

Implementation of High Voltage Gain RS Cell- Based DC-DC Converter for Offshore Wind

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Abstract : This paper proposed a new high-voltage gain resonant switched-capacitor dc-dc converter for high-power offshore wind energy systems. The proposed new dc-dc converter is characterized by the resonant switching transitions to achieve minimal switching losses and maximum system efficiency. Here, the converter operates at fifteen times as high as the input voltage with a small device count. Finally, the performance of the proposed converter is evaluated with the simulation as well as experimental results of a prototype system.

Keywords : High voltage gain, offshore wind energy, resonant switched-capacitor (RSC) converter, resonant switching transitions.

1. INTRODUCTION

Offshore wind farms are growing rapidly because of their comparatively more stable wind conditions than on-shore and land-based wind farms [1], [2]. Offshore 5–10-MW marine turbines are becoming more attractive for the wind power industry [3], [4]. In particular, they increase the efficiency and reduce generation cost, compared to previous wind turbine technologies[5].It will increase sizes of the component. Therefore, bulky and huge electrical components have high investment costs because of the most difficult erection and the equipment transportation from the shore to the installation sites [6]. An optimal power conversion system should feature high-power density, high efficiency, high reliability, and low costs for high-power offshore wind energy applications. In this regard, high -voltage dc (HVDC) transmission promises a very flexible and efficient technology for offshore wind farms that requires power conversion systems to step-up and control the wind turbine output. A conventional HVDC system uses an AC line frequency (50/60 Hz) transformer to boost the voltage and AC-DC converters for rectification and power flow control [7]–[9]. This technology is robust and reliable, but it causes a considerable increase in weight and volume, which leads to higher installation cost. A high-power density can be obtained by replacing the bulky 50/60-Hz transformers with high-frequency transformers [10]–[12]. But, high-frequency transformers with large turn ratios are difficult to design at high voltages and mega power levels because of the enormous expense of the magnetic material, core, and dielectric losses. To overcome the increasing power losses and maintain a high-power density, it is expected that large marine turbines will require a higher voltage with high-voltage gain dc-dc conversion systems to interface with the power transmission networks. Single-module dc-dc boost converters can theoretically achieve infinite voltage conversion ratios but practically, the maximum gain is limited by circuit imperfections, such as parasitic elements and switch commutation times [13], [14]. Multiple-module boost converters have been proposed to achieve high conversion ratios for applications to offshore wind farms [15]. Recently, the common

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types of switched-capacitor (SC) converters are considered as an attractive solution for meeting the requirements, such as high-power density and control simplicity. In [16] a resonant SC (RSC) converter was investigated, where an extra inductor was added to form a sinusoidal manner with the capacitors to perform a soft switching. In [17] a multilevel RSC topology was proposed with significant benefits, including a modular structure, low-voltage stress of the switches, and reduced switching loss. On the other hand, a large number of capacitors, high passive component losses, and inevitably large physical size of the converters have limited the use of these topologies in high-voltage gain offshore wind energy systems. A 55kW (the output voltage is three times the input voltage) flying-capacitor dc/dc converter was introduced for hybrid electric vehicles [18]. The major drawbacks are the nonmodular structure, complicated switching scheme, and low-voltage gain. An RSC voltage Tripler an interleaving capability and high efficiency and Nevertheless, it still has several problems including the passive component counts when a high-voltage gain is required for high-power applications due to the low-voltage conversion ratio of the circuit. To solve the problems listed previously, this paper presents a new high-gain RSC dc/dc converter for offshore wind energy systems. The proposed converter combines the output of two modular cells to reduce the device count, output capacitance requirements, and total capacitor power rating. The principle of a soft-switching operation and output voltage analysis of the proposed converter are described in detail. The output capacitors are charged and discharged continuously by an 180° phase shift with respect to each other to eliminate the output voltage ripples without adding extra components. In this paper, the series modular and cascade RSC configurations are introduced to increase the reliability and reduce the control complexity. These configurations are verified by a simulation and their efficiency, volume, weight, and device count are compared with a counterpart to highlight its advantages for high -voltage and high-power offshore winds applications carried out to evaluate the feasibility of the proposed converter.

2. TOPOLOGY

A. Proposed RSC configuration

Fig. 1 shows the general block diagram of three-phase generated AC voltage and an AC-DC converter in the front-end of the proposed RSC converter. A large capacitor is assumed to be used for energy storage at the output of the ac-dc converter. The RSC converter consists of three modular cells which use a new arrangement of the solid-state switches, diodes, capacitors, and inductors.

B. Principle of the Proposed RSC Converter Operation

Fig. 2 presents a fifteen level RSC converter with three stages. The RSC converter is composed of six resonant capacitors (C_{r1} , C_{r2} , C_{r3} , C_{rb1} , C_{rb2} and C_{rb3}), two output filter capacitors (C_{to} and C_{bo}), four resonant inductors (L_{r1} , L_{r2} , L_{r3} , L_{rb1} , L_{rb2} and L_{rb3}), two output resonant inductors (L_{to} and L_{bo}), six diodes (D_{t1} , D_{t2} , D_{t3} , D_{to} , D_{b1} , D_{b2} , D_{b3} and D_{bo}), and four switches (S_{t1} , S_{t2} , S_{b1} , and S_{b2}). In this paper, subscripts “ t ” and “ b ” represent the corresponding variables to the circuit components at the top and bottom cells, respectively. The switches (S_{t1} , S_{t2}) and (S_{b1} , S_{b2}) are controlled complementarily with a 50% duty cycle to minimize the conduction losses in the power devices and passive components. Here, the following assumptions are made to simplify the analysis:

1. All the switches, diodes, capacitors, and inductors are ideal.
2. The switching frequency is less than the resonant frequency to achieve a zero-current switching (ZCS).
3. V_s is an ideal dc voltage source and the load is modeled by a pure resistor (R_{load}).

Mode 1: In this first mode S_{t1} , S_{t2} and S_{t3} are on and S_{b1} , S_{b2} , S_{b3} and S_{b3} are maintaining off condition. In this case D_{t1} , D_{t2} and D_{t3} are forward bias condition and D_{rb1} , D_{rb2} , D_{rb3} are reverse bias condition so that there is no current flow through the lower bottom of the circuit. The upper side inductance and capacitance are started to charging and another lower part switches start to discharging the energy to the load.

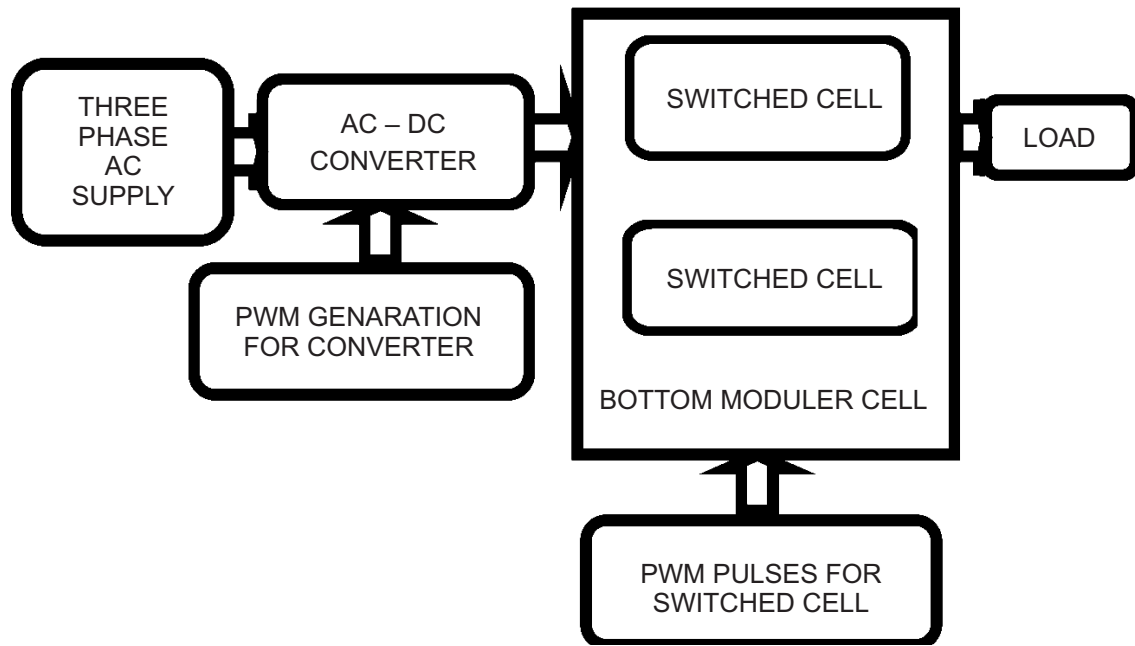


Figure 1: Block diagram of the proposed RSC converter

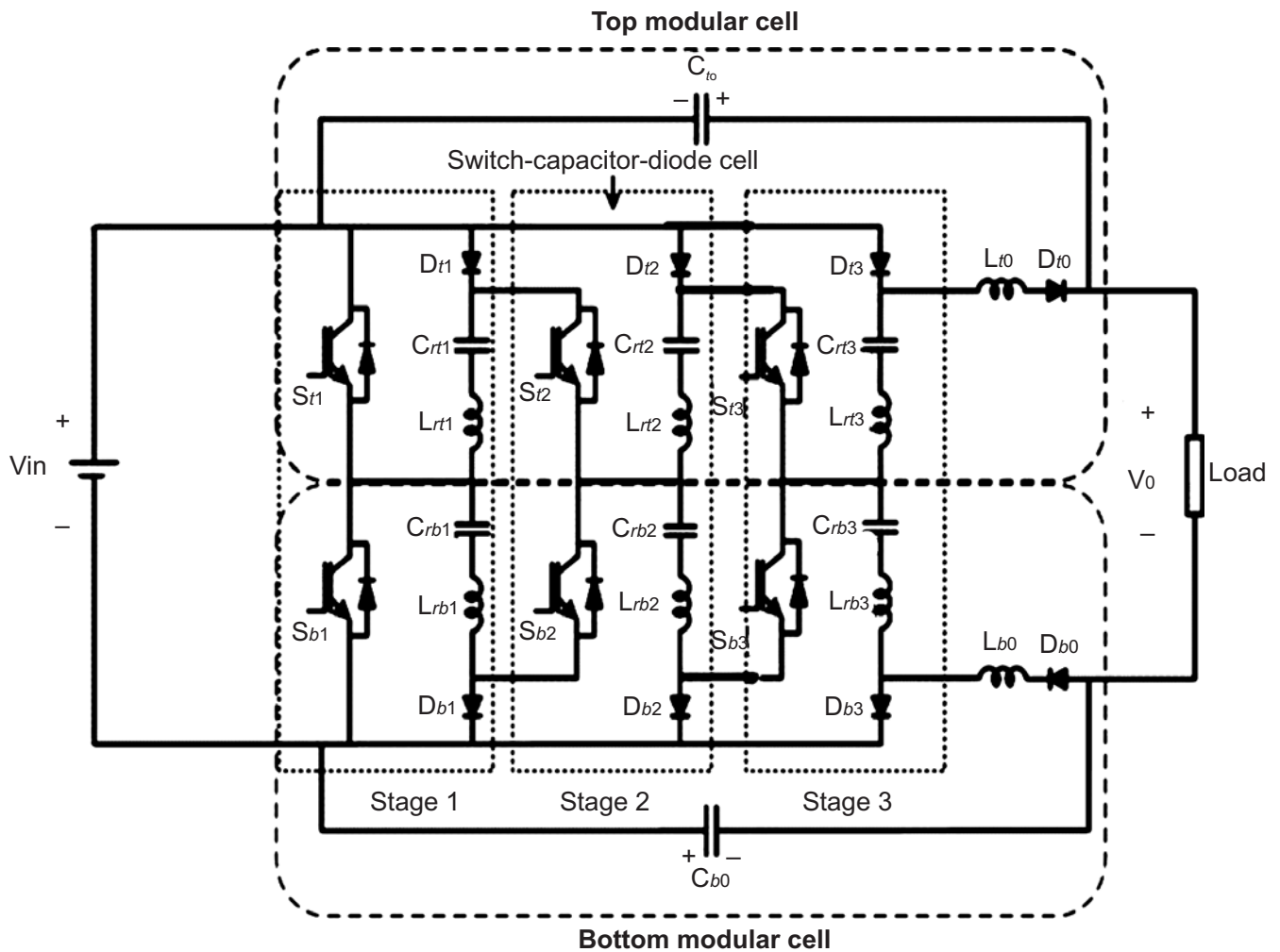
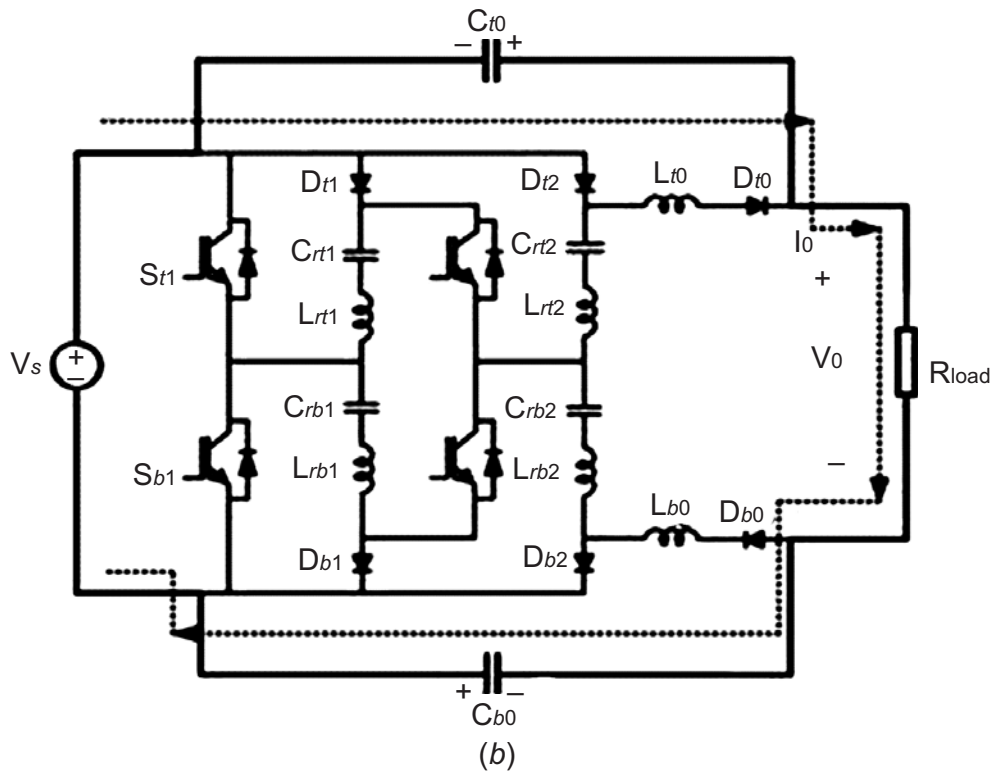
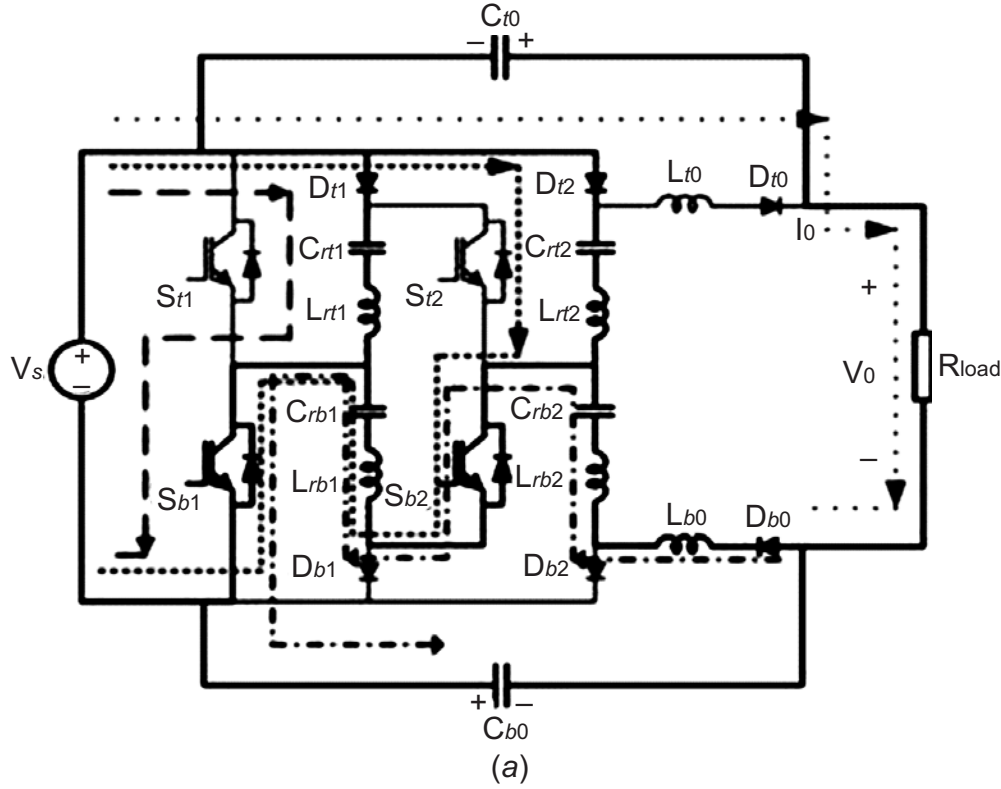


Figure 2: Topology of the proposed RSC converter

Mode 2: In this mode, the upper switch S_{b3} is on in this case D_{b3} is forward biased. The other switches kept off condition so its start to discharge the energy to the load to maintain the voltage as constant.

Mode 3: In this mode, the bottom switches S_{b1} , S_{b2} , S_{b3} are conducts and s_{t1} , s_{t2} , s_{t3} are not conducted. In this case C_{rt1} , C_{rt2} , C_{rt3} , C_{rb1} , C_{rb2} and C_{rb3} , L_{rb1} , L_{rb2} and L_{rb3} are charging .The bottom inductance and capacitance get start to discharging.

Mode 4: In this mode S_{t1} , S_{t2} and S_{b3} are conducts and s_{b1} , s_{b2} and s_{t3} are not conducts. The D_{t1} , D_{t2} , D_{t3} are forward biased and D_{b1} , D_{b2} , D_{b3} are reverse biased. The capacitance C_{rt1} , C_{rt2} and C_{rb3} are charging and another capacitance is discharging the energy to maintain the output voltage as constant.



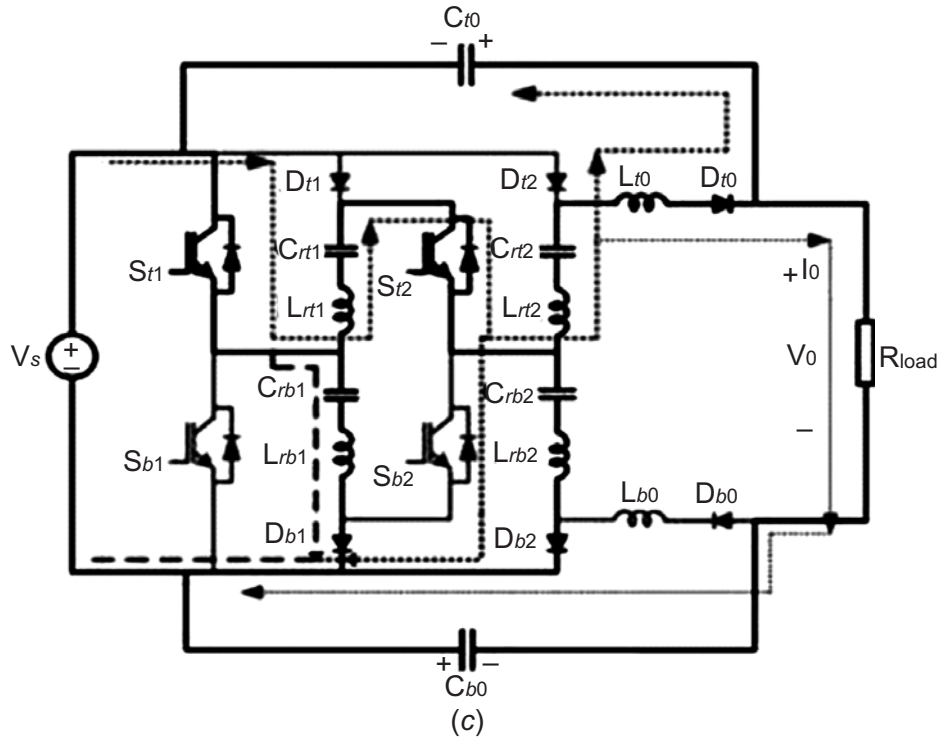


Figure 3: Operating modes of the -level RSC converter. (a) Mode I (b) Mode II and (c) Mode III

Mode 6: In the final mode bottom switches are turn on and upper switches are maintaining off condition. In this case C_{rb1} , L_{rb1} , C_{rb2} , L_{rb2} , C_{rb3} , L_{rb3} are charging and the upper capacitance and inductance are discharging the energy to maintain the output voltage as constant. All the above modes of operation diagrams are shown in fig3. Through the fig3. we will know basic operation of the proposed RSC cell based converter operations and also derived expression for output voltage and current etc., Applying the charge balance principle to C_{t0} leads to

$$-\int_{t_0}^{t_2} \frac{P_0}{V_0} dt = -\int_{t_2}^{t_3} \left(i_{L_{t0}}(t) \frac{P_0}{V_0} \right) dt + -\int_{t_3}^{t_4} \frac{P_0}{V_0} dt \quad (1)$$

Where P_0 and V_0 are the output power and output voltage respectively. By ignoring the impact of the short times $t_1 \leq t \leq t_2$ and $t_3 \leq t \leq t_4$. Therefore, equation 1 can be rewritten as

$$i_{L_{t0}}(t) = \frac{-\pi P_0}{V_0} \sin(\omega_r t) \quad (2)$$

By applying the principle of charge balance to C_{rt2}

$$\int_0^{T_s/2} (i_{C_{rt2}}(t) dt) = \int_{T_s/2}^{T_s} i_{L_{t0}}(t) dt \quad (3)$$

Therefore, the resonant capacitor and inductor currents and the output filter capacitor currents of C_{t0} and C_{b0} are

$$i_{C_{rt2}}(t) = i_{L_{rt2}}(t) = \frac{\pi P_0}{V_0} \sin(\omega_r t) \quad (4)$$

$$i_{C_{rt1}}(t) = i_{L_{rt1}}(t) = \frac{2\pi P_0}{V_0} \sin(\omega_r t) \quad (5)$$

$$i_{C_{rt0}}(t) = \begin{cases} -\frac{P_0}{V_0} & 0 \leq t \leq T_s/2 \\ \frac{-\pi P_0}{V_0} & T_s/2 \leq t \leq T_s \end{cases} \quad (6)$$

$$i_{Cr_{b0}}(t) = \begin{cases} \frac{-\pi P_0}{V_0} \sin(\omega_r t) - P_0 & 0 \leq t \leq T_s/2 \\ \frac{-P_0}{V_0} & T_s \leq t \leq T_s \end{cases} \quad (7)$$

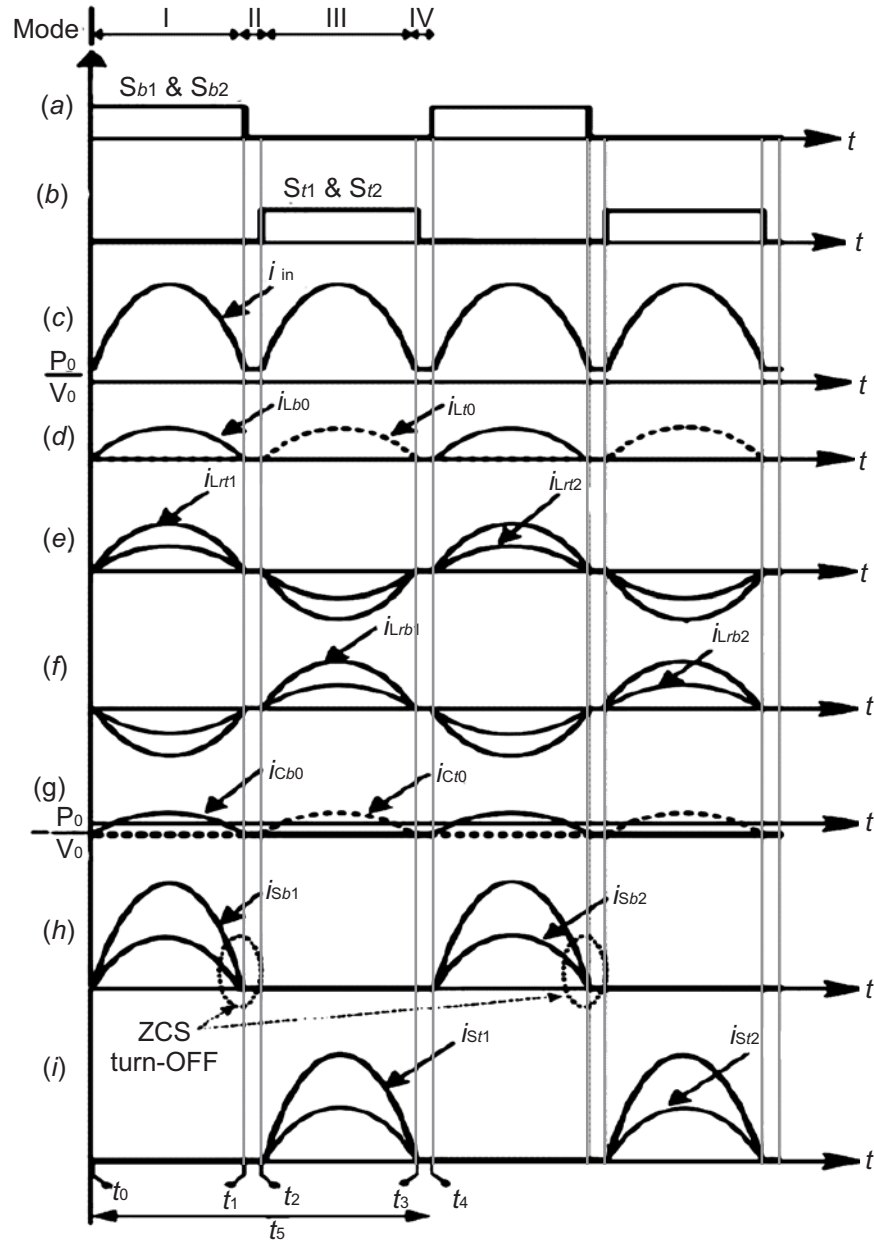


Figure 4: Key waveforms of the fifteen level RSC converter at the steady state. (a) and (b) witching patterns (c) Input current (d) output inductor currents. (e) and (f) resonant inductor currents. (g) output capacitor currents. (h) and (j) switch currents.

3. TECHNIQUES USED

(i) Series-Modular Configurations

The series-modular configurations are designed with the specifications such as input voltage, output voltage, and input power, used in simulation. Therefore, three modular cells A, B and C are designed for equal voltage gains. The voltage and current stresses of the components can be obtained.

(ii) Cascade Configurations

For the cascade configurations, three stages of the proposed RCS converter must provide a voltage gain. The voltage and current ratings of the components of the proposed converter. For the cascade ZCS-RSC configuration, seven stages are required to achieve a voltage gain of 15. Each stage consists of two resonant

inductors, two resonant capacitors, two output filter capacitors, and four diodes .For all the configurations, each switch or diode is comprised of several series and parallel-connected devices to withstand the rated current and voltage. The switching frequency, inductances, and resonant capacitor values are the same as those in the simulation for both RSC and ZCS–RSC converters. The output filter capacitors are considered larger than the resonant capacitors in the ZCS–RSC configurations .The suitable high-power capacitors and inductors with their weights and sizes are selected from AVX, GS-ESI, and REO. These converters are compared based on the following features : (i) total number of devices; (ii) passive component weights and volumes and (iii) losses.

4. SIMULATION RESULTS

Developing resonant switched capacitor cell based dc-dc converter for 15-level with series modular configuration technique is simulated in MATLAB Simulink for performance analysis. The proposed converter simulation circuit and output waveform are shown in fig, 5, 6, 7 and fig. 8.

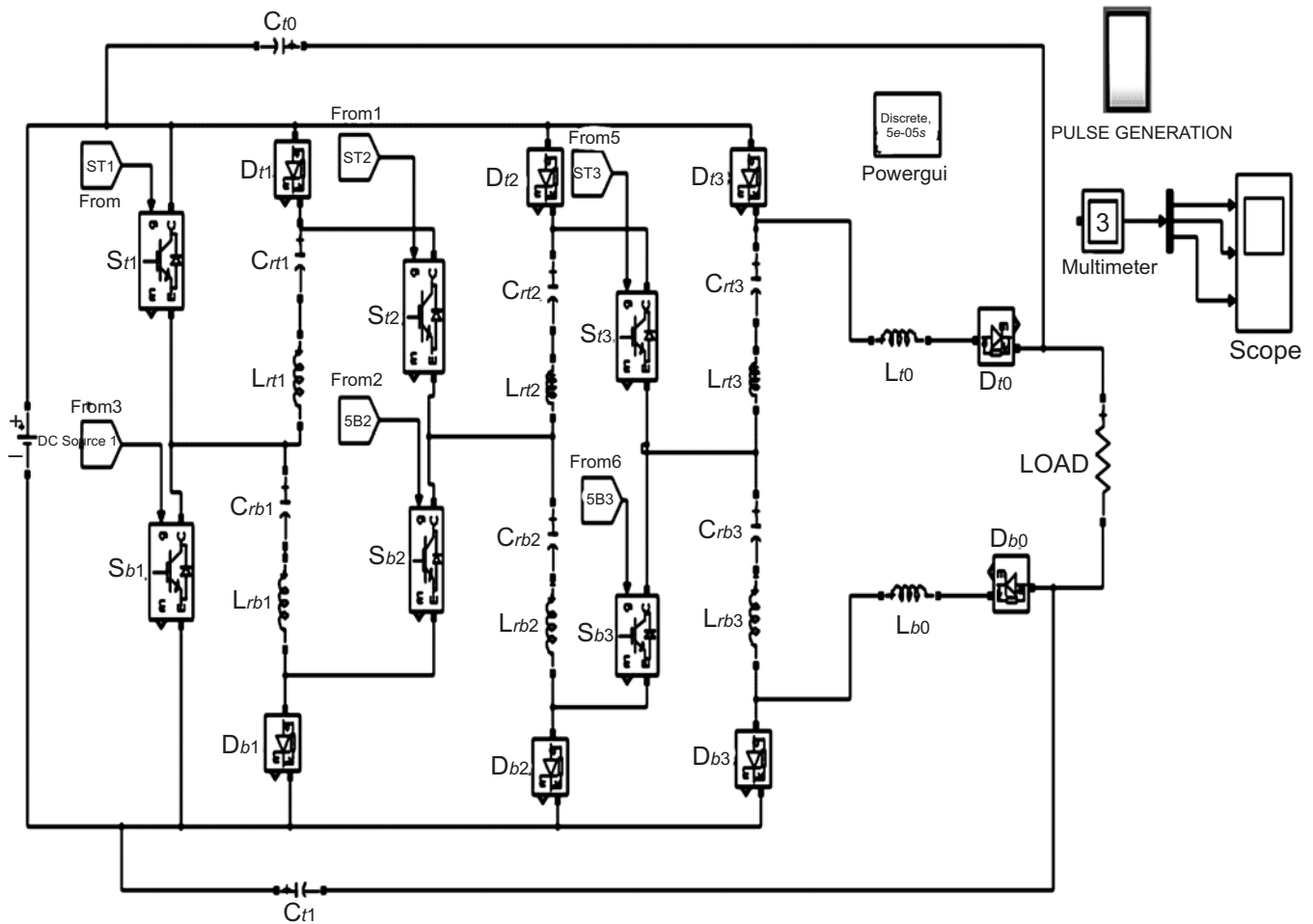


Figure 5: Proposed System Simulation Circuit

5. CONCLUSION

In this project, RSC cell-based dc-dc converter with a high voltage gain is proposed for offshore wind energy applications. The soft-switching action is provided by the resonant condition of the circuit. Therefore, the switching losses are minimal in both ON and OFF instants, and the power density of the system can be enhanced by increasing the switching frequency. Output filter capacitor voltages are phase shifted by 180° with respect to each other to eliminate the output voltage ripples without adding extra components. The proposed series-modular and cascade RSC configurations have the inherent advantage of being readily applicable to multistage power switching converters. Conceptual comparisons of the

proposed converter to a counterpart show that the proposed converter is well suited for high-voltage and high-power offshore wind applications requiring a high-power density and high efficiency. Finally, the operation and performance of the proposed converter are verified with experiments on a 15-level converter prototype.

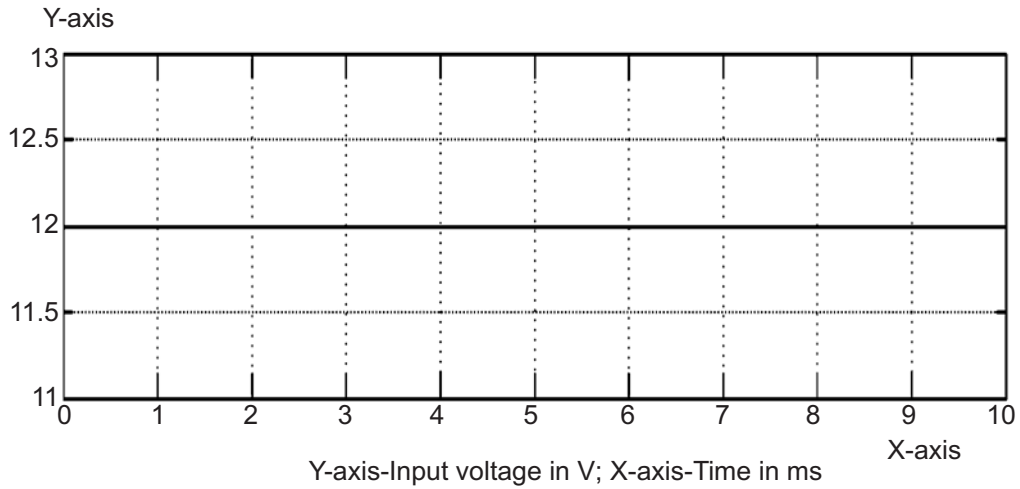


Figure 6: Proposed System Input Voltage Waveform

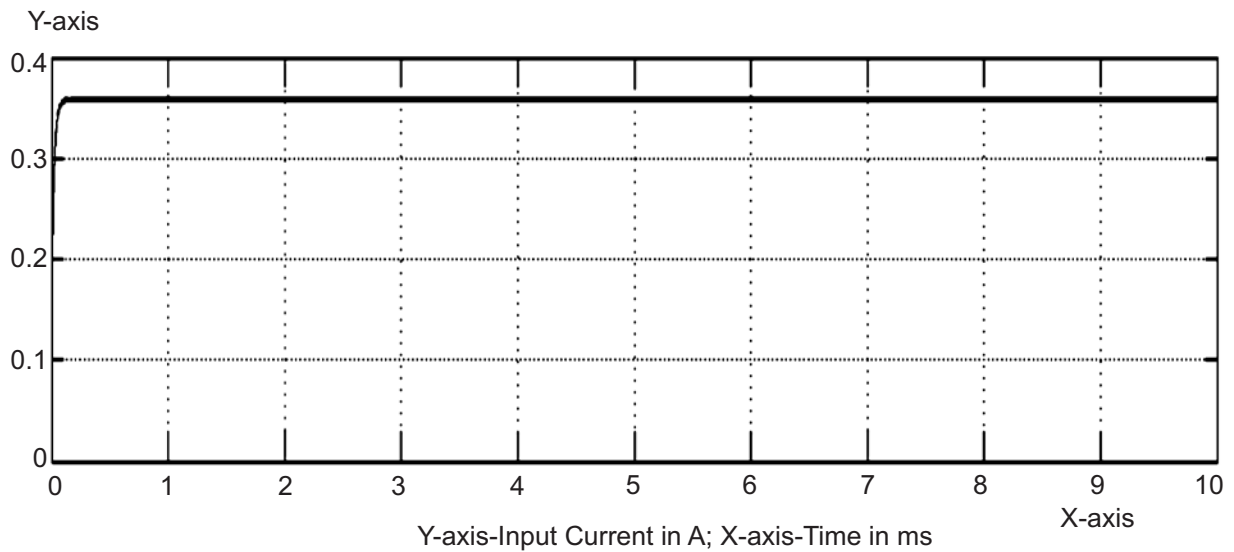


Figure 7: Proposed System Input Current Waveform

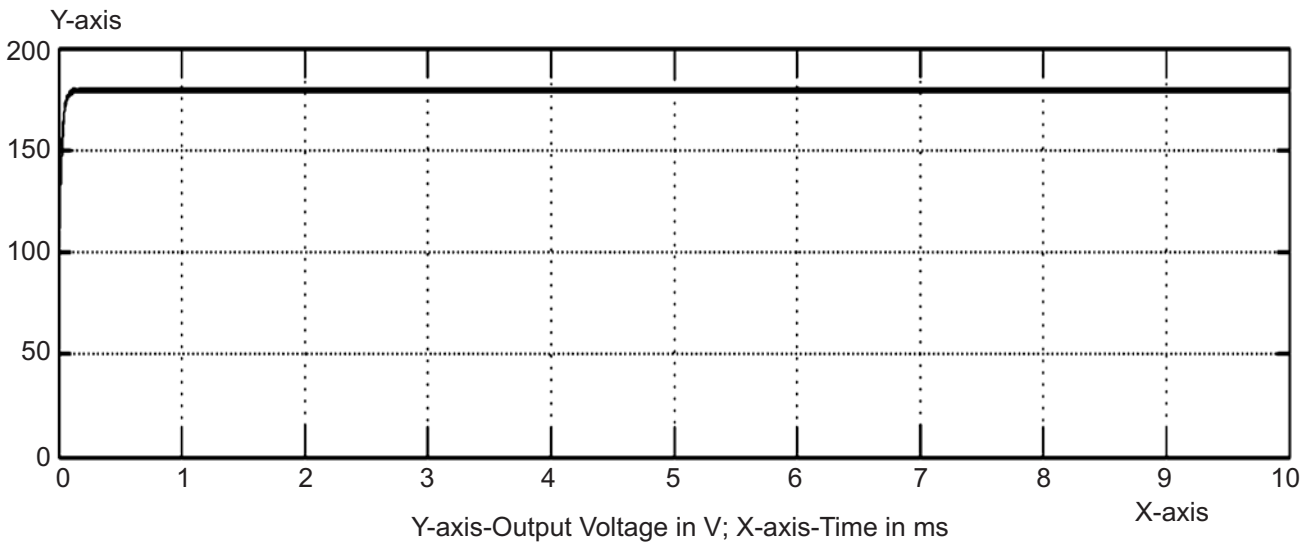


Figure 8: Proposed System Output Voltage Waveform

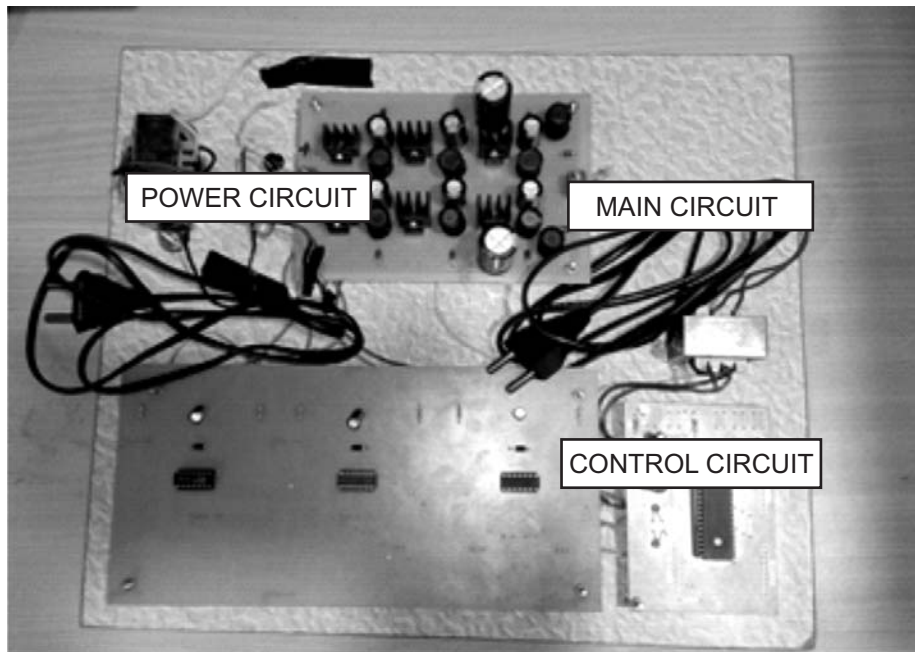


Figure 9: Proposed Hardware circuit

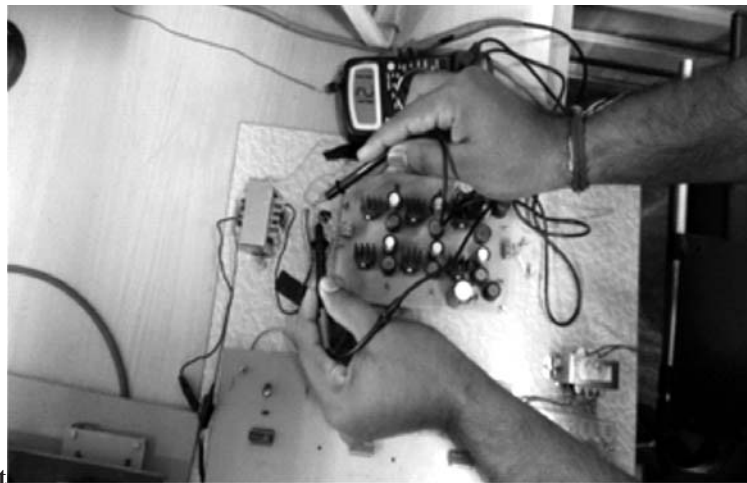


Figure 10: Proposed Hardware Circuit Input Voltage

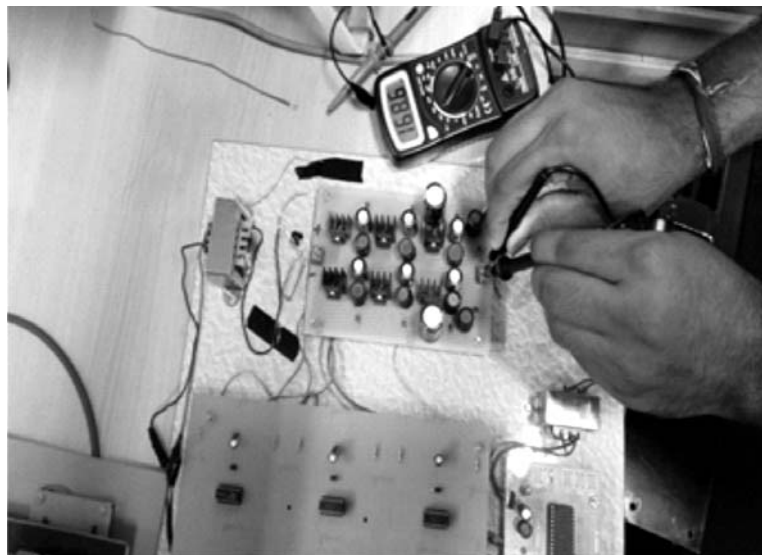


Figure 11: Proposed Hardware Circuit Output Voltage

6. REFERENCES

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