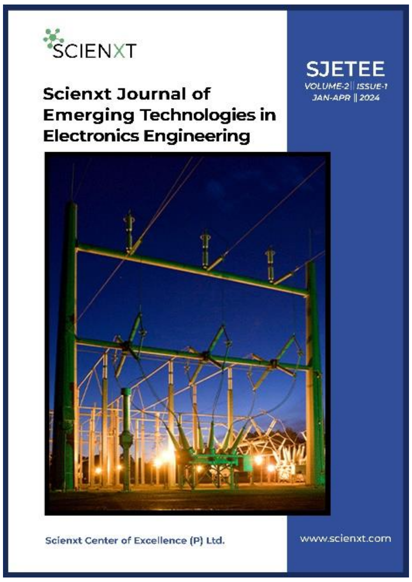

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Modeling and simulation of bidirectional DC-DC converter for energy storage systems

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Abstract:

As the use of renewable energy sources grows in grids, battery energy storage systems become increasingly important for grid stability and reliability. The bidirectional converter can provide battery devices charging and discharging of energy in both directions. This paper presents a bidirectional DC to DC converter for energy storage systems and a proportional and integral controller (PI) for charging and discharging applications. The simulation is carried out in MATLAB/Simulink environment.

Keywords:

Energy storage system, battery, constant voltage source

1. Introduction:

Due to day by day increasing power consumption in various forms and to deal with the problems of the unpredictability of weather and frequent climatic change (on which renewable energy sources rely) the requirement of renewable energy storage is essential [1], [2]. To store the energy, we have a battery, but to control the flow of power, we use a bidirectional DC-DC converter, allowing in both directions. The desire to get an uninterruptable power supply increases with the growing population and technology [3], [4]. This thirst cannot be fulfilled with conventional energy sources. As a result, the need for non-conventional energy sources is increasing exponentially. To meet the demand practically, we must overcome several factors and conditions. Hence the concept of using renewable energy systems is getting more interest. With the growing population and advances in science and technology, the energy demand will need to be matched with available sources. The existing traditional sources of energy are insufficient to supply the power demand. Thus, non-conventional sources of energy are developing in creative ways and attracting the attention of the energy sector. Bidirectional DC-DC converters can be used in a variety of applications, including dc power supply, rechargeable battery circuits, telecommunications power supply units, and computational power systems because while keeping the same voltage polarity at both ends, they can change the direction of current and therefore power [5]. In most cases, the voltage difference between the DC bus and the battery is quite large.

Globally, energy storage technology is growing fast. Reduced costs and organizational incentives are causing a surge in energy storage device investments. Costs have decreased by 74 percent since 2013, depending on the application, and are expected to continue to reduce at an annual rate of 8% through the mid-2020s [6].

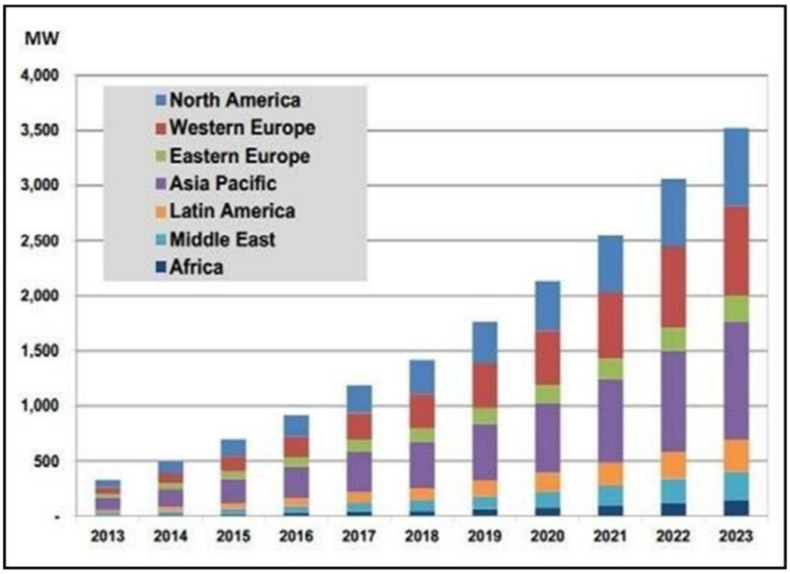

Figure. 1: New installed energy storage capacity for auxiliary services

Fig. 1 represents a region-wise graph for new installed energy storage capacity for auxiliary services in a decade (2013-2023) [7]. According to [7], In the following decade, the global demand for auxiliary services applications of energy storage systems (ESS) is expected to grow rapidly [8], [9], with revenues increasing from $412 million in 2011 to more than $3.2 billion by 2021. Figure 2 represents the total installed revenue by ESS for ancillary services by technology in a decade (2011- 2021).

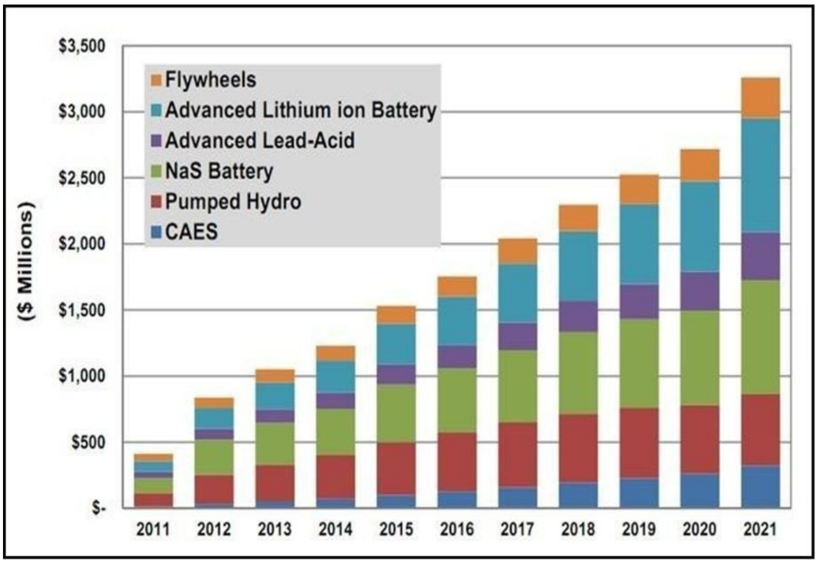

Figure. 2: Installed revenue by ESS for ancillary services by technology

Due to the advancement of various areas, Bidirectional DC-DC Converter can be employed as per power application categorized into two parts: Isolated and non-Isolated type. The major difference between their electric circuits is that each isolated circuit has its return or ground reference due to isolation. A non-isolated converter's input and output are connected by common ground, allowing current to pass between them. Compared to a non-isolated bidirectional dc-dc converter, the isolated boost bidirectional converter has a larger size, more components in the circuit, a core saturation problem, more switching losses, and lower efficiency.

The output power obtained from renewable energy systems is intermittent and unreliable as these energy systems highly depend on weather conditions [10]. As a result, renewable energy systems are planted with energy storage devices to cope with the demands. The major goal is to stimulate and develop an efficiently harnessed energy system. DC-DC converters and charge controllers are two common energy harvesting methods. There are several steps in the conversion process [11]. As a result, the system's complexity, size, and cost grow. The system includes a bidirectional DC-DC converter and control circuits [12]. The converter minimizes component losses while improving the entire system performance. The entire system is represented in MATLAB/Simulink environment.

The structure of this paper's remaining part explains the beginning concepts of bidirectional DC to DC converter. Then, the energy storage, charging, and discharging applications system is modeled, followed by simulation results. In the last, concluding observations have been reported.

2. Bidirectional DC-DC converter:

Traditional converters, such as Buck-boost, can only control the flow of power in one way, but bidirectional converters can control power flow in both directions. The voltage level can be stepped up or down with bidirectional DC to DC converters and can flow power in both the direction, either forward or backward [13]. Around the globe, the penetration of renewable energy sources is kept increasing in the grids, and these sources are highly dependable on different environmental conditions. The output power fluctuates with the change in environmental conditions. A stand-alone system cannot rely on these energy sources because output power fluctuates. Hence, the energy storage devices like batteries and super capacitors are connected with these energy sources. Excess renewable energy generation is kept in these energy storage devices and used when demand is high, or electricity generation is low due to severe weather conditions. A bidirectional DC-DC converter is required to govern power flow in both directions (forward and backward) [14]. By employing anti- parallel diodes in conjunction with MOSFETs or IGBTs, which permit current flow in both directions via controlled switching operation, a normal dc-dc converter can be upgraded to a bidirectional converter [15].

Fig. 3 represents the conventional buck-boost converter, and this has transformed into a bidirectional converter by switching diodes. It depicts a bidirectional buck-boost converter with two modes of operation: buck (diode D2 and switch Q1 conduct) and boost (diode D1 and switch Q2 conduct). Furthermore, each of these two modes has two intervals determined by the diode and switch conductivity.

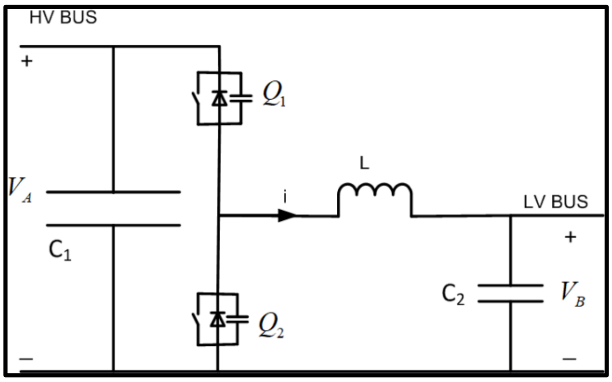

Figure. 3: Bidirectional Buck Boost Converter Circuit

Based on the galvanic isolation given between the input and output; bidirectional DC-DC converters are classified as [16],

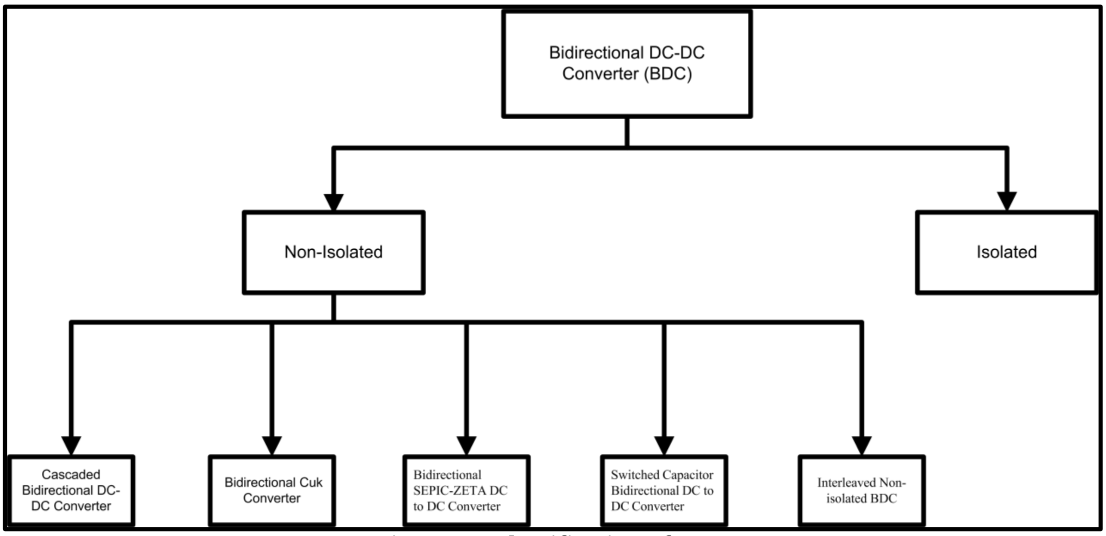

Figure. 4: Classification of BDCs

Similarly, we have two types of Isolated Bidirectional DC-DC Converters: half bridge and full bridge Isolated Bidirectional DC to DC Converter. For low power applications, non-Isolated bidirectional DC- DC converter is suitable as there is no high-frequency transformer to isolate electrically between source and load. In contradictory, galvanic isolation is provided via a high-frequency transformer in isolated bidirectional DC-DC converters [17].

2.1. Modeling of bidirectional DC-DC converter:

Since BDC is a combination of two converter buck and boosts such that able to sharing of power in charging and discharging mode of operation, continuous conduction mode is a good choice of selection as it provides a better dynamic response in the output of converter operation.

Buck Mode – In this mode of operation, input side voltage is greater than the output side voltage. It consists of a switch, inductor, capacitor, and a diode. The basic buck topology is shown below,

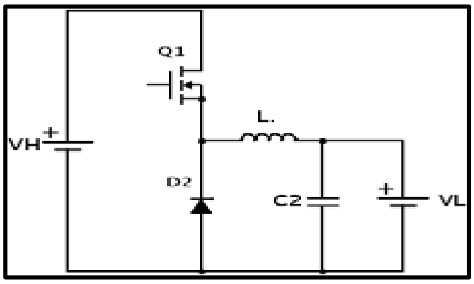

Figure. 4: Basic buck converter

Energy stored by the inductor is given by, E= 1 $LI2$ (1)

Since inductor current is increasing and decreasing depending on switch is on and off respectively, so the voltage across the inductor is given by, $VL = L\ dt$ (2)

An increase in inductor current is given by

$\Delta ILon = \int Ton\ VL\ dt = Vi{-}Vo\ .\ ton = DT$ (3)

0 L L

Similarly, decrease in inductor current is given by

$\Delta IL\ off = \int T{=}ton\ {+}toff$

$VL\ dt = Vo\ .\ toff = (1 - D)$ (4)

0 L L

We suppose that converter is in steady-state condition so at starting and ending of commutation cycle the energy stored in each of its components is equals then the energy in inductor is given by

$Vi\ {-}Vo\ \Delta ILon + Vo\ \Delta ILoff$ (5)

L L

Since we have ton = DT and toff = (1-D)T, after implying this in the above formulae, finally we get

$D = Vo$

Vi (6)

Where D is the duty cycle of the buck converter.

Similarly, we can write for boost mode converter that is shown in Fig. 5(b)

$D = 1 - Vi$

$V0$ (7)

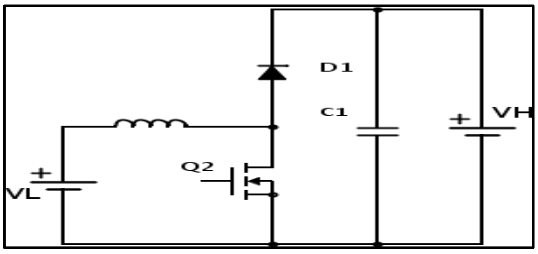

Figure. 5: Basic boost converter

The electrical circuit for considered bidirectional DC to DC power converter linked with the battery is illustrated by the simulation model in figure 6. The two MOSFETs are switched so that the converter is in a constant state of operation. An ideal switch is used during simulation to connect or disconnect the main supply. The battery used in this model is a Lead acid battery and a nominal voltage of 24 volts with a rated capacity of 50 Ah. The nominal parameters of the battery decide the discharging parameters.

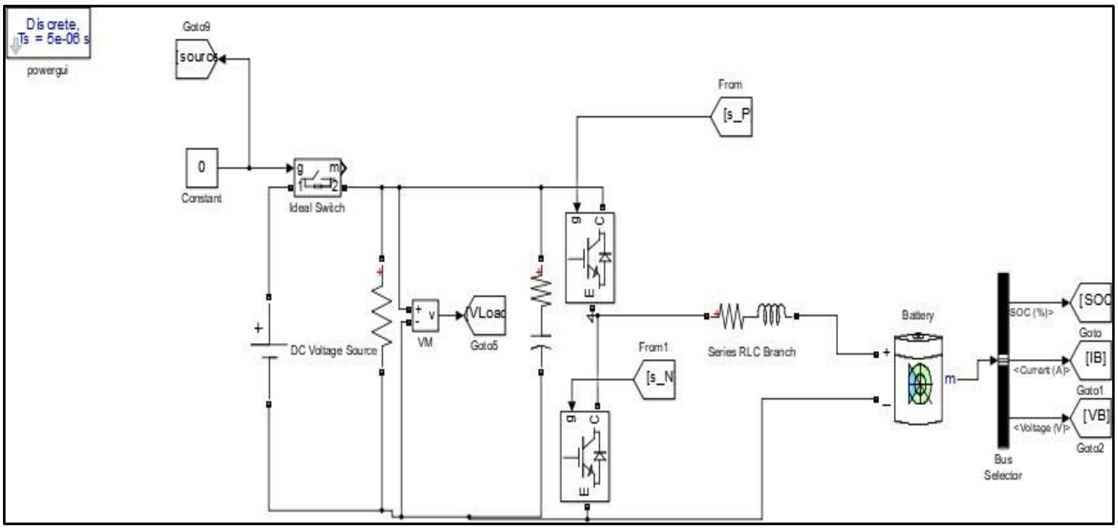

Figure. 6: Simulink model

3. Simulation results:

The MATLAB/Simulink environment is used to simulate the proposed system. A common load is connected across the DC source and the battery. It is assumed that the battery is 50 percent charged and that the main power source is turned on. As a result, the load is fed from both the mains and the batteries. After a long time, the main supply is turned off, and the load is switched to battery power. Figure 7-10 illustrates the output waveform showing that the maximum permissible current in both control schemes (current and voltage control) is 22 A. The open-circuit voltage at the 80% state of charge (SOC) of the battery is 25.9 V. The PI controller is used for determining the reference battery current. PI controller minimizes the error between measured and reference values. When the DC source is supplying power, the charging mode takes place to the battery, and it will be charged. The current through the battery is 16 A, the maximum voltage is 25.9 V, and the voltage across the load is 48 V. In other cases, the DC source is disconnected then the battery starts supplying power to load. The current is 16.4 A, and the voltage decline to 25.6 V. The state of charge in the battery during the charging and discharging mode of operation is depicted in Fig. 7. The current flow through the battery and the reference current is shown in Figure 8. While Fig. 9 shows the voltage characteristics of the battery, and the voltage across the load is illustrated in Fig. 10.

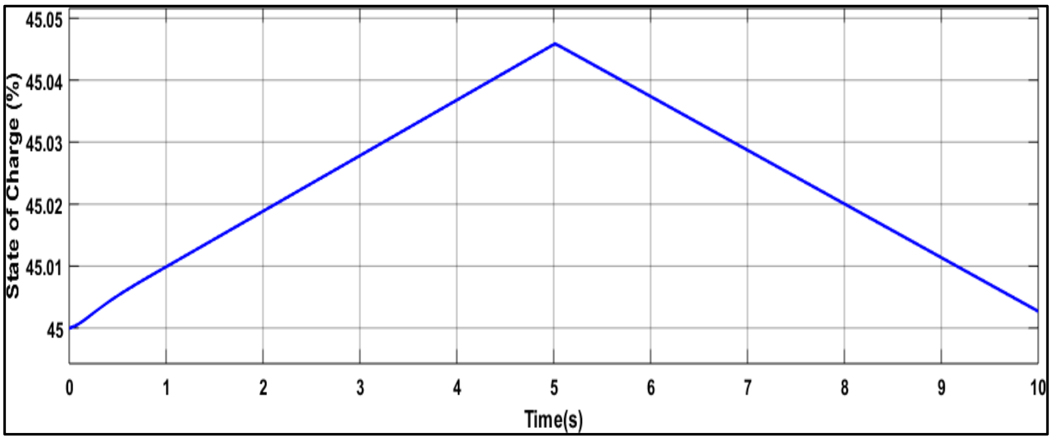

Figure. 7: State of Charge of Battery

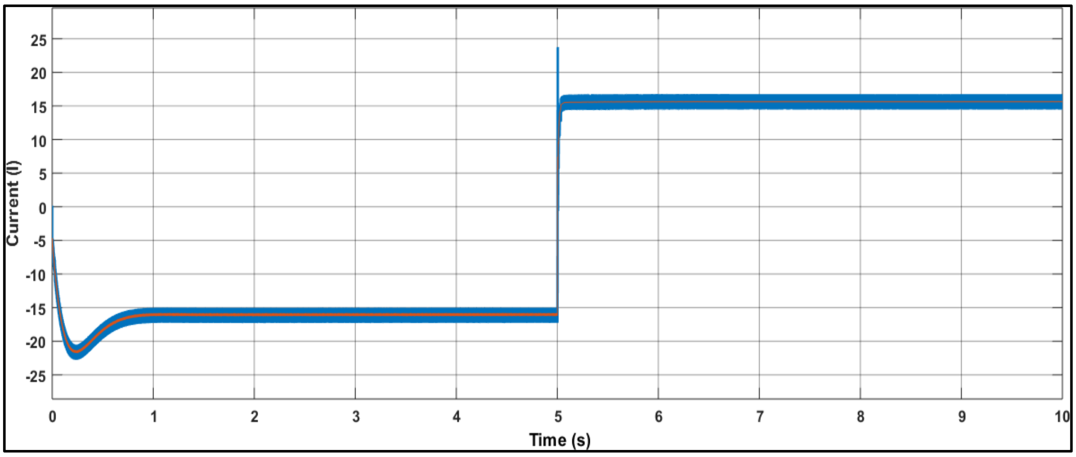

Figure. 8: Battery current characteristic actual and reference

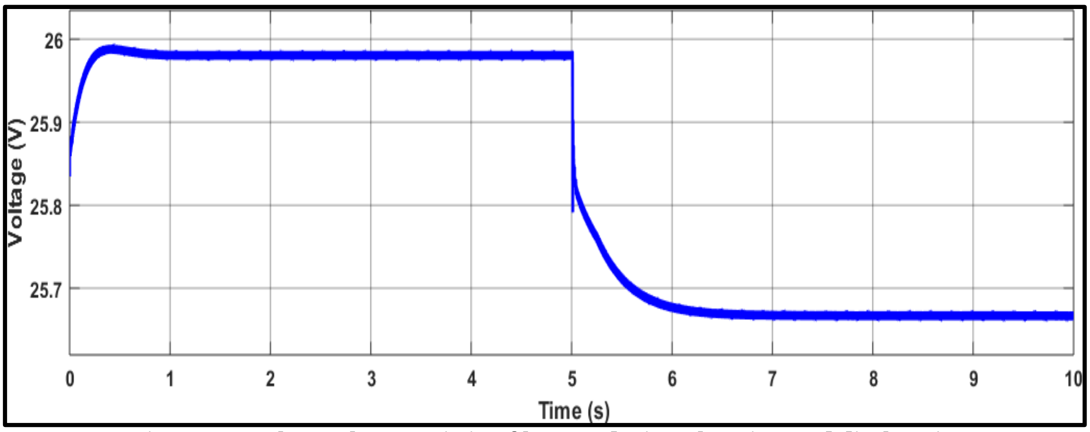

Figure. 9: Voltage characteristic of battery during charging and discharging

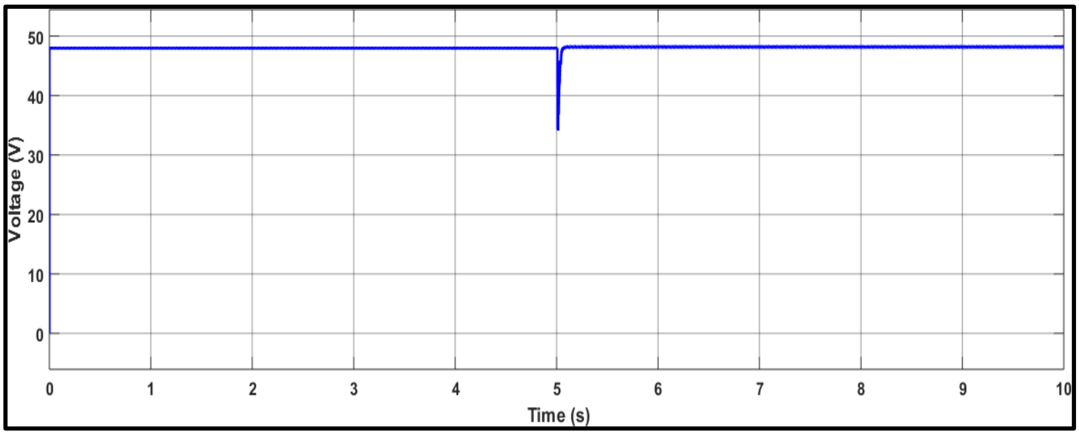

Figure. 10: Load voltage Characteristic during charging and discharging

4. Conclusion:

The bidirectional converter's design analysis is presented, and the simulated bidirectional converter may share power with both the supply and the battery. The suggested method can be employed in various applications, including power supply reliability, renewable energy grid integration, and dc motor drives.

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