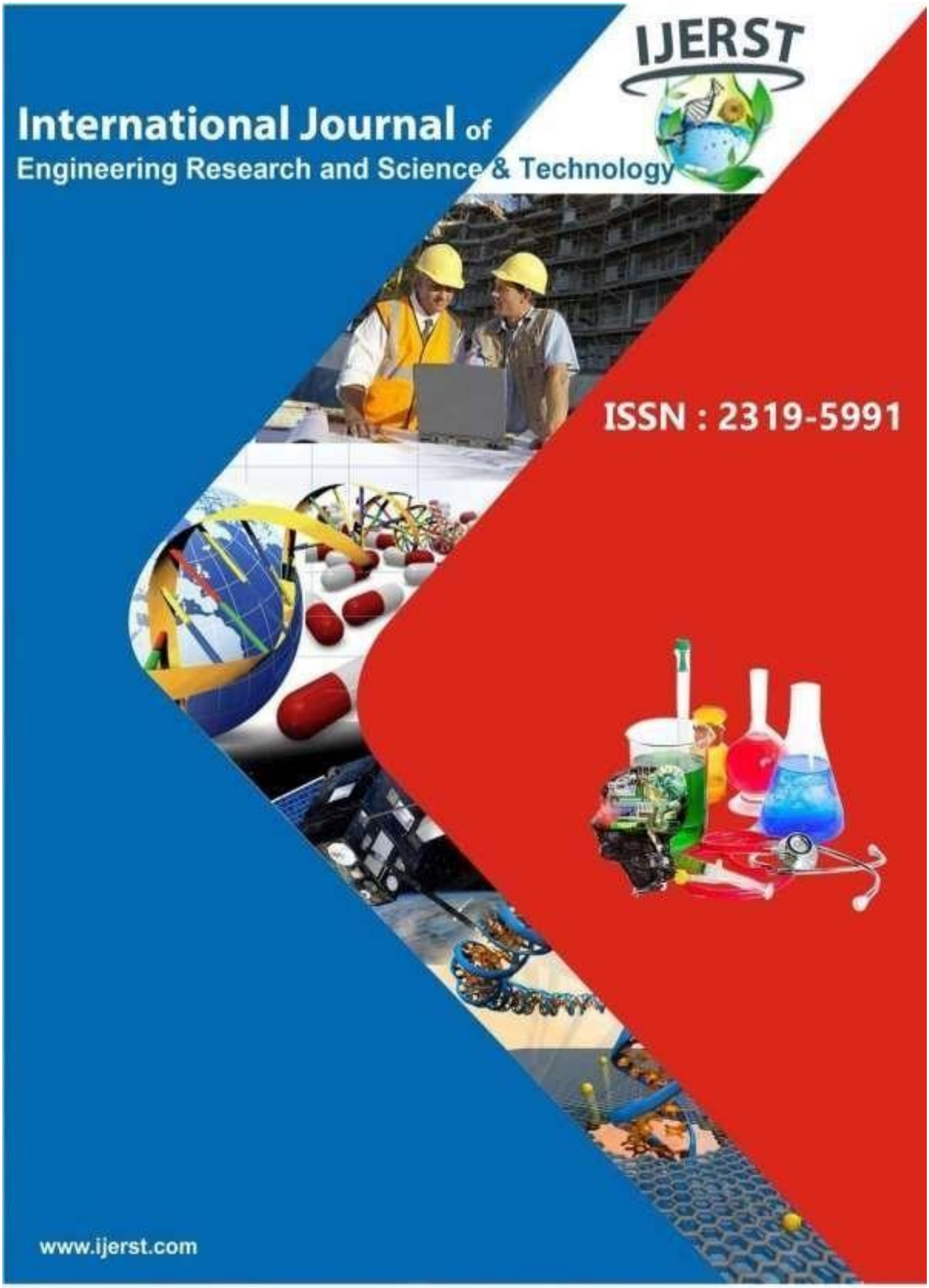

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INTEGRATING BIDIRECTIONAL POWER FLOW CONTROL WITH PULSE AND SINE-WAVE-RIPPLE-CURRENT CHARGING STRATEGIES FOR THREE-PHASE GRID-TIED CONVERTERS

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ABSTRACT

In this project we propose bidirectional charging/discharging trategies for three-phase grid-tied converters. The bidirectional power flow control feature of the converter is able to realize both charging and discharging capability. Besides, in order to achieve high charging efficiency as well as extend the life of the battery, five charging strategies are adopted and developed: 1) the constant current (CC)charging, 2) the pulse-ripple-current (PRC) charging, 3) the sinusoidal ripple-current (SRC) charging, 4) the bidirectional pulse-ripple-current(BPRC) charging and 5) the bidirectional sinusoidal- ripple-current(BSRC) charging. The direct quadrature (d-q) transformation is utilized for the converter to realize different charging methods. These method scan be achieved by using MATLAB/SIMULINK software. In addition, the charging power differences between each strategy are considered and analysed in this project

INDEX TERMS: Three-phase grid-tied converter, bidirectional chargers, energy storage system.

1.INTRODUCTION

Over the past few decades, novel energy technologies such as renewable energy generation systems, electric vehicles and advanced consumer electronics have been rapidly developed to deal with the fossil fuel usage and carbon dioxide emission issues . Besides, the battery module usually exists in these applications for energy storage . In order to transfer the electric energy between the battery and the grid, a grid-tied DC-AC converter is necessary while the three phase H-bridge circuit is one of the most commonly used topologies forhigh power applications. In addition, the bidirectional power flow control of the converter is also an essential function to realize both charging and dischargingability for the battery. The droop-based charging/discharging is alsoanimportant mode whereas it was discussed in [16].

Moreover, the bidirectionalcharger has become an essential component for the electric vehicle(EV)applications . In order to increase the charging performance as well as extend the batterylife, various kinds of charging techniques have been presented [21], [22]. Typically, the constant current constant-voltage (CC-CV) charging is one of the most commonly adopted charging methods. As soon as the battery voltage is lower than its predefined value, the CC charging will be selected. On the contrary, the CV charging will be chosen as soon as the battery voltage is higher than the predefined value. Although the CC-CV charging can realize the fast charging, the over-heat phenomenon caused by the continuous charging current mightdamage electrode plates as well as shorten the life of the battery. In view of this, the pulse ripple-current charging (PRC) and the sinusoidal ripple current charging (SRC)

technologies were developed . 8Because of the zero charging current period feature of the PRC and SRC, electron ions in the battery is able to be homogeneous distributed. In other words, the charging stability and the battery life can be increased. Moreover, amodified PRC charging, the Reflex TM concept, was developed . In comparison with the conventional PRC charging, the negative charging period will beincluded in the Reflex TM method. According to , the negative chargingperiodis able to not only stable the chemical reaction of the battery but enhance the uniform distribution of electrolyte concentration. Besides, the Reflex TM charging was utilized for the sealed lead-acid batteries of electric vehicle. The similar bidirectional charging concept can also be adopted for the SRC charging . Some literatures focused on the control and analysis of the PRCandSRC charging techniques . First, the SRC charging strategy and optimal charging frequency study for Li-ion batteries were proposed in . The battery impedance analysis considering DC component in SRC charging was presented in . Referring to, a two stage Z-source resonant wireless charger with line frequency sinusoidal charging was proposed. Besides, presented an online tracking algorithm to allocate and track the optimal charging frequency for common batteries in real time under any condition. In addition, challenges of the SRC charging of Li-ion batteries were proposed in.

Although these proposed methods are effective, the bidirectional power flow control combining the PRC and SRC methods integrated with the three-phase converter are not considered and exposed. In [33], a three-Phase battery charger with the CC and the PRC charging was proposed. However, the SRC charging feature was not considered whereas the bidirectional charging/discharging capability was not developed.

Therefore, the aim of this paper is to propose bidirectional charging/discharging strategies for three-phase grid-tied converters. 9Main innovations can be summarized as: 1) develop a three-phase AC-DCconverter with bidirectional power flow control, 2) integrate charging/discharging strategies with the proposed charger, 3) reveal detailed control concepts and operational principles with mathematical derivations and4)propose the charging power analysis of different charging strategies. It is worth mentioning that these methods can be realized by the digital signal processor(DSP) without adding extra circuit components. Finally, a 5kWprototypecircuit with both simulation and experimental results demonstrate the performance and feasibility of the proposed charging strategies.

2.INVERTERS

2.1 DC- AC CONVERTER (INVERTER)

An inverter is an electrical device that converts direct current (DC) toal ternating current (AC); the converted AC can be at any required voltage and frequency with the use of appropriate transformers, switching, and control circuits. Solid-state inverters have no moving parts and are used in a wide range of applications, from small switching power supplies in computers, tolarge electric utility high-voltage direct current applications that transport bulk power. Inverters are commonly used to supply AC power from DC sources such as solar panels or batteries.

2.2 CIRCUIT DESCRIPTION

2.2.1 BASIC DESIGNS

In one simple inverter circuit, DC power is connected to a transformer through the centre tap of the primary winding. A switch is rapidly switched back and forth to allow current to flow back to the DC source following two alternate paths through one end of the primary winding and then the other. The alternation of the direction of current in the primary winding of the transformer produces alternating current (AC) in the secondary circuit.

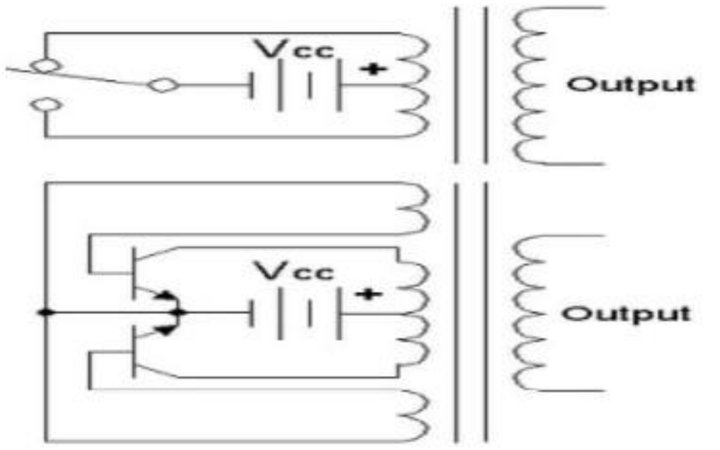

Fig :2.1 Simple inverter circuit shown with an electro-mechanical switch and automatic equivalent

3.BATTERY

3.1 Energy Storage

Power is a more adaptable use than different types of energy, as an exceptionally organized type of energy can effectively change over into different kinds. For instance, it can change over its mechanical structure with around 100 percent yield or hotness with 100 percent yield. Nonetheless, it can't change over nuclear power into energy with high proficiency since it is an arbitrary type of power in iot as. Along these lines, the general warm to the electrical transformation proficiency of an average fossil nuclear energy station is substantially less than half

3.2 Battery

Basic battery, which converts chemical power into electricity. The batterystores energy in electrochemical form and is the most widely used tool for storing energy in branching packs. The main types of electrochemical batteries are:

3.3 Types of Battery

There are at least six major rechargeable electro-chemistries available today.

They areas follows:

- Lead-acid (Pb-acid)
- Nickel-cadmium (NiCd)
- Nickel-metal hydride (NiMH)
- Lithium-ion (Li-ion)
- Lithium-polymer (Li-poly)
- Zinc-air

4 PROPOSED CIRCUIT CONFIGURATIONS AND BASICCHARGINGCONCEPTS

The circuit diagram and control blocks of the proposed three phase grid-tied converter are shown in Fig. 1. The dc side of the converter is connected to the battery module while the ac side is connected to the grid. In order to simplify the control of the three-phase converter as well as to achieve different charging strategies, the direct -quadrature (d-q) transformation is a commonly adopted method to control the three-phase converter . Besides, a voltage modulated direct power control was proposed in . It does not need phase locking and exhibits similar control performance with voltage oriented (d-q) control methods. Therefore, in this paper, the d-q control concept is utilized to achieve the bidirectional power charging strategies.

First, the three-phase voltages and currents should be transferred as directed axis voltage and current components, Vd and Id , and the quadrature axis voltage and current, Vq and Iq viathed- q transformation block. Therefore, the complex power of the three-phase converter,

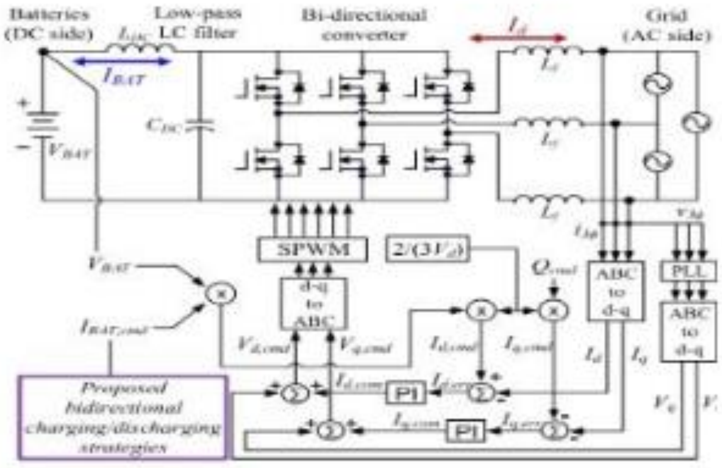

Fig.4.1. The circuit diagram and control blocks.

S, can be expressed as:

$$S = {}^{3}\!/_{2}\left[\left(V_d I_d + V_q I_q\right) + j\left(V_q I_d - V_d I_q\right)\right].$$

4.1 PROPOSED BIDIRECTIONAL CHARGING/DISCHARGINGSTRATEGIES

In order to further enhance the charging performance as well as extend the life of the battery, the bidirectional charging/discharging strategies are proposed. Both of the PRC and SRC cases are considered and realized via the three phase grid-tied converter. In addition, analysis of the charging power differences between each charging method will also be presented in this section.

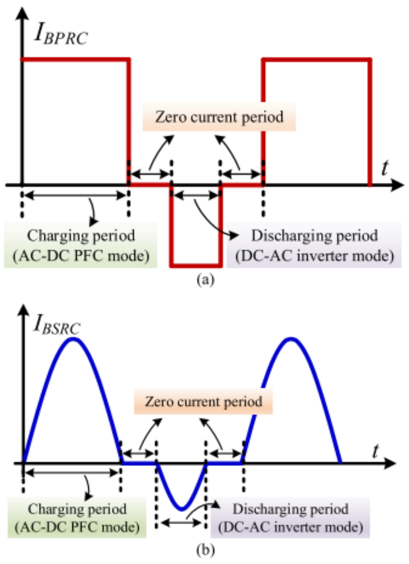

FIGURE 3. The proposed bidirectional charging/discharging strategies (a) The BPRC charging (b) The BSRC charging.

On the other hand, the conceptual diagram of the bidirectional SRC (BSRC) charging is shown in Fig. 3(b). Similar with the BPRC, there are also three charging states, including the charging, zero current and discharging period of the BSRC. It is worth mentioning that the control of both BPRC

and BSRC can be realized by the DSP. Besides, the maximum charging/discharging current and the charging/discharging period can be determined by the engineers.

B. THE CHARGING POWER ANALYSIS

The proposed PRC, SRC, BPRC and BSRC charging strategies controlled via the bidirectional three-phase converter is able to homogeneous distribute the electron ions as well as extend the life of the battery. However, the charging power might be decreased because of nonlinear charging current characteristics. Therefore, the charging power difference between each charging strategy should be considered and analyzed.

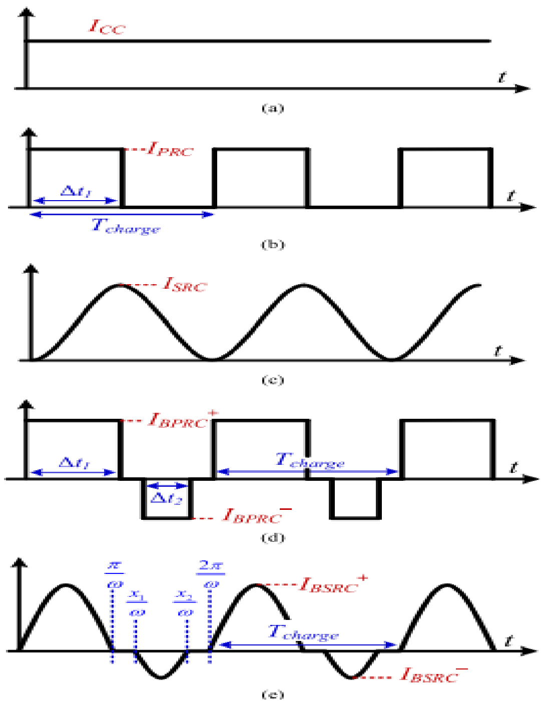

FIGURE 4. Conceptual diagrams of the charging current with different strategies (a) The CC charging (b) The PRC charging (c) The SRC charging (d) The BPRC charging (e) The BSRC charging.

Fig. 4 shows the conceptual diagram of the charging current with different strategies. First, Fig. 4(a) shows the current waveform with the CC charging while the PRC charging waveform is shown in Fig. 4(b). The charging power of the PRC charging, PPRC, can be expressed as:

$$P_{PRC} = V_{BAT} \times I_{PRC,avg} = V_{BAT} \times \left(\frac{I_{PRC} \times \Delta t}{T_{ch\arg e}}\right),$$

while IPRC,avg is the average current of the PRC charging. IPRC represents the peak charging current. 1t is the positive charging period whereas Tcharge represents the total charging period. Therefore, the charging power difference between the CC and the PRC charging, 1PCC−PRC, can be written as:

$$\begin{aligned}\Delta P_{CC-PRC} &= P_{CC} - P_{PRC}\\ &= V_{BAT}\left[I_{CC} - \left(\frac{I_{PRC} \times \Delta t}{T_{ch\arg e}}\right)\right],\end{aligned}$$

while PCC and ICC represent the power and current with the CC charging, respectively. If IPRC is equal to ICC, 1PCC−PRC can be modified as:

$$\Delta P_{CC-PRC} = V_{BAT} \times I_{CC} \times \left(\frac{T_{ch\arg e} - \Delta t}{T_{ch\arg e}}\right).$$

According to Fig. 4(c), the charging power with the SRC charging method, PSRC, can be defined as:

PSRC = VBAT × ISRC,avg = VBAT × 1 2 ISRC

while ISRC is the maximum SRC charging current. ISRC,avg represents the average SRC charging current, which is equal to 50% of ISRC. Besides, the charging power difference between the CC and the SRC charging, 1PCC−SRC, can be written as:

$$\Delta P_{CC-SRC} = P_{CC} - P_{SRC} = V_{BAT}\left[I_{CC} - \frac{1}{2}I_{SRC}\right].$$

If I_{SRC} is set as I_{CC}, ΔP_{CC-SRC} can be calculated as:

$$\Delta P_{CC-SRC} = \frac{1}{2} \times V_{BAT} \times I_{CC} = \frac{1}{2}P_{CC}.$$

Fig. 4(d) shows the scenario of the BPRC charging strategy whereas the BPRC charging power, PBPRC, can be expressed

$$P_{BPRC} = V_{BAT} \times I_{BPRC,avg} = V_{BAT} \times \left(\frac{I_{BPRC}^+\Delta t_1 - I_{BPRC}^-\Delta t_2}{T_{ch\arg e}}\right),$$

while IBPRC,avg is the average BPRC charging current. I + BPRC and I − BPRC are the peak positive charging current and peak negative charging current, respectively. 1t1 and 1t2 represent the positive charging period and negative charging period, respectively. The charging power difference between the CC and the BPRC charging, 1PCC−BPRC, can be calculated as: 1PCC−BPRC = PCC – PBPRC

$$= V_{BAT}\left[I_{CC} - \left(\frac{I_{BPRC}^+\Delta t_1 - I_{BPRC}^-\Delta t_2}{T_{ch\arg e}}\right)\right]$$

If I + BPRC and I − BPRC are equal to ICC, 1PCC−BPRC can be determined as:

$$\Delta P_{CC-BPRC} = V_{BAT} \times I_{CC} \times \left(\frac{T_{ch\arg e} - \Delta t_1 + \Delta t_2}{T_{ch\arg e}}\right)$$

Finally, the BSRC charging scenario is shown in Fig. 4(e). The BSRC charging power, PBSRC, can be written as:

PBSRC = VBAT × IBSRC,avg.

while IBSRC,avg is the average BSRC charging current, which can be defined as:

$$I_{BSRC,avg} = \frac{\int_0^{\pi/\omega} I_{BSRC}^+ \sin\omega t dt - \int_{x_1/\omega}^{x_2/\omega} I_{BSRC}^- \sin\omega t dt}{T_{ch\arg e}/2}.$$

The definition of 1PCC−PRC, 1PCC−SRC, 1PCC−BPRC and 1PCC−BSRC are given in this section. From the analysis, it can be confirmed that the average charging power of the PRC, SRC, BPRC, BSRC charging will be lower than the CC charging. In other words, compare to the CC charging, the charging period with the four different charging strategies will be longer. Moreover, because of the zero and negative charging period, the required charging time of the BPRC and BSRC charging will be greater than the required charging time of the PRC and SRC charging, respectively. Therefore, longer charging time will be the main disadvantages of the PRC, SRC, BPRC, BSRC charging methods. However, according to [25], the negative charging period is able to stable the chemical reaction of the battery as well as to enhance the uniform distribution of electrolyte concentration. In other words, main advantages of the PRC, SRC, BPRC, BSRC charging are to decrease the battery rising temperature and to increase the battery life.

5.SIMULATION RESULTS & DISSCUSIONS

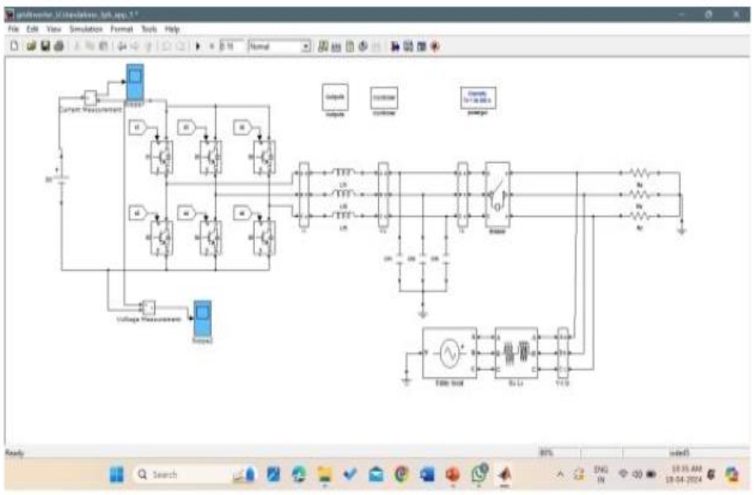

FIG 5.1 SIMULINK MODEL

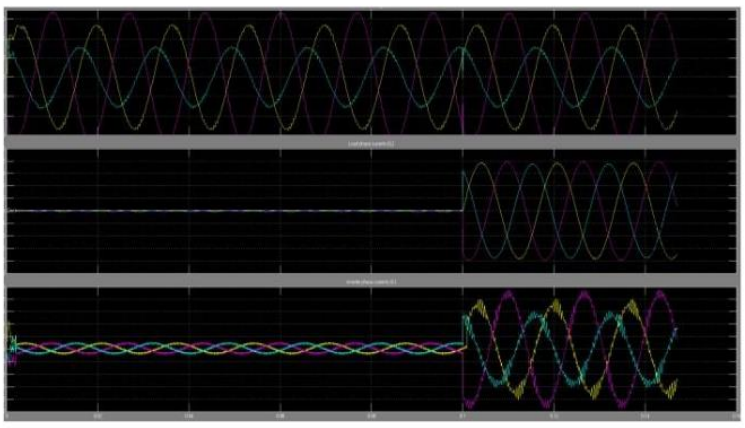

FIG 5.2 OUTPUT WAVE FORMS

The proposed charging strategies are first verified via the Matlab/Simulink. Figures shows the main circuit and control block 49diagrams with the proposed bidirectional charging strategies and the output wave forms of the bidirectional power flow. The bidirectional power flow control should be considered and realized by the converter in these two scenarios. During the charging period, the converter is operated in AC-DC(PFC) mode to extract power from the grid to the battery. On the contrary, the converter willbe operated in DC-AC (inverter) mode during the discharging period. We have many future scopes by this bidirectional power flow control integrated with pulse and sinusoidal-ripple-current charging stratergies for three phase grid-tied converters. Therefore the results were observed via Simulink model in the matlab/ Simulink and output wave forms are observed in the scope. finally the required output is obtained.

6.CONCLUSION

This Project proposes a bidirectional three-phase grid-tied converter with charging/discharging strategies. The converter is able to be operated in the AC-DC (PFC) mode and the DC-AC (inverter) mode to realize the bidirectional power flow control feature. In order to increase the charging efficiency as well as extend the battery life, five charging strategies are considered and developed. Main contributions of this paper can be concluded as: 1) a three-phase AC-DC converter with bidirectional power flow control is developed, 2) five charging/discharging strategies are integrated with the proposed charger, 3)detailed control concepts and operational principles are revealed with mathematical derivations and 4) the charging power analysis of different charging strategies is presented. These charging methods can be achieved by the proposed bidirectional converter with the d-q transformation concept. Moreover, comprehensive analysis and mathematical derivations of the charging power differences between each strategy are presented. Finally, both simulation and experimental results obtained from a 5-kWprototype demonstrate the performance and feasibility of the proposed bidirectional charger.

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