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Design and Control of Series Resonant DC-DC Converter for DC Wind Turbines

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***Abstract:** High power reliability and high energy density are always in demand, and this is driving the evolution of power conversion technologies. People have begun to examine the potential positions of dc systems in both current and future power equipment due to the rise in the use of renewable energy and the implementation of energy storage in recent decades. Because of its efficiency and power density, dc voltage representation has found use in a wide range of fields, including data centres, the aerospace industry, and dc micro-grids. Resonant DC-DC converters, with their gentle switching and minimal EMI, provide a promising solution to these problems. Finding and examining the various modes of operation of the converter while employing the pulse-removal approach is the primary objective of this study. The new method of operation utilises variable frequency and variable phase displacement in sub-resonant mode, which promises to reduce the transformer size while also facilitating the soft-switching change of the insulated gate bipolar transistors (IGBTs) and line frequency diodes on the rectifier side. The pulse elimination approach, a revolutionary mode of operation for the converter, involves phase and frequency shift modulation at varying rates. Using the results of MATLAB/SIMULINK simulations, the suggested control technique may be utilised to establish the baseline switching function configuration necessary to attain high power efficiency.*

***Keywords:** Dc Wind Turbine, Series Resonant Converter (Src), Hvac, Pwm, Offshore Wind Farm.*

1. INTRODUCTION

There is a serious increase in the need for energy in every region of the world. Renewable energy sources are becoming increasingly important due to rising demand for electricity and decreasing supplies of nonrenewable resources. Limits on traditional energy production are necessitated by environmental concerns. For these purposes, several different kinds of power converters are available. DC-DC converters are frequently employed in systems that combine photovoltaics (PV) with batteries. The dc input source may require a step-up or step-down converter at various times. It is necessary to transfer power in both directions in some situations. Their purpose is to balance electrical loads. This convenience has led to the widespread usage of DC-DC converters in a wide variety of modern applications, including regulated power supplies, home appliances, automobiles, battery charging, and more. These converters can serve as power sources for control circuits, especially those that require many outputs.

New technological issues exist in the design and regulation of dc power systems for a variety of uses. In Fig. 1 we have a schematic representation of a common dc power supply setup. Dc power supply systems, like the one seen in Fig. 1, typically include a front-end rectifier plus dc supply network. Connecting the dc supply network to the ac transmission system, the front-end rectifier inverts the current from alternating current to direct current. Front-end rectifiers are connected to the ac system as a load, while providing energy to the dc system as a source. Depending on the use case, the front-end rectifier's output voltage or current can be controlled. Power supplies, or "loads," and various dc-dc converters serve various functions in the dc supply network. In a dc supply network, voltage transfer or current transfer using dc-dc converters is used to supply the loads with the appropriate amount of energy. The dc electric utility system can be broken down into two distinct types, dc voltage supply and dc current supply, depending on the design of the dc supply network.

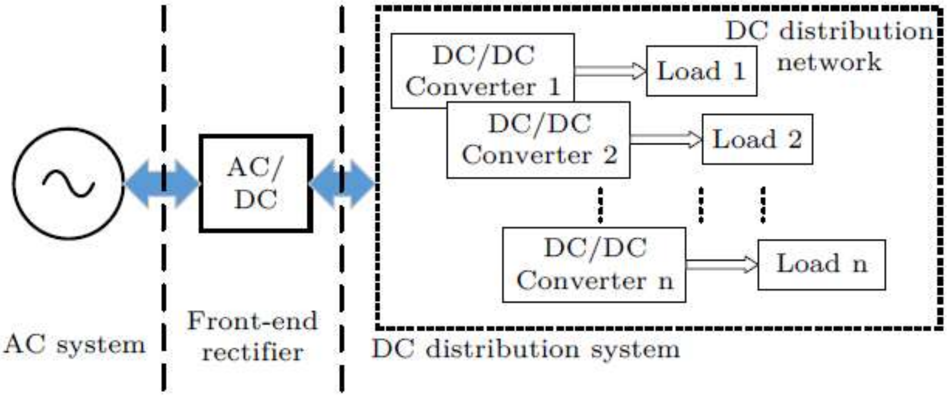

Fig.1: structure of DC power supply system.

Depending on the architecture, the switch network can make use of a variety of control mechanisms, such as converting frequency and voltage and phase shift control. Many different networks including various permutations of resonant inductors & resonant capacitors can be used for the resonant network. In Fig. 2, we see examples of some common and widely-known tank networks, including the series and parallel networks as well as the LCC & LCL tank systems.

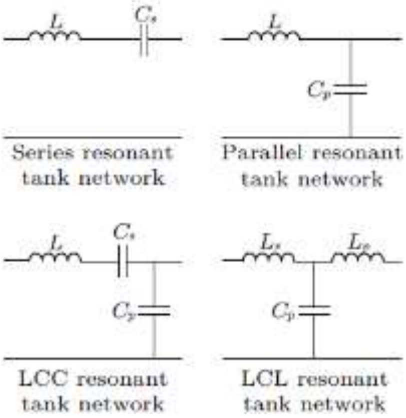

Fig.2: Types of resonant tank networks.

Dynamic modelling and operation of dc-dc sequence resonant converters remains a difficulty in power electronics. The SRC belongs to the family of hybrid systems known as switched linear dynamics because of the switching behaviour of semiconductors. While the SRC is a hybrid system, it is often described as if it had entirely continuous dynamics using the essential harmonic (sinusoidal) estimate and extended averaging theory. Since this estimated model is nonlinear, it is often linearized around a critical point, or reduced to a piecewise linear model, for a localised portion of state space. The fundamental rationale for such a modification is to ease structural analysis and circuit design. Our research suggests using variable phase and frequency shift adjustment in sub-resonant mode to operate the SRC and regulate the LV DC link voltage. Both the advantages and disadvantages of this technique are examined, along with a comparison to an SRC that is operated only by means of frequency control. A overview of traditional SRC is presented, along with an explanation of why a pulse removal approach is necessary in order to save space and eliminate the requirement for a large transformer.

Circuit description

For this reason, these power converters are sometimes referred to as "resonant" devices. This occurs in an LC resonant circuit when the reactance of the inductor and capacitor are equal. Switching losses are reduced as little as possible in a resonant power converter's operation. When the current through the switch is zero or the voltage across the component is zero, the devices turn on and off, respectively. The resulting switching voltage or current is zero. Losses caused by switching increase in tandem with the square of the voltage across the switch and the current through it. A key feature of low loss switching is that it keeps either the voltage across or the current inside the switch very near to zero during the process. As a result, the sum of their products is almost zero, and the switching losses are similarly small. This allows for more efficient power conversion and the utilisation of greater switching frequencies. A further perk is that the inductor, capacitor, and transformer sizes may be minimised as a result. This makes the converter more compact by cutting its weight and size. While pulse-width-modulated converters (buck, boost, Cuk, etc.) are generally recognised, the class of dc-to-dc converters seen in Fig. 3 is not as well known. Because the primary time constants are so short in relation to the switching period, the state-space averaging approach, which has been so useful in the study of pulse-width-modulated converters, cannot be used to resonant converters. However, the same sort of analytical outcomes, especially the dc-to-dc conversion ratio, are as desired for resonant converters as they are for pwm converters.

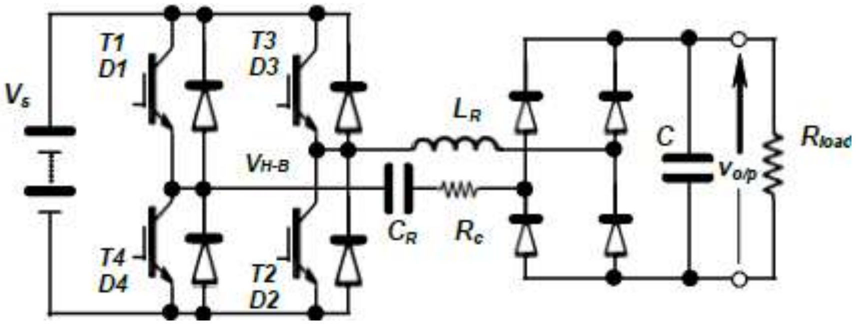

Fig.3: Circuit diagram of SRC.

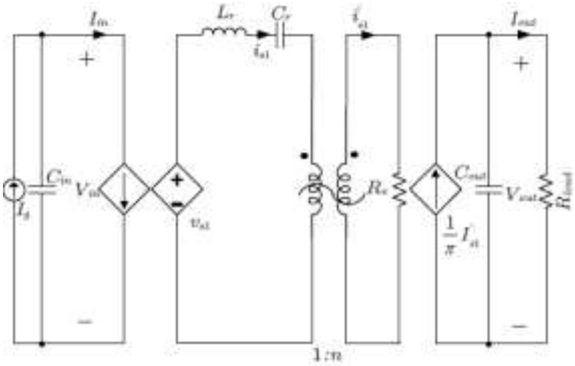

Fig.4: Equivalent circuit of SRC.

Since the inductor and capacitor in a resonant circuit are linear variables, they may be represented directly in the equivalent circuit. See Fig. 4, equations for the approximate resistance R_e, the line current I_{in}, and the regulated voltage source v_{s1}:

$$R_e = \frac{2}{\pi^2} R_{load},$$

$$I_{in} = \frac{2I_{s1}}{\pi} \sin(\frac{\alpha}{2}) \cos(\varphi_s),$$

$$v_{s1} = \frac{4}{\pi} V_{in} \sin(\frac{\alpha}{2}) \sin(\omega_s t).$$

Fig.5 depicts the concept of the phase shift angle α.

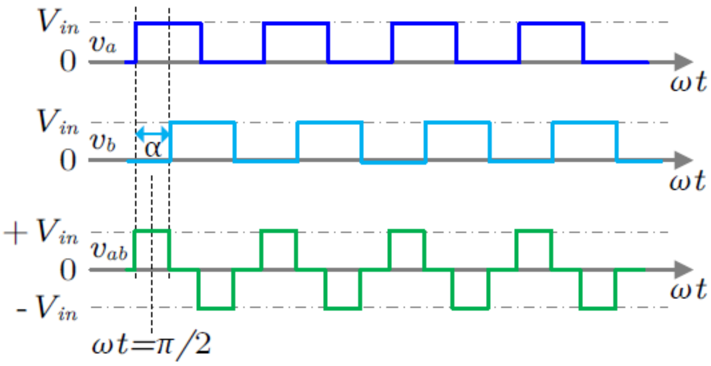

Fig.5: Phase shift angle α.

In Fig. 6, we see the new series resonant converter architecture, which consists of a complete voltage source inverter, monolithic 1: N transformer, reactive tank, and medium voltage rectifier. Transmission of energy from V_{in} to V_{out}. By gently toggling the major side switches and decreasing conduction loss, the converter acts as a PWM entire series-resonant converter with excellent power conversion efficiency. The DC turbine converter benefits from the series resonant converter's maximum reliability, high voltage conversion ratio, and isolation from galvanic faults for turbine generators of varying ratings.

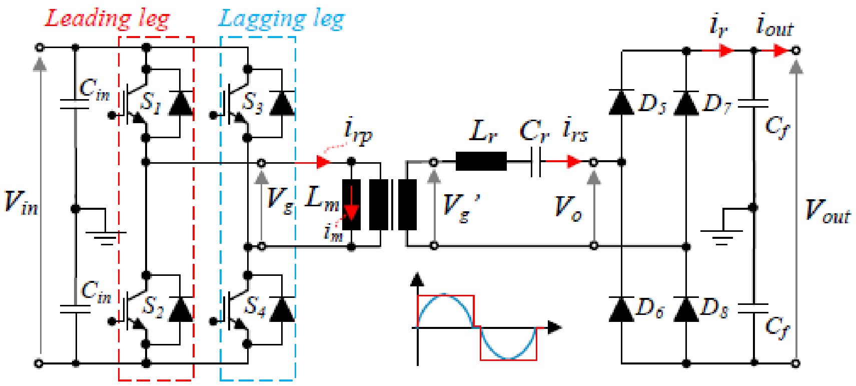

Fig.6: Suggested SRC topology.

2. SIMULATION RESULTS

Using MATLAB/SIMULINK, the authors of this study analyse and simulate a series resonant converter. Based on the switching frequency period, this section describes the waveforms and conduction modes of the converter.

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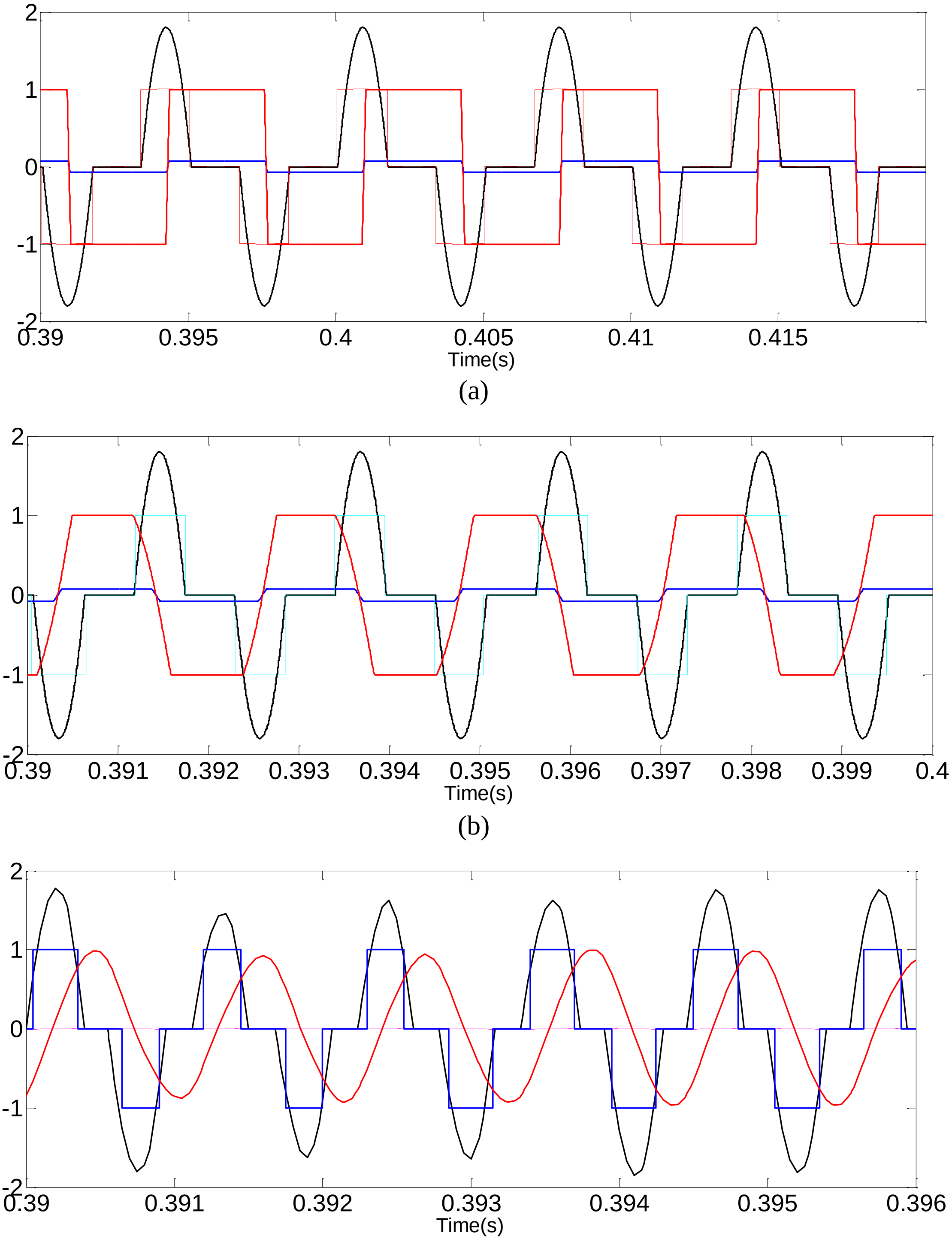
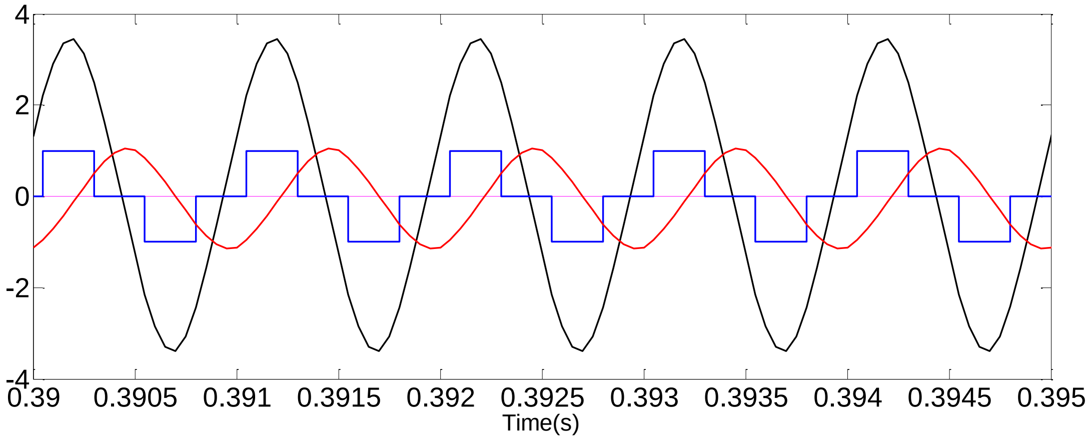


(a)

(b)

(c)



(d)

Fig.7: SRC steady state operation, (a) 150 Hz, (b) 450Hz, (c) 900 Hz, (d) 1000 Hz.

As can be seen in Fig. 7, the output power is dependent on the switching frequency that is actually being used (cf. Fig. 7 a, b). Throughout its usable range, the converter's peak resonant voltage and current remain unchanged because of its DCM1 mode of operation. Current and voltage patterns (primary irp, secondary irs, inverter Vg, capacitor VCr, magnetising im) are shown in Fig. 7b, c, and d, respectively. The pulse elimination approach has no effect on the magnetising current, which remains constant regardless of the applied frequency.

3. CONCLUSION

Due to its great efficiency and small transformer design, the SRC with resonant tank on the HV side is a potential option for megawatt HV dc wind turbines. For high-power resonant topologies, frequency management in the subresonant region has been found as the ideal control strategy for regulating output power and maximising efficiency. The disadvantage, however, is that the transformer must be built with the lowest possible working point in mind. A novel operating procedure, dubbed pulse removal, is proposed to address this problem. Its primary idea is to clamp the input power to zero as quickly as the resonant current reaches zero, hence reducing the flux buildup on the transformer core, allowing variable phase and frequency change in subresonant mode to be utilised to regulate output power. The study of SRC# is the primary emphasis of this work, and the possible conduction modes experienced by the topology as a result of varying output voltage drops are discussed. Resonant current or voltage formulae, together with predicted electrical output, reference voltage, and current stress, were provided for all possible modes. The MATLAB/SIMULINK simulation results were analysed for their insight into the pulse removal approach and the anticipated conduction patterns.

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