Abstract—Renewable energy sources has become tremendous area of attraction for researchers and industrialist. This attraction leads to look for DC micro grid installation to save energy. DC micro grid systems are of different types. Standalone DC micro grid system is very useful for remote places etc. The standalone DC micro grid system uses a battery backup along with renewable energy source. The battery has to be connected with a DC – DC bi directional converter. This bi directional converter decides and controls the flow of power from source to load and battery and from battery to load when source is not available. The control strategy of this bi directional converter plays a very important role for the reliable operation of DC micro grid. In this paper a new simplified control strategy for bi directional DC – DC converter is proposed. A simple automatic control mechanism based on the sensing and comparison of voltages on both sides of the converter has been proposed. This control strategy is aimed at providing a smart, user-friendly, economical and efficient control. Solar Photovoltaic is taken as renewable energy source. The circuit is simulated using PSIM.

Keywords— DC Microgrid, Bi Directional DC-DC Converter, Control, Solar Photovoltaic, PSIM

I. INTRODUCTION

Our existing power system was built about 120 years ago. The sources of energy in the ac power system are mainly the non-renewable sources, mainly the fossil fuels. Ac power has always been the dominant form of power because of its two major advantages over its dc counterpart. Firstly, it can be generated more easily and economically and secondly, it can be transmitted efficiently over long distances at high voltages via the transmission lines [1]. But with the changing times, the electric GTD is also undergoing a transformational change both in infrastructure as well as operation.

Owing to the large energy demands of the developed world, the reserves of fossil fuels are exhausting at a rapid rate and therefore, there is an urgent need to relieve the stress on these resources by exploiting the energy from the renewable sources such as solar, wind etc. Most of these sources generate energy which, in its most native form is dc. Moreover, the combustion of fossil fuels also leads to environmental issues which have serious impacts and therefore, their use needs to be limited. It is because of these factors that the use of renewable sources is being encouraged globally.

Renewable energy generation is clean, simple, efficient and eco-friendly. The power from distributed sources of energy can be utilized locally which eliminates the high transmission losses which are involved in the long distance transmission associated with ac distribution [2-3]. Local utilization implies that the sources of power generation are located in close proximity to the served load. Moreover, the renewable resources of energy are freely available and easily accessible to most parts of the world. The solar power constitutes the major source of power among all the renewable resources due to its inherent advantages such as its presence on the earth in abundance and ease of availability and installation [4-5].

In addition to all these factors, another major factor which has motivated the replacement of ac power by dc power is the widespread use of electronic semiconductor devices. These devices are
ubiquitous in today’s technologically advanced world and have become indispensible. These devices form the majority of the total loads of all homes, offices and schools today. The basic fact underlying the operation of these devices is that they can be operated only with dc. Presently, the dc power generated by the renewable sources has to be converted to ac before it can be transmitted to the loads through a transmission system designed to work on ac. At the load side, the power which is received has to be converted to dc inorder to be used by these devices and these conversions involve power losses [6]. There are millions of such conversions taking place in the entire world each second and thus, a huge amount of power is being wasted.

Overall, it can be said that both the nature of sources as well as loads is changing and hence the present power network also needs modification. Therefore, a new concept of power GTD, known as ‘DC Microgrid’ has been proposed which aims at dc power generation from distributed sources and localized distribution to the dc loads directly, eliminating any ac-dc or dc-ac conversion [7-8]. The basic topology of a DC microgrid system is shown in Figure 1. The configuration shows a solar panel as a source of power connected to the dc loads via a dc-dc converter. The dc-dc converter enables the solar panel to work at its maximum power point. To increase the reliability of this system, a battery is used which is connected to the dc bus via a bidirectional dc-dc converter.

The bidirectional dc-dc converter allows the flow of power from the dc bus to the battery and vice versa according to the system requirements. The controlling of the bidirectional converter is a major technical issue in these systems. This paper proposes a simplified technique for the control of flow of power through the bidirectional converter and presents a DC Microgrid topology for residential applications. Section 1 gives the basic configuration of the connection of a bidirectional converter in a DC microgrid system. The modes of working of a bidirectional converter have been studied and analyzed mathematically in section 2. In section 3, the control circuit for power flow management has been described. Section 4 consists of the simulation results of the working of the converter in various modes. The simulation has been done in PSIM. Finally, the conclusion has been presented in section 5.

![Basic topology of a DC microgrid system using a bidirectional converter.](image)

**II. SYSTEM DESCRIPTION**

A DC microgrid system suitable for residential applications has been described in this section. The system uses a 500W solar panel. The output of the solar panel is regulated using a maximum power point tracker, which enables the system to operate at the maximum power point of the solar PV (photovoltaic) output. The energy from the sun is intermittent and unavailable during the night. It necessitates the use of a backup system inorder to supply the loads during the times of unavailability of solar power. The storage battery can serve as a backup as shown in figure 1. The DC bus voltage is maintained constant at 100V. It can vary within 10% of its rated value and hence can fluctuate in the
range of 90V ($V_{\text{min}}$) to 110V ($V_{\text{max}}$). The battery voltage is kept constant at 24V ±10%, and is therefore variable in the range of 21.6V ($V_{\text{bat(min)}}$) to 26.4V ($V_{\text{bat(max)}}$). The loads are attached directly to the dc bus if their rated voltage corresponds to the bus voltage otherwise, they can be connected using a dc-dc step-up or step-down converter as required. Ac loads can also be connected to the system using an inverter. The output of a solar panel is highly dependent on the ambient temperature and incoming solar irradiation. The standard temperature and solar irradiation for maximum power output is 25°C and 1000W/m² respectively. The characteristics of a solar cell are shown in figure 2 and 3.

![Figure 2: Variation of solar PV output power with ambient temperature.](image2)

From these graphs, the variation of maximum power output of a solar PV with temperature and solar intensity can be seen. Therefore, while designing a dc microgrid system, these variations should be considered and a control mechanism which can smoothly control the flow of power from the sources to the loads becomes necessary.

When the solar PV output is low due to unsuitable ambient conditions and the power output is insufficient to meet the load demands, then the battery comes into action and supplies the load. The power flow mechanism is shown in figure 4(a). Similarly, when the battery power is low then it draws power from the solar PV in case enough power is available and the flow of power is as shown in figure 4(b).
III. DC/DC BIDIRECTIONAL CONVERTER

The Buck-Boost Bi directional DC-DC converter is used in the standalone DC-DC microgrid system used in this paper shown in Fig 4. There is a dc bus which corresponds to 100V and its tolerance is ±10%. The battery corresponds to 24V. The minimum battery voltage can be 21.6V and maximum can be 26.4V. When dc bus voltage is between 90V to 110V, then solar panel can easily supply power to the loads and if there is residual power, then the residual power is used to charge the battery. If the battery voltage is less than its minimum value, that means battery needs charging. If the battery voltage is between 21.6V and 26.4V, then battery can either absorb power or supply power to the loads. If the battery voltage is 26.4V, then battery is able to supply to the loads. So, if the dc bus voltage is 26.4V, then battery is able to supply to the loads. If the battery voltage is less than 90V, then battery supplies to the loads and if the battery is not able to supply, then system goes in shutdown mode. The dc/dc bidirectional converter works as a buck converter when the battery is getting charged and when the solar power is insufficient then battery provides the back up and bidirectional dc-dc converter acts as a boost converter. The two mode of operation are described as following:
3.1 BATTERY CHARGING (BUCK MODE)

- **Mode 1**
  In this mode, the MOSFET switch Q1 is controlled. Q2 remains OFF. Q1 is turned on for time $t_{on}$. Firstly the inductor charges via the MOSFET switch and when it is fully charged, then the charging process is stopped. The current and power flow is as shown in Fig 5(a). The corresponding KVL equations for this mode are

$$V_1 = L \frac{di}{dt} + V_2 \quad (1)$$

$$V_1 - V_2 = \frac{\Delta i}{t_{on}} \quad (2)$$

Where $V_1$ is the DC bus voltage and $V_2$ is the voltage of battery. $i$ is the current flowing through Inductor.

- **Mode 2**
  In this mode, Q1 is turned off and diode D2 turns on. The fully charged inductor discharges via the diode and the battery. The corresponding KVL equation for this mode is:

$$V_2 = \frac{(L \cdot \Delta i)}{t_{off}} \quad (3)$$

After solving the equations for both the modes, we get the relation between the voltages of dc bus and battery as

$$V_2 = D \cdot V_1 \quad (4)$$

Where $D$ is the duty cycle.

3.2 BATTERY SUPPLY (BOOST MODE)

- **Mode 1**
  In this mode, Q2 is controlled. Q2 is turned on for time $t_{on}$. In this mode, the flow of current is reversed. Now, the inductor is charged by the battery. The direction of current and power is shown in the Fig 5(b). The KVL equation for this mode is

$$V_2 = \frac{(-L \cdot \Delta i)}{t_{on}} \quad (5)$$

- **Mode 2**
  In this mode, Q2 is turned off and the diode D1 turns on. The equation for this mode is

$$V_2 = \frac{(L \cdot \Delta i)}{t_{off}} + V_1 \quad (6)$$

Fig. 4: Configuration of a Bidirectional DC-DC Converter.
Here, when the equations are solved for both the modes, the result we get is

\[ V1 = \frac{V2}{1 - D} \]  

(7)

**IV. CONTROL MECHANISM**

The control of the bidirectional dc-dc converter is the key to the efficient operation of a dc microgrid system. Complex control methods are proposed in [5]. A simple, smart and economical control strategy based on the sensing of dc bus and battery voltage has been presented here.

Fig 6 shows the control system employed using digital logic gates. The control mechanism enables the dc microgrid system to operate in various modes as described in the previous section. The dc bus voltage is sensed and it is subtracted from the maximum allowable voltage i.e. 110V \( (V_{\text{max}}) \). It is then compared with a reference value of 20V, i.e. \( V_{\text{max}} - V_{\text{min}} \). It is done because the solar panel can continue to function independent of battery till its voltage is above 90V. If it falls lower than this value, then battery needs to supply the load, the bidirectional converter operates in boost mode.

Therefore, it can be seen that if the difference between the dc bus voltage and \( V_{\text{max}} \) is more than 20V at any instant of time, then it implies that the solar panel output voltage is less than that required for its independent operation i.e. \( V_{\text{min}} \). So the output from the comparator can be used to determine whether the solar PV output is sufficient or the system requires a battery.

If the comparator 1 output is high, it implies that dc bus voltage is lower than required and the battery needs to supply the load, while if it is low, then the dc bus voltage is within the appropriate range. The output of comparator 1 is referred to as signal1.

Similarly, the battery voltage is sensed and if the difference between the sensed voltage and the maximum allowable battery voltage (26.4V) is more than 4.8V, it implies that the battery voltage has dropped to a value lower than \( V_{\text{min}} \) and it requires charging. So the output of comparator 2 goes low. When the battery is charged and its voltage lies in range of allowable battery voltage value (21.6V to 26.4V), then this difference is lower than 4.8V and the comparator output is high. The output signal of comparator 2 is called signal 2. This has been depicted in Table 1.

The signal 1 and 2 are then applied as select lines to a demultiplexer. The function of a demultiplexer is to switch the high signal at the input to one of the four output lines. The selection of the output line is governed by the combination of the signals at the select lines. The truth table showing the bit combination at the select lines and the corresponding selected output is shown in figure 6.

The system conditions along with the modes of operation of a DC-DC converter has been shown in table 2 and the control logic design has been shown in figure 6. According to the truth table, it can be seen that a low signal at both S1 and S2 will make the first output pin high. From table 2, it can be
seen that in this situation, switch Q1 needs to be controlled. Similarly, when S1 is low and S2 is high, again switch Q1 is the controlled switch as seen from table 2 and pin b output goes high. Therefore, Q1 is to be subjected to gating pulses whenever, pin a or pin b output goes high. So, in the control circuit the output of both pin a and b are applied to an OR gate. The output of OR gate is ANDED with the gating signal of switch Q1 and the resulting signal is applied to the gate of switch Q1. This control mechanism assures that Q1 is switched whenever, pin a or pin b output is high.

Likewise, when both signals S1 and S2 are high, the system requires discharging of the battery and the bidirectional converter should operate in boost mode. Switch Q2 needs to be controlled. From the truth table, it is observed that a high combination at both the select lines will result in the high signal at output pin c. This signal is then ANDed with the gating pulses for switch Q2 and the resulting signal is applied to the gate of switch Q2.

TABLE I.

| Comparator 1(S1) | Comparator 2(S2) |
|------------------|------------------|
| Output high (1)  | Output low (0)   |
| Dc bus voltage low. Battery voltage low. | Dc bus voltage within the allowable range |
| Battery supplies the load. | Battery to be charged. |

Table II

| Signal (S1) | Signal (S2) | System Condition          | Mode of operation | Switch to be controlled |
|-------------|-------------|---------------------------|-------------------|-------------------------|
| 0           | 0           | 90V ≤ Vh ≤ 110V Vl ≤ 21.6V | Buck Mode         | Q1                      |
| 0           | 1           | 90V ≤ Vh ≤ 110V 21.6 ≤ Vl ≤ 26.4V | Buck Mode         | Q1                      |
| 1           | 0           | Vl ≤ 90V Vh ≤ 21.6V      | Shut Down         | None                    |
| 1           | 1           | 21.6 ≤ Vl ≤ 26.4V       | Boost Mode        | Q2                      |

Fig. 6: Control Circuit of Bidirectional DC – DC Converter.

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A high signal at S1 and a low signal at S2 symbolizes that the system is in shutdown mode. Therefore, no gating pulse is required at either Q1 or Q2. Such a bit combination at the select lines of the multiplexer will result in selection of pin d. A high output signal at pin d is applied to the gate of a switch which has been grounded, such that the net output signal applied to Q1 or Q2 is zero. Therefore, this control strategy enables the perfect control of the bidirectional converter during different conditions of operation. Control signal for each mode are generated depending on the values of battery voltage and dc bus voltage at any given instant of time.

V. SIMULATION RESULTS

The operation of bidirectional (buck-boost) dc/dc converter are in two modes. When Q1 is controlled, the converter operates in buck mode and the battery charges and when Q2 is controlled, the converter operates in boost mode and the battery discharges. The simulation was performed in PSIM software.

A. Buck mode

In this mode, as calculated the value of L1 is 0.912mH and V1 is 100V having a duty cycle 24% with frequency 25kHz. The capacitor C2 is of value 200uF. The simulation results are shown in figure 7. The output voltage was found to be 24.9V which is very close to the actual voltage. Also, the behaviour of current is almost the same as the required results.

B. Boost mode

Here, as calculated, the value of inductor L1 is 0.912mH, the value of capacitor C1 is 3.04mF. The duty cycle is 76% with frequency 25kHz. The simulation results are shown in the figures 8. After some transients, the output voltage of boost mode was found to be almost 100V which is good enough to match with the required output. Also, in this mode, the direction of flow of current is reversed. Therefore, the current waveforms are found as in figure. The simulations were successfully done. Fig 9-13 are the simulation results of different signals of gate operating in different mode.

![Fig 7: Output voltage of bidirectional converter in buck mode.](image)

![Fig 8: Output voltage of bidirectional converter in boost mode.](image)
Fig 9: Signal S4 is high, i.e. Battery Needs Charging

Fig 10: Output current of bidirectional converter in boost mode.

Fig 11: Signal S3 is high, i.e. Battery is to be discharged

IV. CONCLUSIONS

The control of bidirectional dc-dc converter presented in this paper has many advantages over any of the control system proposed so far for such an application. It is not only simple but also easy to implement and cost effective. It provides a control signal for all possible working conditions of the dc microgrid system. The grid is also functional during the night or during cloudy weather conditions
due to the presence of a battery. The smart and efficient control of the bidirectional converter makes the dc microgrid system reliable and less vulnerable to ambient temperature and sunlight variations. Moreover, since it can be implemented using IC technology, therefore the power consumption of the control circuit is very less.

The working of bidirectional converter in various modes has been verified by simulation results. The future of dc microgrids is very bright because it provides the solutions to the present day problems of electric power systems. These systems can further be extended to connect them with the ac grids using bidirectional AC-DC converter. Such a sustainable technology would ensure the best out of both dc and ac networks and will be easily adaptable.

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