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Analysis of Resonant Boost Power Factor Corrector for DC Motors

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ABSTRACT

In this paper an analysis of a resonant boost PFC for DC motor is being discussed. A resonant boost PFC converter fed DC motor could increase the efficiency and improve the power factor by minimizing the THD of the system. The proposed system could give Zero Voltage Switch for the used MOSFET switches and Zero Current Switch for the used diodes. A resonant boost converter along with a PFC circuit has a capability for achieving high PFC without a current control loop. Then the circuit complexity can be reduced. In this paper DC Motor output with and without PFC circuit is analyzed. The performance analysis is done using MATLAB/SIMULINK software.

***Keywords**:* Power Factor correction (PFC) Converter, Resonant, Soft-switching, MATLAB/Simulink, Boost Converter, Total harmonic distortion (THD).

I. INTRODUCTION

Day to day application of DC motor is extensively increasing in industries. Usually a single phase diode rectifier is used to feed these DC motors. Nowadays large DC Motors are used in propulsion of electric vehicles, elevators and hoists, and in drives for steel rolling mills. The main problem faced by the system is its low power factor and high THD. In order to reduce this problem, a PFC converter needs to be introduced. Usually a boost converter is used as PFC because of its ease of use, even though it has disadvantages of higher complexity of control, high conduction and switching losses. To solve these problems in a traditional boost converter, many methods have been proposed in the literature.

Among them the most effective one is the resonant boost power PFC converter with soft switching [1]. The ratio of active power to apparent power gives power factor. In order to make most favorable conditions of a supply system from engineering and economical viewpoint, it is important to choose power factor close to one. Low power factor causes several problems such as large kVA rating of equipment greater conductor size, large copper loss, poor voltage regulation and reduced handling capacity of the system. In order to meet harmonic regulations such as the IEC 61000-3-2, power supplies with active power factor correction (PFC) techniques are necessary for electronic equipment. Even though a low power factor leads to a reduction in the power available from the utility grid, a high harmonic distortion of the line current causes problems like electromagnetic interference and cross interferences, through the line impedance, between diff erent systems connected to the same grid. Many eff orts are being carried out to develop interface systems which can improve the power factor of standard electronic loads and the system. An ideal power factor corrector (PFC) should mirror a resistor on the supply side while maintaining a fairly regulated output voltage.

PFC has several advantages such as better source efficiency, lower power installation cost, lower conducted EMI, reduced peak current levels, ability to act as a filter for conducted EMI and common input filter for paralleled supplies [4].

A boost converter operating in discontinuous current mode (DCM) can offer a number of advantages, such as inherent PFC function, very simple control, soft turn on of the main switch, and reduced diode reversed-recovery losses. The DCM operation results in soft turn-on switching and a fairly low inrush current [5]. The voltage gain can be extended without extreme duty cycle operation which makes the proposed topology suitable for universal line voltage applications.

PID Controller is used to give feedback or switching pulse to the MOSFET. PID controller keeps calculating the difference in the measured value and reference value and find the error value. It always compare the output value with a given constant value and generate a pulse which will help to switch the MOSFET. It increases the efficiency of the system and help to provide soft switching to the MOSFET [10].

A resonant Boost PFC converter for DC Motor is proposed in this paper. The proposed circuit provides benefits like simple and symmetrical structure, simple modulation, control circuit, intrinsic high power factor capability, continuous input current with low ripples even with small inductors with DCM currents, and resonant behavior providing soft-switching for all of the semiconductors. The current which is given as input is divided equally between two input inductors which is a continuous one, even in the lower parts of the input voltage in the line cycle. With the help of controller soft-switching is provided to switch semiconductors in the circuit. Here Zero Voltage Switching (ZVS) is provided to turn-on the MOSFETs, and Zero Current Switching (ZCS) is provided to turn-off the diodes.

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II. PRINCIPLE OF OPERATION

The block diagram of a DC motor fed from resonant boost PFC converter with soft switching is shown in Fig. 1. Here PWM controller is used for switching the MOSFET and the feedback from output voltage of converter is given to the PID controller. This PFC converter is an advanced type of boost converter with a 2% efficiency than conventional interleaved Boost converter. And the resonant boost PFC converter has a near unity power factor [1].

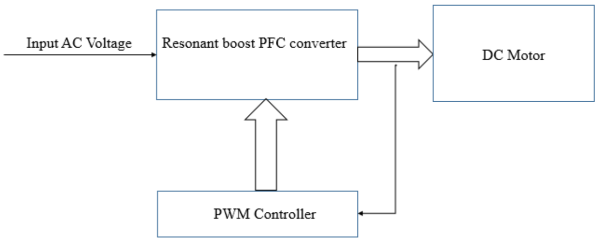


Fig 1.Block diagram of DC motor fed by Resonant Boost PFC Converter

The controller gives the pulse to the gate of the MOSFET. And through soft-switching high power factor is attainted. Fig. 2 shows the equivalent circuit of proposed system. Two series diodes i.e. in positive cycle D_1 and D_2 works and in the negative half cycle D_3 and D_4 and these diodes are used to prevent reverse power from flowing to the input. Because of the symmetrical structure of the system the switching operation of the proposed converter is same in the both half cycles. In both half cycle there are eight different operational modes for switching. Since the operation of the converter is symmetrical, first four mode and second four modes are same. A high input power factor is achieving without considering the current control loop in the circuit. Through this the complexity of the control circuit can be reduced.

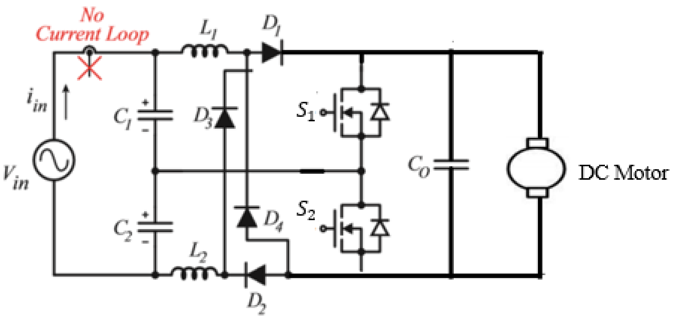


Fig 2 Proposed circuit Diagram

III. MODES OF OPERATION

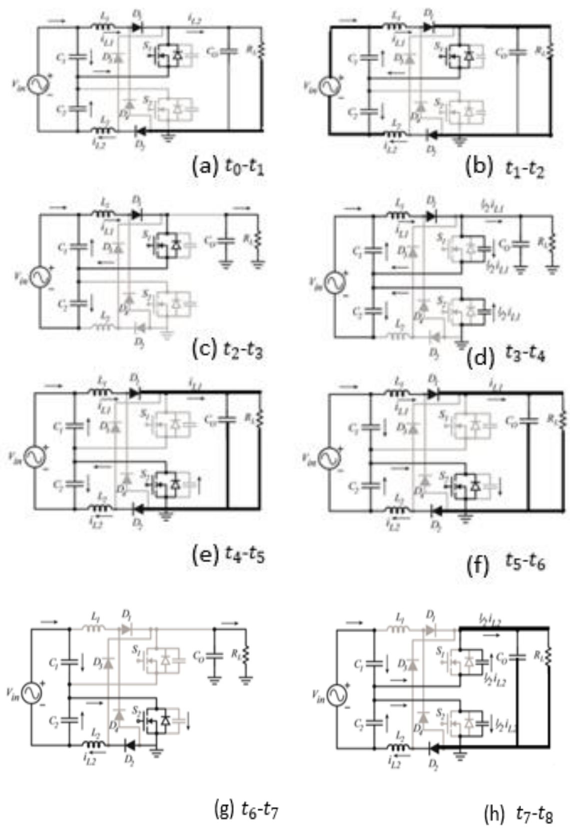
As already said there are mainly eight modes of operation are there for the system. Taking drain-source capacitor of switch S_1 is discharged and capacitor of the switch S_2 is fully charged to the output voltage before considering the first mode. Also, considering that the anti-parallel diode of switch S_1 is conducting. Due this the switch S_1 turned on with the help of ZVS condition.

Mode I [t_0 - t_1] Fig. 3(a) shows the first mode. When the body diode of the switch start to conduct this mode start. S_1 can be switched on with the help of ZVS when the body diode of S_1 is conducting. During this mode, i_{S1} is negative and increasing upwards and eventually it reach zero and then this mode gets ended i.e. when i_{S1} reach zero, this mode ends. During this time, the input capacitors current become zero, and since i_{C1} was
positive before that, the voltage of C_1 will be at its peak so that voltage of C_2 becomes its lowest value in that cycle.

Mode II [t_1 - t_2] Fig. 3(b) shows the second mode of operation. During this mode the current flowing through D_1 and S_1 will charge inductor L_1. At the same time L_2 is supplying the load through D_2 and S_1. After t_1, the net current of L_1 and L_2 is positive flowing from the drain to the source of S_1. In this mode, i_{L1} is ramping up and i_{L2} is ramping down. At t_2, i_{L2} touches zero, at that time through ZCS diode D_2 is turned off and stops the inductors from feeding the output capacitor.

Mode III [t_2 - t_3] Fig. 3(c) shows the third mode of operation. Here, after the diode D_2 turned off the i_{L1} value is ramping up through S_1 and D_1, and i_{L2} is zero. At that time, voltage of C_1 decreases because of the negative value of capacitor current, i_{C1} and since the current of C_2 is positive, V_{C2} is increasing. End of this mode with the help of controller switch S_1 is turned off.

Mode IV [t_3 - t_4] Fig. 3(d) shows the fourth mode. During



this
i_{L1} is experiencing its maximum i_{Lmax}. Since the current of an inductor cannot change suddenly, i_{L1} cannot reach zero suddenly, and the only way it can close its path, is to flow through the drain-source capacitors in the MOSFETs i.e., it is

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Fig 3: Eight modes of operation of the resonant Boost PFC converter structure in the positive half cycle during each switching interval.

This mode of operation can be explained with graph having the input current, inductor current, capacitor Voltage, capacitor current, gate switching, voltage across the switch, and switch current as shown in the Figure 4. Here it is given a duty cycle of 50%.

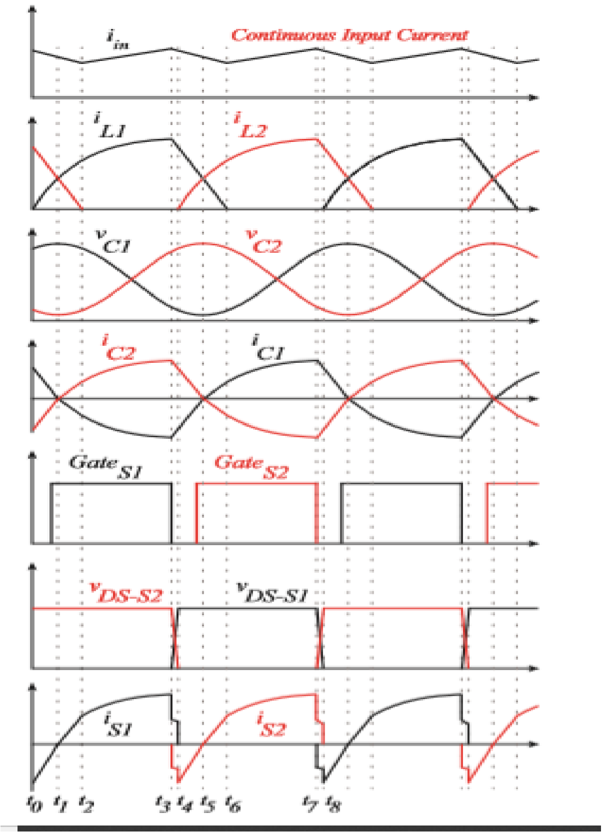

Fig 4: Eight modes of operation of converter with different switching intervals. The circuit with a duty cycle of 50% works with simple switching frequency modulation and complementary gate signals. These waveforms shows the converters first eight modes or positive half-line cycles. Since the circuit is symmetrical we can explain the operation of the negative half-line cycles with this topology.

IV. MODELLING OF MOTOR

Separately excited DC motor of 5HP is used, field current I_f is constant, the speed depends on torque and armature current. Initially the starting current will be very high since the current proportional to back emf and at start there will be no back emf. This may result in damage of motor. So in order to avoid the risk a starter is provided.

Table- I: Parameters of Motor

Parameter	Specification
Power	5HP
Voltage	350-400V
Torque	200Nm
Field Inductance, Lf	120H
Armature Inductance, La	0.012H
Inertia Constant, J	$1 kg.m^2$
Armature Resistance, Ra	0.6Ω
Field Resistance, Rf	240Ω

V. MATLAB/SIMULINK MODEL

The simulations for the analysis are done in MATLAB software and the models are given below. Fig. 3 shows the simulation diagram for DC Motor without PFC converter. Here the input of the system is 220±20%V AC voltage it is converted to DC with the help of a pulse generator with duty cycle 0.5. Two MOSFET switches are used here with an output boost capacitor.

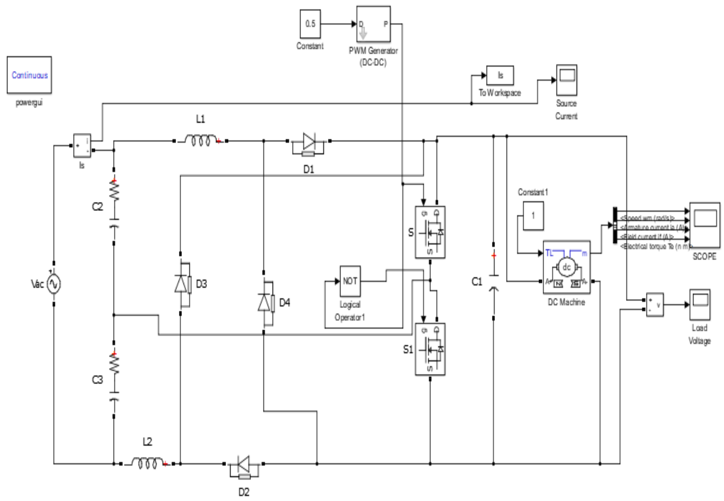

Fig 3: Simulation diagram for DC Motor without PFC

Fig. 4 shows the simulation diagrams of DC Motor with resonant boost PFC with soft switching. With the help of PID controller the soft switching is provided to the MOSFET switches.

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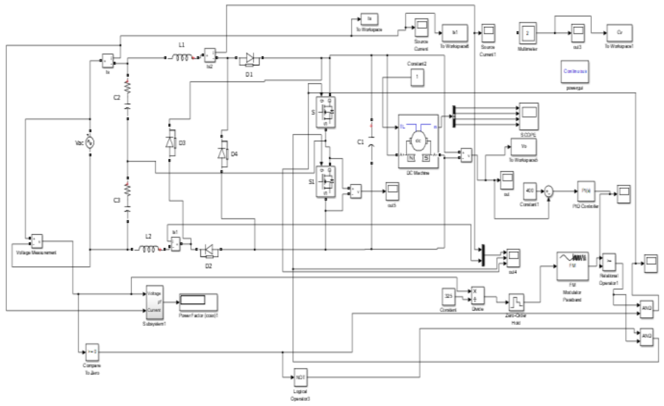

Fig. 4 shows the simulation diagrams of DC Motor with resonant boost PFC with soft switching.

TABLE II. Parameters of Resonant Boost PFC Converter

Parameter	Specification
Input Voltage	220V
Output Voltage	400V
Input Power	2.789A
Load Resistance	400Ω
Capacitance	19.9nF
Inductance	63.7μH

VI. SIMULATION RESULTS

VI.1.Open loop response of DC Motor

Fig. 5 Shows the Input current characteristics of an open loop PFC fed to a DC Motor.

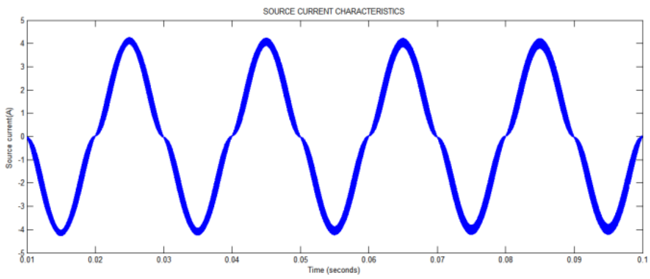

Fig. 6 Shows the Output Voltage characteristics of an open loop PFC fed to a DC Motor.

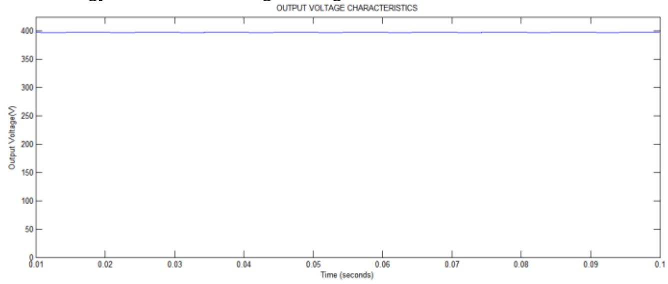

Fig 6 Output Voltage of open loop

Fig. 7 Shows the THD characteristics of an open loop PFC fed to a DC Motor.

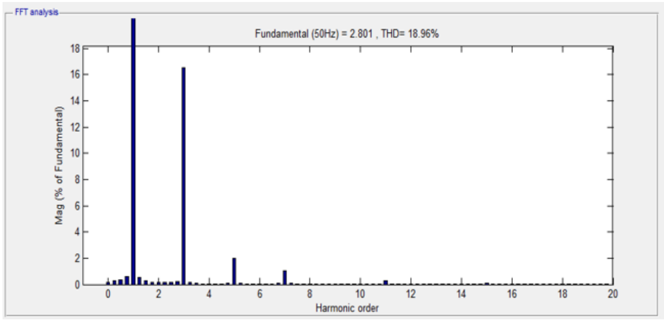

Fig 7 THD of open loop

VI.2. Simulation results for Resonant Boost PFC Converters

Fig. 8 Shows the Input current characteristics of Resonant Boost PFC with PID controller (PWM) fed to a DC Motor.

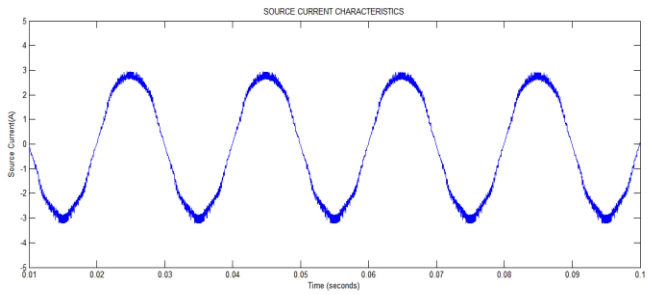

Fig 8 Input current of Resonant Boost PFC with soft switching

Fig. 9 Shows the Output Voltage characteristics of Resonant Boost PFC with PID controller (PWM) fed to a DC Motor.

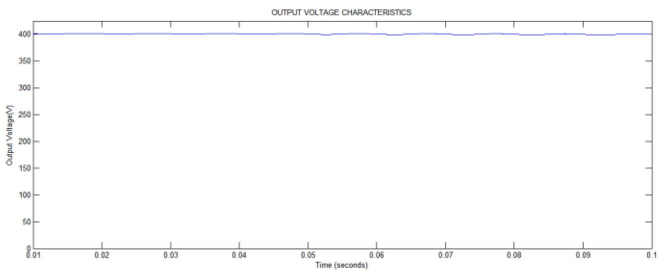

Fig 9 Output Voltage of Resonant Boost PFC with soft switching

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Fig. 10 Shows the THD characteristics of Resonant Boost PFC with PID controller (PWM) fed to a DC Motor.

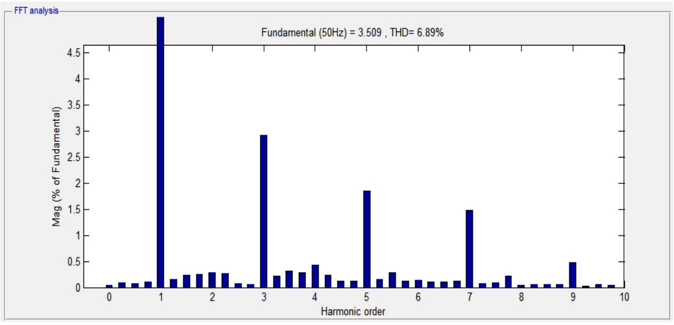

Fig 10 THD of Resonant Boost PFC with soft switching

VI.3.Comparison

While comparing open loop with the close loop system it is clearly showing the difference in the THD value and power factor of the system. In Open loop THD is about 18.96% and power factor is about 0.95. But for the Resonant Boost PFC Converter THD is 6.89% and power factor is 0.98 i.e., for proposed system THD is very low and Power Factor is very high which is the needed input for a DC Motor or any power system. So the proposed system could increase efficiency and due to low THD it increase its life time.

VII. CONCLUSION

A separately exited dc motor fed from a Resonant Boost PFC with soft switching converter's modelling and simulation is presented in this paper. The suggested system is more efficient than the existing model, it has much low THD than the existing system and Power Factor also very high. The proposed system has the advantages like its simplicity, symmetrical structure, good and smooth output voltage for a variation of input voltage. Using PID controller output voltage of the resonant boost PFC converter maintained constant. Continuous input current with low THD can be provided by the resonant boost PFC converter, even with small disturbance in the current. The resonant boost converter can provide a unity-power factor without any extra filter.

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