continuous availability of energy and its quality is a major concern. Several studies (Shakya et al., 2019; Shrestha et al., 2020a), presented the survey results on how the sources connected to the grid affect the system reliability. It was shown that the RES have low availability and can cause performance fluctuation because of their periodic and unpredictable nature (Sah et al., 2018; Shrestha et al., 2016). To solve these issues, people are preferring the concept of MGs by integrating the available DGs in a single system (Hirsch et al., 2018). In most of the rural area, MGs are constructed with a minimum budget so that they can be made affordable (Suryad et al., 2017). Various optimization tools and strategies are used to keep the price of energy as low as possible. A few studies (Bista et al., 2020; Shrestha et al., 2019c), perform the assessment on the isolated hybrid energy system for the rural village and institution in Nepal, considering Distributed Energy Resources (DER) around the regions. Similarly, a few pieces of research (Razmjoo et al., 2017, 2019), discuss the possibility of RES and performed the techno-economic analysis for a standalone solar-wind hybrid system for

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the rural areas in Iran. Similar cost optimization done by [Gioutsos et al. \(2018\)](#) for DER and penetration of renewable energy in six different islands shows an implementation of DER as an option to cost minimization. However, this source management comes along with the implementation of the whole system. As each source has a limitation on how much energy one can supply, the other need to step in to support the system. So coordination between the sources is important to maintain the balance between the systems, and the supply-management-concept can help to maintain the coordination between these sources.

Most of the energy system in the rural area requires an energy management system that can minimize the issues and fulfill with desired system performance. Demand Side Management (DSM) is one of the ways to stretch these limits a bit further, which has been used in various ways to manage the load depending on the supply availability. DSM includes everything that can be done in the demand side of an energy system, this management scheme ranges from changing the old heavy load equipment with a new lightweight load to installing sophisticated load management system. [Palensky and Dietrich \(2011\)](#), categorized the DSM on the basis of timing and impact of the solution. Similarly [Mortaji et al. \(2017\)](#), further discussed other strategies of DSM such based on incentive and time that helps to alter the demand response, which reduces the peak demand and/ or bring the demand to the required level. These strategies have been implemented through changing the price of electricity or providing an incentive to the customer that save power usage during peak hours, and helps in keeping the system balance. A study ([Logenthiran et al., 2012](#)), discussed six broad methods that can be impeding the smart meters: peak clipping, valley filling, load shifting, strategic conservation and strategic load growth. These concepts can be implemented by studying the load profile. As the study on predicting load and generation side has taken a high interest in the past few years. [Bouktif et al. \(2018\)](#) discusses the various method of forecasting and presents an idea to find an optimal method for minimum error on forecasting. Most of the concept on DSM used in the current context, relay on the predicted data of load and availability of energy. The model predictive control method ([Hooshmand et al., 2012](#)), consider the stochasticity of demand and generation to reduce the peak load and maintain the load-supply balance. It further discusses a 3-node situation on varying generation and demand. [Ali et al. \(2016\)](#), uses DSM by considering the gap between the peak load and average load by shifting the load of peak hours, but this scheme requires a day ahead load prediction. Similarly, [Logenthiran et al. \(2012\)](#), discuss the heuristic optimization in DSM to bring the final consumption curve closer to the objective load curve by controlling the appliances used in that area.

As loads are the appliance being used on every house, they classified the appliances as: static and dynamic load ([Khan et al., 2018](#)), Shed-able and unshed-able ([Hoffman, 1998](#)), programmable and dimmable appliances ([Mortaji et al., 2017](#)) and so on. Through the control of appliances, the demand can be shaped by reducing the total load on the distribution system during peak periods, and shift the load for a good time. A research ([Khan et al., 2018](#)), priorities the appliances in terms of time-based and device-based to achieve maximum user comfort in the defined budget limit. As depending upon the uses of appliances and the power satisfaction of the system, the using hours are specified by shifting and/ or shedding the load. With the limitation in the generation capacity of isolated MGs, the priority-based load division control strategy comes in popularity. In [Hoffman \(1998\)](#), the load control is defined by the kVA rating of each equipment, and divided the load into the base and shed-able load. The combined heat and power (CHP) equipment are considered as the shed-able load, and firstly predicted by using an auto-regression model. It is

then calculated the required kVA to be shed and keep the demand below the targeted peak. [Pipattanasomporn et al. \(2013\)](#), perform the analysis on the load profile of each home-based appliance, which shows that the obtained data for each appliance can help to implement the effective home level energy management system.

However, a question arises on the prioritization of the appliances and its basis. [Shakya et al. \(2019\)](#), present a framework on prioritization of load in rural household based on user preference and storability of the load. However, various technical measures like reliability, stability and protection issues are to be considered during the implementation at the real site. A control system set up in Bhutan by Grid share use light indicator to indicate the health of grid and prevent the use of the heavy appliance in households during peak hours ([Quetchenbach et al., 2013](#)), but, this concept is not techno-economic that cost each individual to spend \$93 for the controller unit. Similarly, various smart meters such as Spark meter, powerhive are in practices, which has the capacity to control the peak load and manage the energy consumptions. However, one of the major concern is controlling each appliance, which is no easy task as every equipment need to be connected to the controller, especially in the rural area of developing countries like Nepal. To conduct such a task in the rural area where proper infrastructure is not available, various technical measures are required, which can be achieved via some alternative techniques. A management strategy implemented on a solar MGs in Baidi, Nepal offers three packages: light package “A”, television package “B” and commercial package “C” ([Neupane and Jha, 2017](#)). With the limited generation capacity of isolated MGs, the priority-based load control strategy comes in popularity in such remote locality.

This research put up an idea to shed the loads in terms of priorities, which can help to increase the reliability and quality of the system via automatic control with optimization techniques. For a healthy operation, the proposed method traces the working pattern of each appliance in each household. The individual smart controller is adjusted to follow the consumption characteristics of the appliances, which might spread over a few hours. In this context, this paper presents a framework to control and operate the rural DC-MGs via priority-based concept. The priority-based-algorithms have been integrated with a SCADA system and is tested on a laboratory-based environment. The system specifically focuses on developing a suitable solution for providing reliable electricity to the rural areas of developing countries. At first, the background along with the research gap, motivation has been introduced with the help of recent pieces of literature. Section 2 presents a detailed overview of the developed model and the adopted approaches. The outputs of the developed model and its associated constraints are presented in Section 3. Finally, the conclusion and recommendations are presented in Section 4. Though described in detail, the following are the main contributions of this paper:

- a. A techno-economic approach has been developed to guarantee the reliability issues in rural MGs system. The approach is based on the priority-based-algorithm, and found to be practical for the rural communities. Further, it is validated with the results of experimental analysis.
- b. A cost-effective SCADA system has been developed, which is integrated with the hardware parts, and support to maintain the system's reliability. The SCADA is designed in the open-source platform, and equipped with specific features that require in a typical rural energy system.

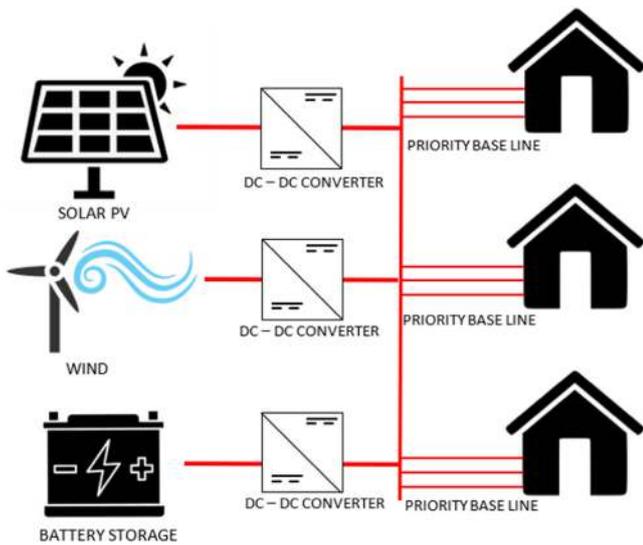


Fig. 1. Architecture of an isolated energy system.

2. System overview and adopted approaches

In the electric distribution system, it is very important to have stable voltage, otherwise, the system may cause damage itself and/ or equipment connected to it. Fluctuation occurs in the system during the switching and load changing events, hence the control system must be dynamic and respond instantly. Fig. 1 presents the proposed architecture of an isolated energy system, which distribute the power in DC form. In a power system with multiple generation sources, it is most likely that certain sources hold higher priority to draw power from than others due to factors like reliability and cost (Gioutsos et al., 2018). Hence, a system that draws the power based on the priorities of sources may help to operate the system in a techno-economic way. The DC-DC converters operating in parallel with priority-based load sharing has been proposed in this study. The DC-DC converters are connected to the generating sources, and the output is directly connected to the distribution lines so that the converters are responsible to maintain the desired voltage level. Similarly, PID based converters have been added to stabilize the distribution voltage in a minimum time frame. On the demand side, the distribution lines are introduced with four lines single-phase supply scheme; where one is neutral and three single-phase lines. The three single-phase lines are provided with different priorities depending upon the types of loads they are connected to (i.e. L1, L2

Table 1

Specification of the developed model for the experiment.

Parameters	Values
Voltage level	24 V
Battery capacity	20 Ah, 12 V
Solar capacity	30 Wp
Maximum current capacity	10 A
SCADA data logging rate	2 sample per minute
Special features	The priority-based algorithm implemented on both source and demand-side

and L3). These loads and sources are managed and controlled by a SCADA system. A priority-based algorithm is implemented in the SCADA system, which provides the ways to operate and control loads of the whole system, so that the system obtains the desired performance. An overview of the developed SCADA system and the experimental set of the proposed model is presented in Fig. 2 (a and b). Similarly, the detailed specification of the developed prototype is provided in Table 1.

2.1. Design of DC-DC boost converter

A boost converter consists of an inductor, capacitor, MOSFET and a diode in an arrangement as shown in Fig. 3. When the MOSFET turns on the inductor which is directly connected across two terminals of the source and it charges itself quickly at a high voltage level. After that, the MOSFET gets turns off and the inductor consumes its energy to the capacitor before the MOSFET turns on again. At the instant, the capacitor maintains a high voltage level than that of the source. To prevent the backflow of current, a diode is normally placed in-between the source and capacitor. The converter has a boundary in which it can supply the output current. If the output current exceeds the limit, the converter cannot maintain the constant output voltage. The boost converter is designed to have a maximum output current of 5A and constant output voltage of 24 V. The input voltage range from 8 V to 16 V with an allowable output ripple voltage of 0.2 V and switching frequency of 31.2 kHz.

The necessary calculations have been conducted for each component with verified specifications. The selection of the duty cycle for input voltage that provides the required output voltage is determined by using Eqs. (1) and (2) (Instruments, 2009). During the calculation, the converter efficiency is considered to be 80%. During the design, the minimum and maximum duty cycle are calculated to be 33% and 84% for the switching pulses.

$$D_{max} = 1 - \frac{Vin_{min} * \eta}{Vout} \tag{1}$$

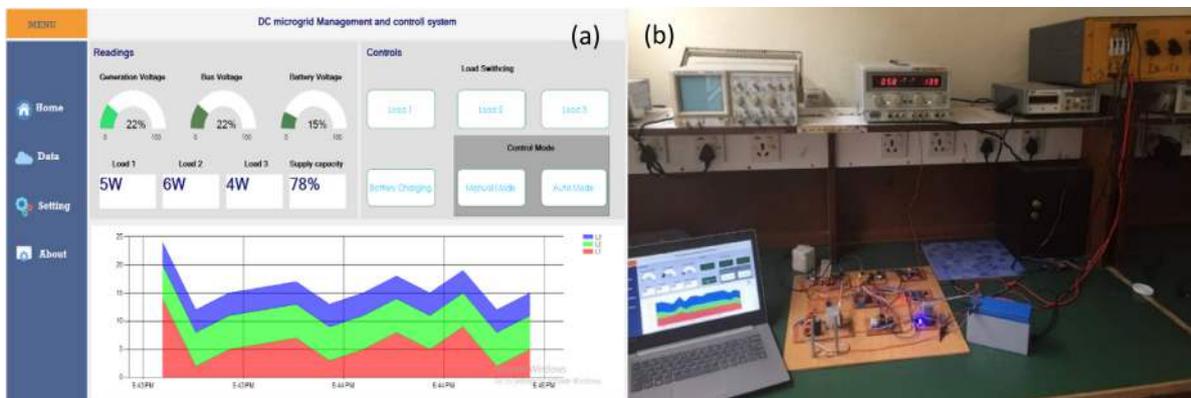


Fig. 2. (a) Developed SCADA system for the DSM based system, and (b) Lab-based set-up of the designed model for experiment purpose.

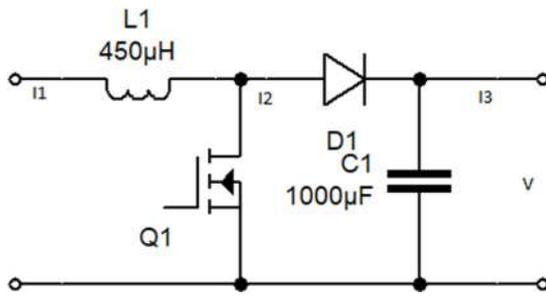


Fig. 3. Circuit diagram of the boost converter.

$$D_{min} = 1 - \frac{V_{in_{max}} \cdot \eta}{V_{out_{min}}} \quad (2)$$

Similarly, the inductor size and the inductor ripple current can be obtained by using Eqs. (3) and (4) (Instruments, 2009). The minimum size of the inductor size is calculated to be 11.3 μH.

$$L = \frac{V_{in} * (V_{out} - V_{in})}{\Delta I_L * F_s * V_{out}} \quad (3)$$

$$\Delta I_L = (0.2 \text{ to } 0.4) * I_{out_{max}} * \frac{V_{out}}{V_{in}} \quad (4)$$

On the other hand, the size of the capacitor and the output ripple voltage can be obtained by using Eqs. (5) and (6) (Instruments, 2009). The minimum output capacitor is calculated to be 800 μF.

$$C_{out_{min}} = \frac{I_{out_{max}} * D}{F_s * \Delta V_{out}} \quad (5)$$

$$\Delta V_{out} (esr) = ESR * \frac{I_{out_{max}}}{1 - D} + \frac{\Delta I_L}{2} \quad (6)$$

The components of the boost converters required in this study are designed using these Eqs. (1)–(6). The designed boost converter is then simulated and built-in hardware according to the calculated value of the components. A closed loop-controlled boost converter is designed that consists of a controller. The controller is so designed that it takes voltage feedback from the output terminal and provides a firing pulse with the required duty cycle to the gate of the MOSFET. When the load starts drawing more current, the output capacitor gets discharged to lower voltage level, and the voltage across output starts going to lower levels instantly. There needs to be more power stored in the capacitor to maintain the output voltage within the required value until the next capacitor charging pulse starts. For this condition, the controller needs to charge the inductor for a longer time, and increase the energy of the charging pulse for the capacitor. The detailed mathematical model of the DC–DC boost converter is shown in Fig. 4.

2.2. Logic behind the system

2.2.1. Source side management approach

DC-MG may consist of multiple energy sources like solar, wind, biomass, battery etc., and one may hold higher preference over others due to the factors like price and reliability. In such a case, there is a need for a logic that can draw power from multiple energy sources according to the level of preference. Priority-based parallel operation of boost converter may be a suitable one to perform required operation in such situations. In priority-based parallel operation of boost converters, the sources are divided into different priorities according to the demand. The converters are connected in parallel. The converters with lower priority act as an extension of the converter with preceding higher priority.

Table 2

Priority based logic for the source side management.

Condition	Gate pulse outcome
If (PID < 84%)	P1 = PID P2 = 0
If (PID > 84%)	P1 = 84% P2 = PID – 84%
If (P2 > 84%)	P2 = 84%

To implement the strategy, all of the converters are controlled with a single regulator. As discussed in Section 2.1, a change in the duty cycle is required to balance the system's voltage level. If the required duty cycle is more than the upper limit for the first converter, the controller starts giving additional pulse to the next controller. Similarly, if the power requirement decreases, the duty cycle starts to decrease from the lowest priority converter. The adopted block diagram of the model is shown in Fig. 5. In case of multiple power sources, if the power supply capacity is lesser than the demand, the system will draw maximum possible power from each source. Similarly, when the power supplying capacity is higher than the demand, the system needs a control system that can draw the power from sources according to the priority given to them. To address these issues, priority-based logic has been applied at the source side as shown in Table 2. In the current sharing scheme for the MG, each converter receives the control signal from the central controller. The controller decides which converter contributes, and how much current is to be supplied. Generally, this scheme is useful in the MGs with distributed generators, and each of the converters must be connected with the central controller via some communication medium. In the proposed priority-based power-sharing scheme, the central controller controls the gate signals of each controller, so that the converters can respond faster in this configuration. Especially, in solar-based MG, it is very practical to minimize the battery uses and prefer solar energy to be used directly by minimizing the charge–discharge cycle of the battery. It extends the overall battery life in such case, hence the priority base power-sharing is effective for solar-based MGs.

2.2.2. Demand side management approach

On the other side, priority-based logic has been implemented in the demand side to maximize the distribution of the electricity supply. The conventional DSM techniques like peak clipping, valley filling, load shifting etc. are theoretically effective, but the grid operating system fails to control the system effectively, since these techniques mainly depend on the consumer's actions. Hence, the system needs to go for load shedding mode; cutting off supplies to certain parts of the loads. In such cases, the priority-based DSM techniques can be applied. In this study, loads of each household has been divided into essential and non-essential categories, and help to maintain the continuity of supply for essential loads first. The non-essential loads will get the electricity for an optimum supply time, so that the continuous supply to the essential load can be guaranteed. The logics for the priority-based DSM are listed in Table 3. In Table 3, Load 1 (L1), Load 2 (L2) and Load 3 (L3) are three single-phase lines with different priorities provided to the loads in each household. At this stage, the L1 is considered to be highly prioritized than L2 and L2 is highly prioritized than L3. Here, 'X' is a battery level at which the L3 need to be cut-off and 'Y' is the next battery level, when both L2 and L3 needs to be cut-off. Below the DoD, the battery supply will be shut-down to all of the loads.

Here, both X and Y are dynamic variable, and an algorithm optimizes their values so that the amount of the stored energy can be optimized for each level of the loads. This helps the

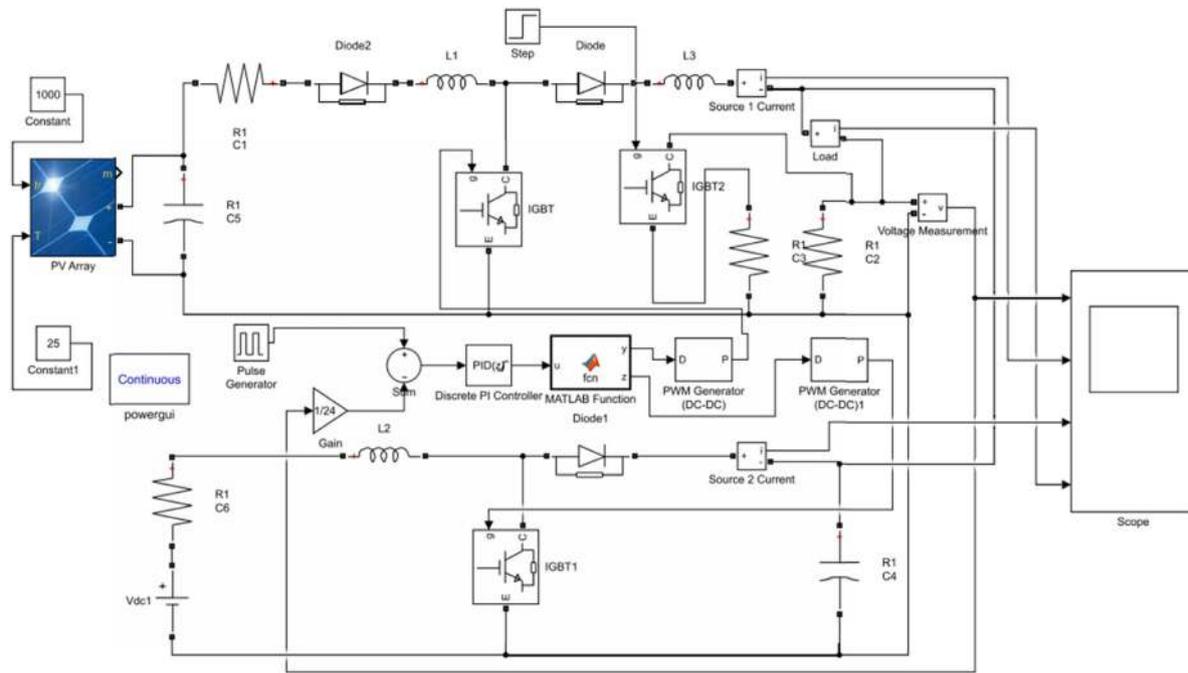


Fig. 4. Schematic block diagram of the DC-DC boost converter.

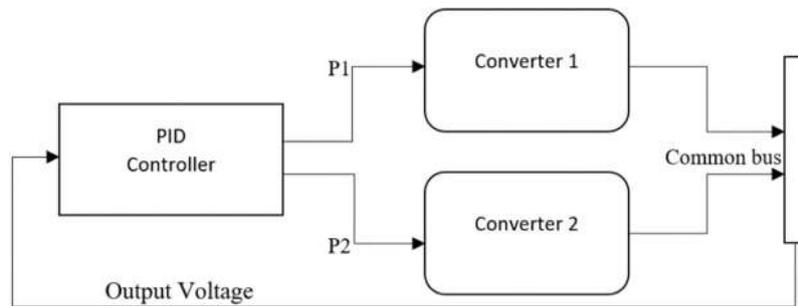


Fig. 5. Block diagram of source-side controller.

Table 3
Priority-based logic for the demand side management.

Loads			Switching conditions
L1	L2	L3	
On	On	On	SoC ≥ X
On	On	Off	SoC < X
On	Off	Off	SoC < Y
Off	Off	Off	SoC < DoD

system to increase the availability without affecting the priority sequences. At first, the value of X and Y are assumed to be 70% and 40%. Table 4 presents the logic for dynamic load switching threshold, where 'A' and 'B' are the switching threshold for L2 and L3 respectively. Similarly, the 'a' and 'b' are flags for L2 and L3. If the value of a and b becomes zero, the threshold values for the respective loads cannot be decreased further. This algorithm is useful for energy management in MGs, when it suffers from energy deficiency and is unable to fulfill the full demand. The proposed algorithm follows the ratio of demand to supply to improve the system supply.

3. Result and discussion

As the system faces fluctuations in both demand and supply side, the supply side is considered to have two different sources:

Table 4
Logic for dynamic load switching threshold.

Load 1		
Supply-demand ratio < 1	A = A + 4%	a = 0
Supply-demand ratio = 1	a = 1	
Load 2		
Supply-demand ratio < 0.8	a = 1	A = A - 4%
	a = 0	B = B + 4%
	b = 0	
Supply-demand ratio > 0.8	b = 1	
Load 3		
	a = 1	A = A - 4%
	b = 1	B = B - 8%
Supply-demand ratio < 0.6	a = 1	A = A - 4%
	b = 0	B = B - 4%
	a = 0	B = B - 4%
	b = 1	B = B - 4%

solar (Source A) and battery (Source B). The sources are connected so that the solar generation holds higher priority and battery are used as a backup. To test the system in realistic condition, the sample for the demand of a scale-downed load at the rural

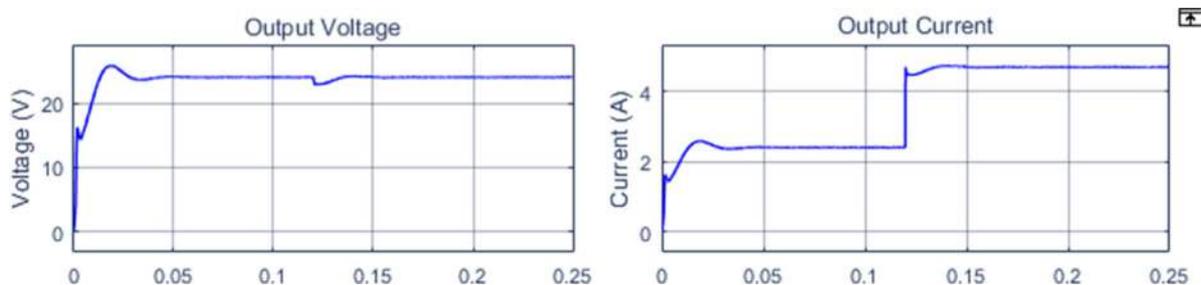


Fig. 6. Tuned response of boost converter.

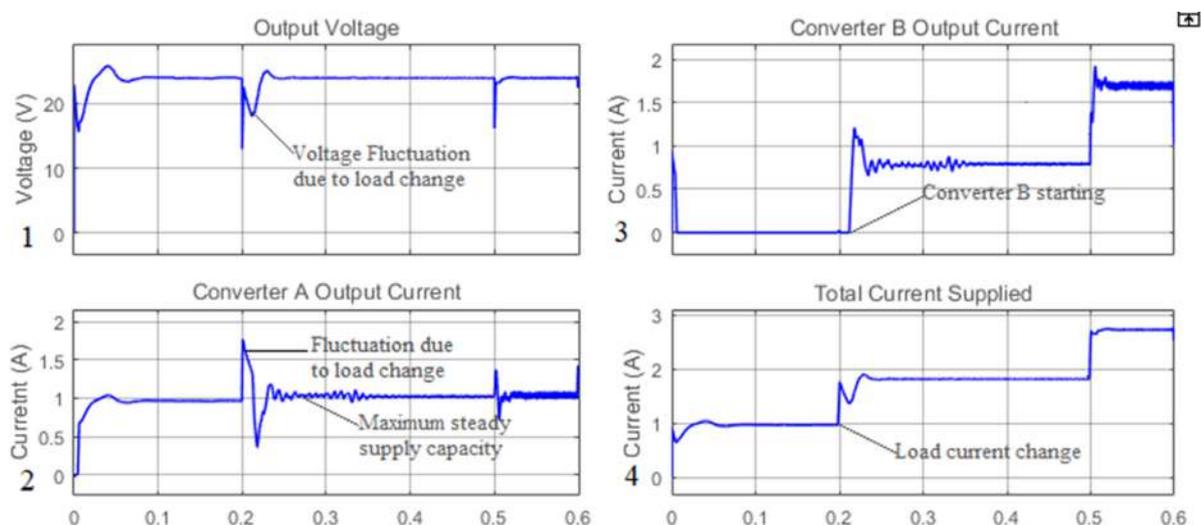


Fig. 7. Response of priority-based parallel operation of energy generators with boost converters.

community has been taken, and the loads are divided into three categories depending upon their level of necessity as in [Shakya et al. \(2019\)](#). These loads are provided with different level of priorities in the power system. The main objective of the proposed algorithm is to ensure the continuous supply to the essential loads while increasing the demand from the non-essential loads. For this, loads are operated in such a manner that each of the loads will be cut-off automatically, after crossing the threshold value of the battery assigned to each load. The threshold value for each load is dynamic and changes every day as per a piece of information getting from the optimization processes of the available power and energy.

3.1. Source side management

The output voltage fluctuates during load changes in a system. To reduce the response time of the system and make the system more stable in such cases, a PID controller has been used that controls the duty cycle with a frequency pulse. The response of the controller after the implementation of PID in the proposed model as seen in [Fig. 6](#). For source-side management, the priority-based power-sharing concept is implemented. As seen in [Fig. 7\(4\)](#), the maximum current limit of source A (Solar) is 1 Amp. When the demand increases and current exceed 1 Amp, source A cannot supply enough power. As shown in [Fig. 7\(4\)](#), the demand increase in the 0.2 and 0.6 s, and the voltage fluctuation occurs. Hence to balance the voltage, the system draws additional current from source B, and supplies the demand. Similarly, as the power requirement decreases, the declines in power supply from source B can be observed. If the power requirement decreases further, source B will completely turn off, and source A will continue to supply the demand. The current from each source is controlled

by the converter A and B, so that the total current will be shared by the sources and maintain the voltage level. The current drawn from each converter for different load conditions can be seen in [Fig. 7 \(2 and 3\)](#).

3.2. Demand side management

On the other side, the reliability and continuity of supply are considered as the major factors, to check the effectiveness of the proposed DSM scheme. The graph on the load profile with and without DSM can be observed in [Fig. 8 \(b and c\)](#). The system's reliability is observed in terms of total hour interruption/week as in [Shakya et al. \(2019\)](#). As observed in [Fig. 8\(b\)](#), the total hour of interruption per week without DSM is more than 30 h. Similarly, the battery level is observed to reach up to DOD every day without DSM which greatly affects the battery health over time. However, after implementing the proposed approach, system continuity is maintained. Like the sources are prioritized, the loads are also classified in three different levels L1, L2 and L3, where, L1 is considered to be the essential load (1st priority) to which supply has to be continuous. Similarly, L2 and L3 are second and third higher priorities respectively. Initially, the threshold of battery level at which L3 cuts off was set to be 70%, similarly, 40% for L2 and L1 would cut-off when the battery level reaches the DOD. Here, the main goal of the DSM algorithm is to reserve enough energy: for L1 to be supplied without interruption, for L2 to be supplied at least 70% of the demand and for L3 to be supplied at least 50% of the demand, but these values can be set as required. While doing this, the algorithm also checks if it is reserving too much energy for L1 than required and adjusts the cut-off threshold of L2 and L3 to increase supply to L2 and L3. These iterations are performed

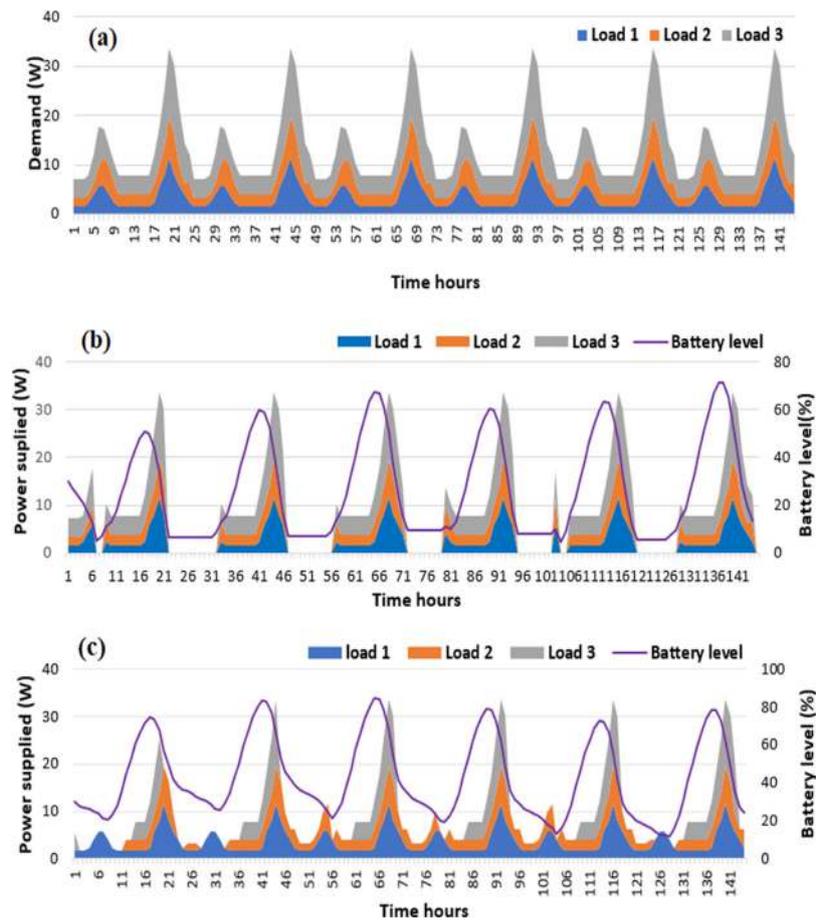


Fig. 8. (a) Demand profile, (b) Supply chart without DSM, and (c) Supply chart with DSM.

daily to achieve require conditions. This paper discusses implementing priority-based DSM algorithm where all three loads are residential, however, this algorithm can also be implemented in an energy system consisting of consumers like Schools, Hospitals and households where each consumer can be given priorities based on their needs. As shown in Fig. 8(a), the load is scaled down for a single house and consumption is considered for six days period. The load curve indicates a short peak at morning and a sharp peak at evening time with the peak values of 18 W and 34 W. To test the effectiveness of the implemented DSM, the system is tested in two different conditions: (a) without DSM, and (c) with DSM. The load served by the system in the first case can be observed in Fig. 8(b), and Fig. 8(c) presents the load chart of the system with the integration of DSM concept. It is observed that there is the unavailability of energy after sharp demand on the system and all of the loads are cut-offs from the supply. However, there is no cut-off for L1 in the system, when the concept of DSM is implemented as shown in Fig. 8(c). After the implementation of DSM, the continuity of supply to the essential load (i.e. L1) has been ensured, while optimizing the power availabilities to the higher priority loads (L1 and L2) as seen in Fig. 8(c). The data from Fig. 8 (b and c) is then used to calculate the supply/demand ratio and supply time in hours/ day for each load for six days, and are shown in Fig. 9 (a and b). It is observed that the supply/demand ratio of L1 is always 1, meaning 100% continuity of L1 has been met. For loads L2 and L3, the ratio has been optimized over the period, which can also be seen in Fig. 9; with the increase in supply and demand ratio the hours per day of supply also increases.

4. Conclusion

In this study, a small-scale DC-MG system has been developed that interfaced with a SCADA system for control and monitoring purpose. The priority-based algorithms have been implemented at both source and load sides. The algorithms help to increase the power system reliability and performance by automatic switching of sources and loads. The automatic control mechanism ensures continuity of the supply to essential loads, while optimizing the supply to non-essential loads as well. Hence, it is concluded that the application of priority-based concepts integrated with a SCADA can help to increase the reliability and system performance significantly. Besides, the proposed concept can be implemented in the large scale MG, but a central control system must be introduced that capable of remote control of the loads. The switching mechanism can also be installed within the large scale MG, which will enforce the energy management algorithm in the residential type consumers. The switching decisions made by central body run the algorithm, and it can be operated remotely with the help of smart meters installed in each household. To avoid the complication in managing the appliances though expensive smart meter, this paper proposed an idea to divide the loads in priorities, and simplifying the computational process, resulting in cheaper and simpler control mechanisms. The proposed model can further improve by introducing priorities-based management framework though appliances based study in each household.

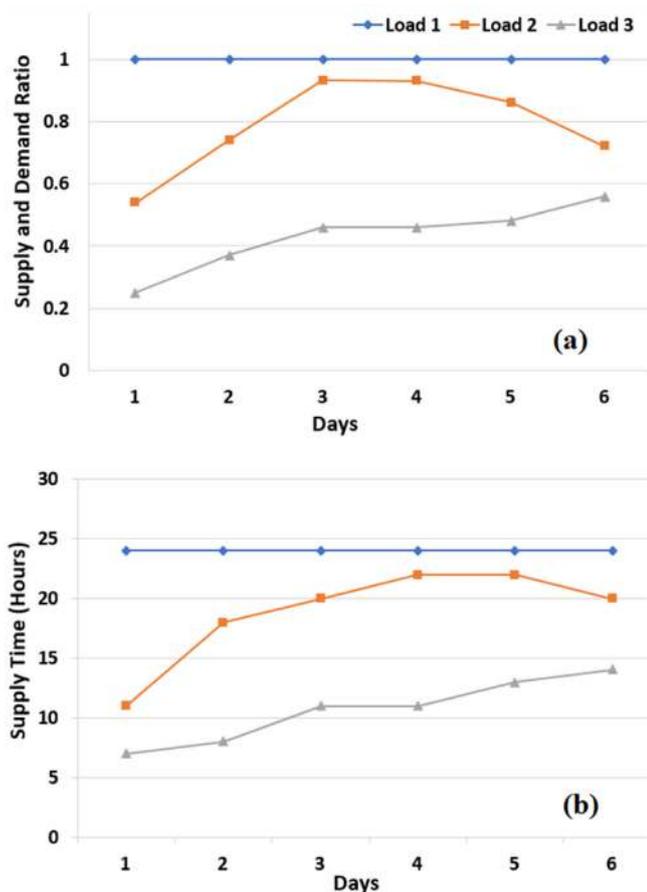


Fig. 9. (a) Supply/Demand ratio chart, and (b) Variation in supply hours per day over time.

CRedit authorship contribution statement

Anup Marahatta: Conceptualization, Methodology, Investigation, Writing and review. **Yaju Rajbhandari:** Methodology, Investigation, Writing and review. **Ashish Shrestha:** Conceptualization, Methodology, Investigation, Writing and review. **Ajay Singh:** Investigation, Writing and review. **Anand Gachhadar:** Investigation, Writing and review, Supervision. **Anup Thapa:** Investigation, Writing and review, Supervision.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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