

# Digital Simulation of Series Parallel Resonant Converter for Electric Vehicle Applications

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**ABSTRACT:** An electric vehicle (EV), otherwise called as an electric drive vehicle uses one or more electric motors or traction motors to create the driving force needed for motion. Considering the power supply for vehicle computer and electronics, battery and DC-DC converter is required. To achieve the required voltage levels, power converters and inductances are required. Resonant converters are popular for the power conversion process due to their relatively smaller size and lower power losses because of its high-frequency operation and natural soft switching. Among all the topologies of the resonant converter circuits, the series-parallel resonant converter (SPRC) is having the collective advantages of both the series and parallel resonant converter circuits. This SPR converter can regulate the voltage output at a invariable switching frequency even if there is a change in load resistance from full load resistance to infinity at the same time maintaining good load efficiency. The purpose of this project is to design a closed loop controller for the phase angle controlled series parallel resonant converter (PC SPRC) thereby providing pure DC supply for vehicle applications.

**KEYWORDS:** Phase controlled operation, digital control, modeling, and resonant power conversion.

## I. INTRODUCTION

An electric vehicle (EV), otherwise called as an electric drive vehicle uses one or more electric motors or traction motors to create the driving force needed for motion. There are three types of electric vehicles exist, a. vehicles directly powered from an external power source, b. vehicles powered from the electricity stored in the batteries from an external power source, c. vehicles powered by an in-vehicle electrical generators, like an engine (a HEV) or hydrogen based fuel cell. Electric vehicles include cars, trains, aero planes, boats, scooters and motorcycles and spacecraft.

Electric vehicles first became reality in the mid-19th century, when electricity was the preferred methods for motor vehicle propulsion, as it provides good level of comfort and easiness in operation which is not possible by the gasoline cars. The internal combustion engine (ICE) is the leading method of propulsion for electric motor vehicles but electric power is common propulsion source in other vehicle types, such as trains and other smaller vehicles.

The basic block diagram of electric vehicle is given as

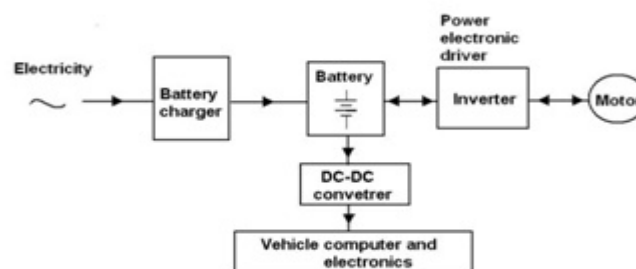


Fig. 1. Block Diagram of Electric Vehicle

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In this, electricity can be generated from a wide range of power sources such as fossil fuels, nuclear power and renewable resources like tidal power, solar power and wind power or combined use of the above mentioned sources. The electricity produced is then stored in the vehicle using devices like battery, flywheel or super capacitors. The energy stored in the battery is used by the inverter to feed the motor. At the same time the same battery energy can also be used to supply other computers and electronics through a DC converters. A key advantage of electric or HEV is regenerative braking, their capability to pull through the energy losses while braking as electricity is restored to the on-board battery. Our objective is to design DC-DC converter in order to supply pure and constant DC voltage for in vehicle electronics components like computer.

Power electronic systems are widely used today to supply power for various applications like transportation, computers biomedical electronics, home appliance operation and DC power transmission. The operating power level varies from mill watts to megawatts. These systems typically involve switching devices like thyristors, MOSFETs, and diodes, along with passive elements such as resistors, inductors, capacitors and IC's for control.

In order to control the size of components used in power supplies, it is desirable to raise the frequency of operation so as to cut the size of L & C. To reduce the higher switching losses resulting from high frequency operation (lower operating time period), resonant power conversion is getting new interest.

Resonant power conversion circuits have many advantages when compared to PWM circuits. Some of the advantages are low magnetic interference, low switching losses, small size of components due to high operating frequency, increased efficiency, and low recovery losses in diodes. Most of the frequency-controlled resonant converters undergo a wide range of frequencies which is required to regulate output voltage against both line and load variations. This makes it difficult to filter electromagnetic interferences and effectively utilize magnetic components. As solutions to these issues, phase-controlled resonant inverters and converters based full bridge circuits have been proposed.

Resonant converters are advantageous for power conversion due to their smaller size and low power losses and natural soft switching. Among all the topologies of the resonant converter circuits, the series-parallel resonant converter (SPRC) provides us the combined advantages of both the series and parallel converters [1]. To control the output of an SPRC, Time ratio control or phase controlled technique are usually used. The frequency control is used in half-bridge inverters. The phase controlled operation may require a full-bridge inverter circuit. Some of the phase-controlled series parallel resonant converters, (PC SPRC) [3], are able to provide inductive loads for the switching devices of the inverter circuit. Thus, the power losses are reduced in these configurations.

The major advantage of series resonant converter is, the series resonant capacitors act as a dc blocking capacitor. For this reason this circuit is used in full bridge topology. The major advantage of parallel resonant converter is that it is particularly valuable for applications with short circuit proof. In SPRC the current carried by the MOSFET's and resonant components is independent of load. The series parallel resonant converter combines the above said advantages.

## II. PROPOSED CIRCUIT DIAGRAM

The PC SPRC comprises of two identical inverters circuits. Each inverter circuit is composed of two power switches, series-parallel resonant circuit and a parallel-connected capacitor C1 shared between the resonant circuits. These two resonant circuits form the tank circuit, which is balanced with respect to C1. The load resistance is connected to this tank circuit through a rectifier and an output filter.

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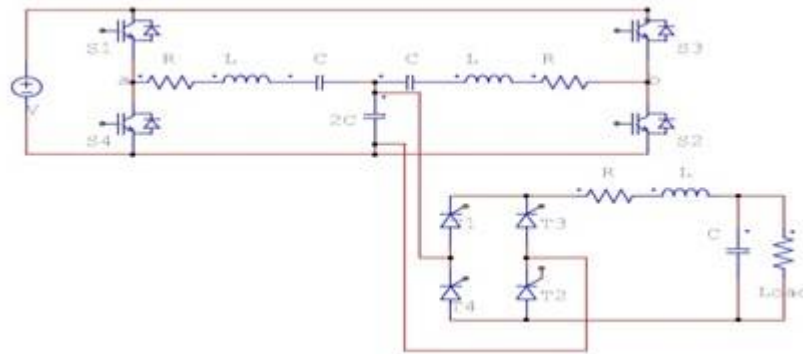


Fig. 2. Circuit Diagram

If the switching frequency is fixed at a value close to the resonant frequency, the output voltage  $V_o$  can be regulated against load and line variations by varying the phase shift between the voltages that drive inverter 1 and inverter 2 while maintaining a fixed operating frequency for both pairs of switches. Zero-voltage switching is also possible by shunting a capacitor in parallel with any one of the MOSFETS in both the legs and using a dead time in voltages used to drive the MOSFET's.

The analysis of the PC SPRI of Fig. 2 begins with the following simplifying assumptions:

- 1) The Q factor of the inverter load is high so that the currents  $i_1$  and  $i_2$  are sinusoidal.
  - 2) The power MOSFET's are assumed to have ON-resistances  $R_{DS}$ .
  - 3) The reactive components of the resonant circuits are assumed to be passive, linear, time invariant.
- 3) Components of both resonant circuits are identical.

### III. GENERAL BLOCK DIAGRAM

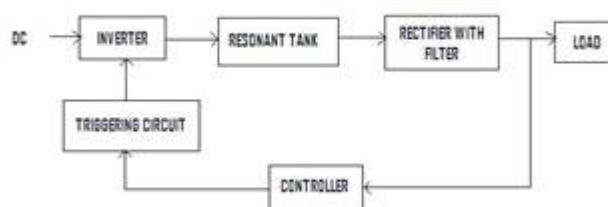


Fig. 3. General Block Diagram

The DC supply is given to the inverter with resonant tank which produces alternating voltages and currents because of resonance. This AC output is fed to a rectifier to obtain rectified voltage output. The resonant converter is used in low voltage power supply applications in EVs and HEVs. The Circuit is simulated in PSIM Software for the above mentioned problem in open loop and the work is being carried out to get result for closed loop. The simulation circuit model is shown in the fig 4 and the pulse waveforms and the current and voltage waveforms are shown in 5 and 6 respectively.

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## IV. SIMULATION RESULTS

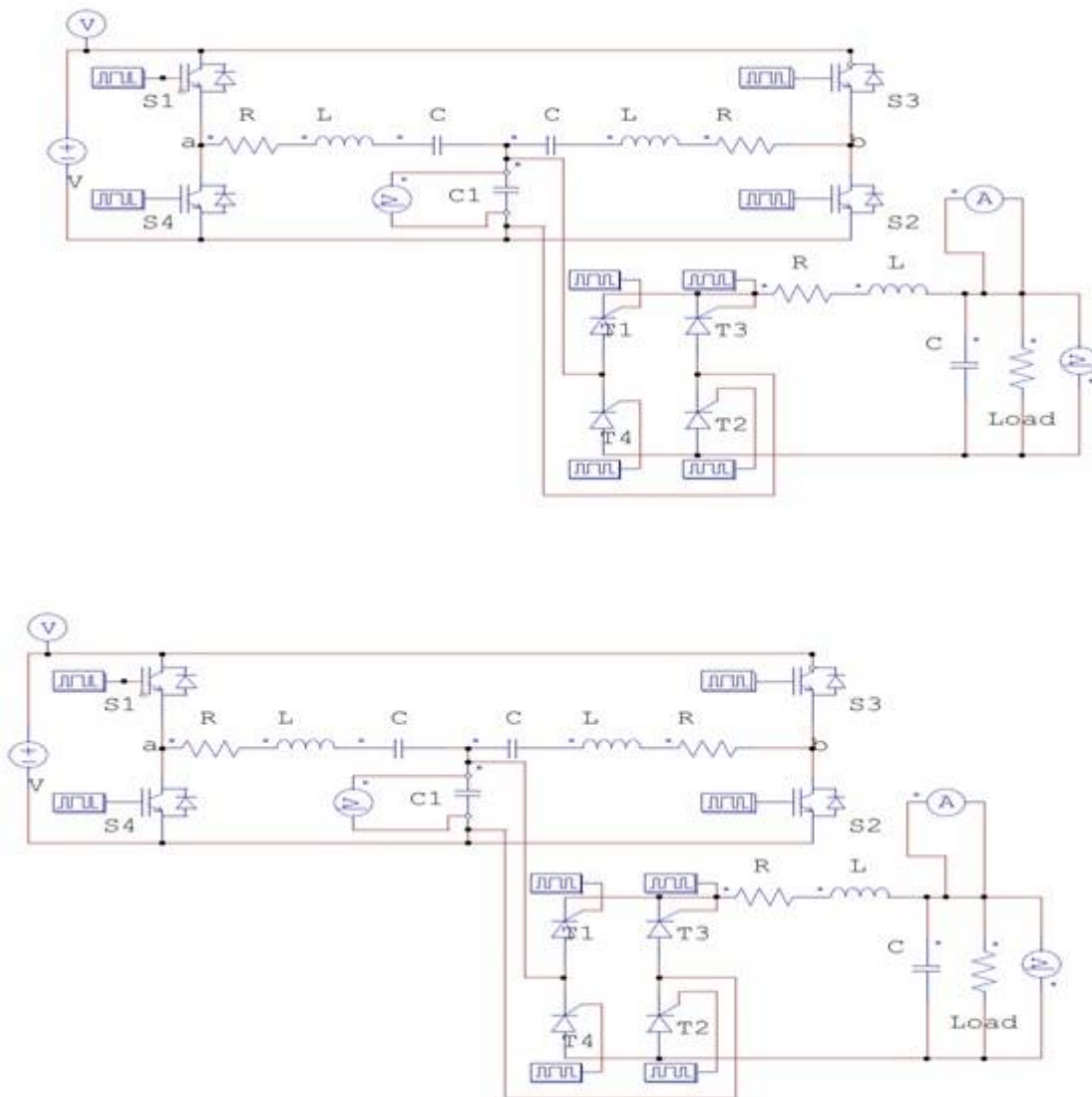


Fig. 4. PSIM Circuit Diagram in Open Loop

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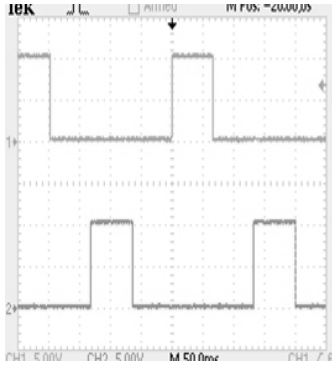


Fig. 5. Pulse Wave form to Switches

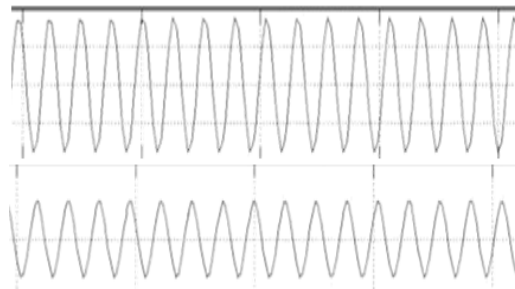


Fig. 6. Voltage and Current Waveforms

The output of the rectifier is appears to be constant for a fixed load and it is varying for variation in the load circuit. The circuit analysis shows that when compared to series or parallel inverter circuits, SPRC runs over a large input voltage range and a large load range (no load to full load) while ensuring an excellent efficiency.

## V. SIMULATION RESULTS

The SPRC has been simulated with both fixed and variable load components. The natural resonating frequency is approximately 18.3 kHz for this converter, and the switching frequency is 1.1 times the resonant frequency. The Component values are designed as 5  $\Omega$ , 1.1 mH and 0.1  $\mu$ F for R,L,C respectively. The shunted capacitor value is 0.2  $\mu$ F. The waveforms are obtained for the voltage across the parallel capacitor C1 and the current flows through the resonant circuit is shown in Fig.6. It is observed that these waveforms are sinusoidal in nature over a wide range of the load resistance. The output voltage of the rectifier is obtained as 99.8 V. For the variable load resistance, the rectifier output voltage is maintained constant at 63 V.

## VI. CONCLUSION

The series-parallel resonant converter based on phase controlled technique has been explained. An attempt is made to study the series parallel resonant converter in open loop for both fixed and varying load conditions. Thus the designed converter provides constant DC voltage for vehicle computer and electronics.

The essential control task is to implement a control algorithm that produce the control signals based on the output measured from the plant. The controller has to generate these signals at a very high speed to control the operation of the plant. The closed loop work is being carried out and the results may be produced at a later stage.

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