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A Novel Integrated Buck-Buckboost High Stepdown Power Factor Correction Converter For Low Voltage Applications

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Abstract— Power factor correction of high frequency switch mode power supply and its application in dc motor speed control is presented in this thesis. A high step-down transformer less single-stage single-switch ac/dc converter is designed. The topology integrates a buck-type power-factor correction (PFC) cell with a buck–boost dc/dc cell for output voltage regulation. It is a one-stage one-switch AC/DC converter which steps down the voltage without a transformer. It combines a buck type PFC cell with a buck-boost type DC/DC cell. Two capacitors are sharing the voltage. Part of the input power is directly coupled to the output. With the above features it is able to achieve a high power factor, efficient power conversion,low intermediate bus voltage less than 130V and low output voltage without a transformer. This reduces the cost and size. Finally a DC motor load is applied and simulation results are presented..Simulation is done in MATLAB/SIMULINK.

Keywords—Discontinuous conduction mode(DCM), Integrated buck-buck-boost converter(IBuBuBo),Power factor correction(PFC),Total harmonic distortion(THD)

I. INTRODUCTION

Power system harmonic issue arise from large number of non linear loads that are present in power system. In recent years , switch mode power supplies are more popular than linear power supplies because they provide a regulated voltage with a higher efficiency. They are more efficient and less bulky.

Power factor gives a measure of how effective the real power utilization in the system is. It represents a measure of distortion of the line voltage and line current and phase shift between them. In linear regulators power factor is simply equal to the cosine of the phase angle between the current and voltage. But in the case of switch mode power supplies, due to their non linear operation cause harmonic distortion to the line current and emit electromagnetic noise via conduction and radiation, interfering the operation of nearby equipments. Non linear loads draws typical distorted line current from the line. In this case ,

$$Power\ factor = \frac{I_{s1,rms}}{I_{s,rms}} cos\theta$$

$I_{s1,rms} = rms\ value\ of\ fundamental\ component\ of\ line\ current$

$I_{s,rms} = total\ rms\ value\ of\ line\ current$

$\theta = phase\ angle\ between\ voltage\ and\ fundamental\ component\ of\ current$

Power factor= distortion factor x displacement factor
Total harmonic distortion is a measure of percentage of distortion.

Conventional way of suppressing harmonic currents generated by non linear loads is realized by installing a bank of passive tuned and one or two high pass power filters beside these loads. The effects of passive filters are very sensitive to temperature and parameter changes and it is costly for low power application. In low and medium power application active power factor correctors are used. In active power factor correctors high frequency switching techniques have been used to shape the input current waveform. By properly controlling the switching duty ratio a pure resistive input impedence and constant output voltage can be achieved. Therefore unity power factor and output regulation can be achieved.

In recent years, the PFC technique has gained wide attention in low power application. There are two types of PFC AC-DC converter , Two stage and single stage. Both these converters consist of a PFC circuit cascaded with dc-dc converter for output voltage regulation. The major disadvantages of two-stage conversion approach are the added cost and the complexity of the two-control-loop, two-power-stage . In low-power applications, for which cost is the dominant issue, it is not reliable. The single-stage PFC ac/dc converters that integrated the two power stages into one, thus reducing significantly the component count and cost, have gained much attention in many low-power applications during the past ten years. It has been approved that the single-stage approach is a cost-effective solution for applications with power levels lower than 200W.

In this thesis, a single-stage single-switch intergrated buck–buck–boost (IBuBuBo)converter with low output voltage and high power factor for switch mode power supply is proposed. Single stage PFC converter has only one feed back loop from the output . Since the input circuit and output circuit are in single stage it is possible for them to share the same power switch. Thus it results in single-stage single-switch PFC circuit. The converter utilizes a buck converter as a PFC cell. It is able to reduce the bus voltage below the line input voltage effectively. In addition, by sharing voltages between the intermediate bus and output capacitors, further reduction of the bus voltage can be achieved. Therefore, a transformer is not needed to obtain the low output voltage.

II. Literature survey

Conventionally ac-dc converters which are also called rectifiers are developed using diodes and thyristors to provide controlled and un controlled dc power flow. They have the demerits like poor power quality in terms of injected current harmonics, voltage distortion and poor power factor at input ac main. Thus arises the need for power factor corrected switch mode power supply.

Single switch topologies of power factor correction techniques exist for different converter topologies. They are the cost effective approach for achieving both the function of high PFC and fast output voltage regulation by using one active switch under a single control loop. The key criteria to be considered while ac-dc single stage converters is to satisfy appropriate input current standards, typically EN61000-3-2 standards on electrical equipment.EN61000-3-2 is applicable to all electronic equipment connected to low voltage AC distribution mains. Four different classes described in this classes are as follows. 1) Class A for dimmer for incandescent lamps, house equipments other than class D 2) Class B limits for portable tool, arc welding equipment etc 3) Class C limits for lighting equipment and 4) Class D limits for PC monitors, radio ,TV receivers.[3]

Some of the existing single stage converter consist of a Boost power factor correction cell cascaded with a dc/dc cell for output voltage regulation. The major objective is not to achieve a high power factor. The performance and cost are the primary concern. One of such converter circuit uses a bulk capacitor voltage feedback with a coupled winding structure to reduce intermediate bus voltage and current stresses in single stage PFC ac/dc converters. Even after the intermediate bus voltage is only reduced upto 408V and it will easily goes beyond 450V at high line application. This high intermediate bus voltage causes component stresses in dc/dc cell [2].

In another topology buck-boost cell acts as PFC cell and buck cell is used as dc-dc converter. In this topology extremely narrow duty cycle is needed for conversion. This leads to poor circuit efficiency ie 77% and limits the input voltage range for getting better performance[4].

A well regulated dc output to feed loads ranging from fraction of watt to several 100kW, power ratings in a large number of applications can be obtained by improved power quality converter technology. In last couple of decades with varying configurations, control approaches, solid state devices, circuit integration, varying magnetic etc. the buck-boost converters are applied in unidirectional and bi-directional power flow approaches. Unidirectional buck boost converters are developed in both non isolated and isolated circuit configurations. It comprises of diode rectifier with buck boost dc to dc converters which are cascaded with a diode rectifier stage to improve the power quality at the ac mains with required variable controllable output dc voltage to meet the need of specific application.[5-6]

The recently reported IBoBuBo converter [7] is able to limit the bus voltage under 400 V, it cannot be applied to the low-voltage application directly due to the boost PFC cell. It has higher conversion efficiency similar to that of proposed converter3, but it cannot be used for low voltage application and component stress on the dc-dc converter is high due to large voltage across capacitor. To reduce the intermediate bus voltage several topologies have been proposed. Among those converters, [3] and [8] use a transformer to achieve low output voltage either in PFC cell or dc/dc cell. Therefore, the leakage inductance is unavoidable. Leakage inductance of the transformer causes high spike on the active switch and lower conversion efficiency. To protect the switch, snubber circuit is usually added resulting in more component counts .

Integrated buck-buck-boost converter addressed in [1] was found to be capable of providing low intermediate capacitor voltage for universal line application. Single stage topology integrates power and control circuitry under a single loop. Both converters are operated in discontinuous conduction mode. Hence it can be used only in low power application

III. Proposed converter and operating principle

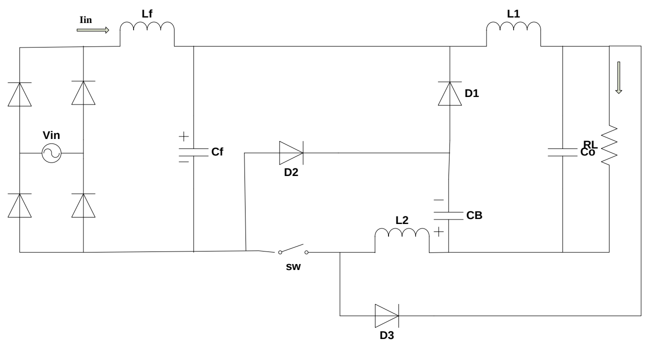

Fig. 1. Proposed Integrated buck-buck boost converter

The IBuBuBo converter integrates a buck PFC cell with a buck-boost DC/DC cell. The PFC cell constitutes C_B, C_o, L_1, D_1 and S_1. The DC/DC cell constitutes C_B, C_o, L_2, D_2, D_3 and S_1. The initial current of both the inductors are zero as they operate in discontinuous conduction mode (DCM). There are two modes of operation.

Mode 1(Vin (θ) ≤ V_B +V_o): In this mode the buck PFC cell becomes inactive as the rectifier bridge is reverse biased because the sum of the intermediate bus voltage and the output voltage is greater than the input voltage. Only the buck-boost cell sustains power to the load. No input current is drawn. It can be divided into three periods.

- Period 1: S_1 is turned ON; the bus voltage V_B charges the inductor L_2. The load is supplied by the output capacitor C_o.

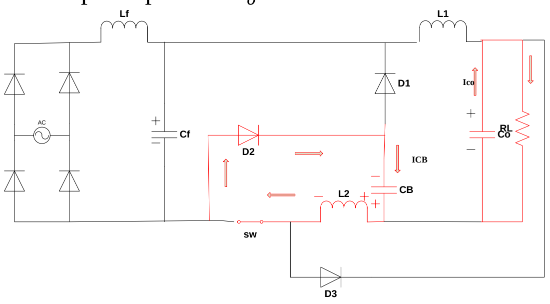

Fig. 2. Mode 1, Period 1 operation

- Period 2: S_1 is turned OFF; L_2 is discharged through D_3 and supplied to Co and load.

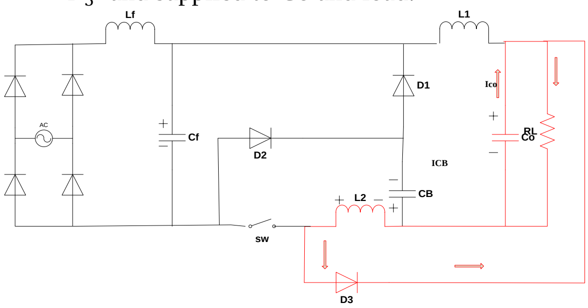

Fig. 3. Mode 1, Period 2 operation

- Period 3: L_2 is completely discharged. The load is supplied by the output capacitor Co.

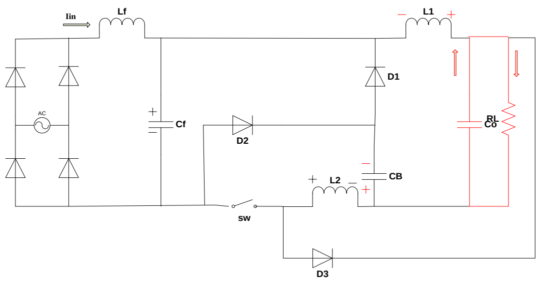

Fig. 4. Mode 1, Period 3 operation

Mode 2(Vin (θ) >V_B +V_o): the input voltage is greater than the sum of the intermediate bus voltage and the output voltage.

- Period 1: S_1 is turned ON; L_1 and L_2 are charged by the difference of voltage across them.

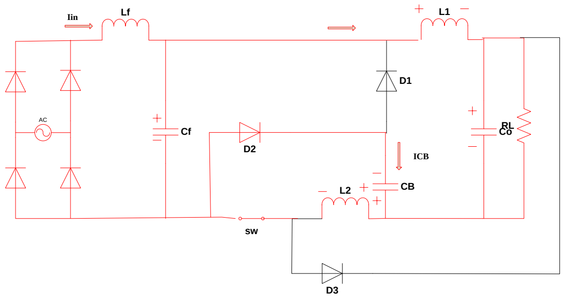

Fig. 5. Mode 2, Period 1 operation

- Period 2: S_1 is turned OFF; the energy of L_2 is released to Co and current is supplied to the load through D_3. Part of the input power is supplied to the load directly. L_1 is discharging to charge Co and C_B this period lasts as long as L_2. has current.

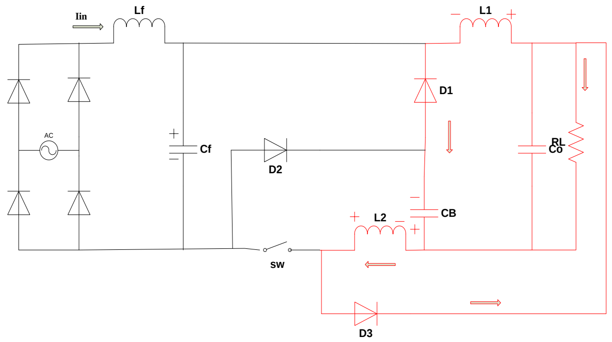

Fig. 6. Mode 2, Period 2 operation

- Period 3: This period lasts as long as L_1 has current and it supplies to Co and load.

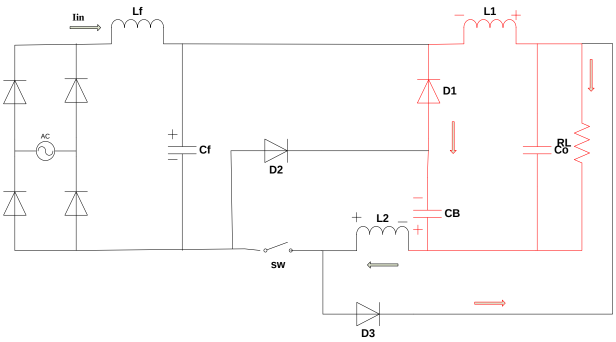

Fig. 7. Mode 2, Period 3 operation

- Period 4: Only Co delivers power to the load.

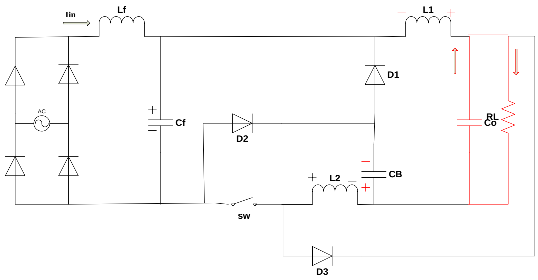

Fig. 8. Mode 2, Period 4 operation

This Integrated buck-buck boost converter shapes the distorted input current waveform to a sinusoidal current that is in phase with the input voltage and supplies a highly reduced voltage at the output without using a transformer.

IV. MATLAB/SIMULINK MODEL AND SIMULATION RESULTS

Here simulation is carried out for two cases in Case 1 AC to DC conversion without APFC is presented and in Case 2 with APFC is presented.

A. *Simulink Model and Simulation Result of AC-DC Converter Without PFC*

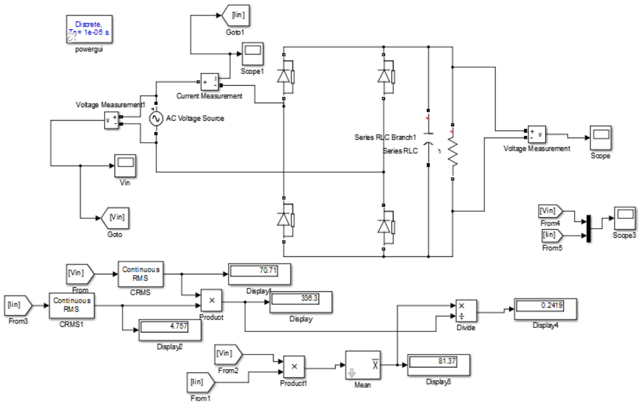

Fig. 9. AC-DC converter without PFC

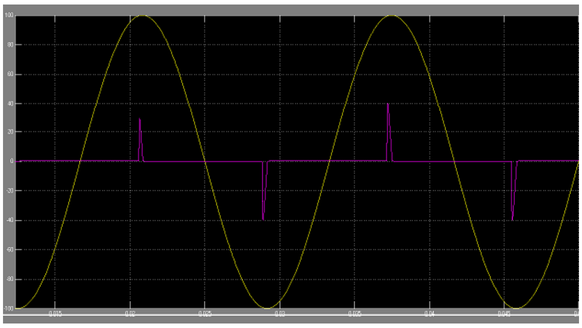

Fig. 10.Input voltage and current Waveform of AC-DC converter without PFC

Input Power Factor = 0.2419

From the waveform it is clear that input current is highly distorted and non sinusoidal with respect to input voltage. Result shows that power factor is very low of about 0.2419. Low power factor results in many supply side issues.

B. *Simlink Model and Simulation Result of Proposed Converter with PFC*

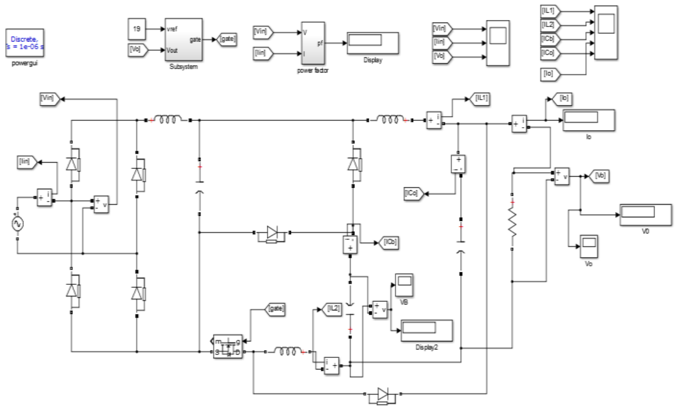

Fig. 11. Integrated Buck-Buck Boost AC-DC converter with PFC

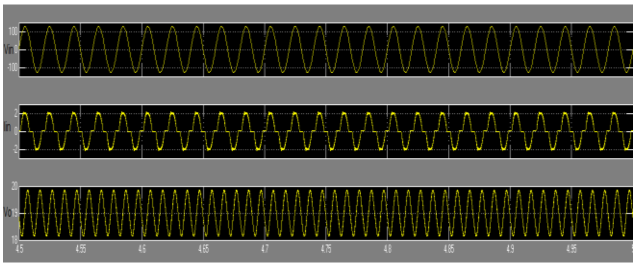

Fig. 12.Input voltage, input current and output voltage Waveform of proposed converter with PFC

Input power factor=.968
Intermediate bus voltage=113(<130)

C. *Simlink Model and Simulation Result of Proposed Converter with PFC with DC motor load*

Permanent magnet DC motor speed regulation can be achieved by using PFC integrated-buck-buck boost converter. Fuzzy logic controller is used to obtain speed regulation. Fuzzy logic controller has been applied to regulate speed of permanent magnet dc motor using integrated buck-buck boost converter. Duty ratio adjusts automatically with respect to speed as a crisp value is obtained by the fuzzy controller. Error signal and delta error signal are input to the fuzzy controller. Nominal value for the error feed back is hence obtained. FIS structure used in simulation is Mamdani. The crisp value was obtained by centroid method. Fuzzy controller does not require mathematical model of the system. It is suitable for non linear control. Fuzzy controller is not a precise controller. It mainly depends on once engineering commensence, intuitions and inferences. By using this controller almost accurate output can be obtained.

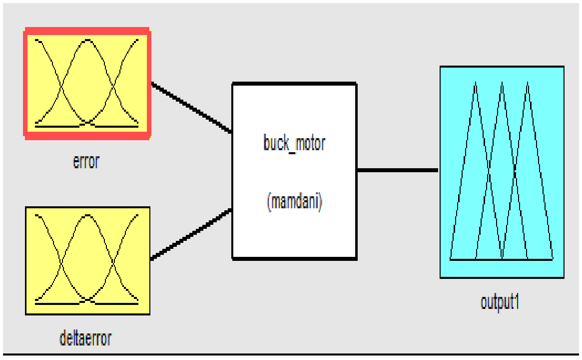

Fig. 13. Fuzzy input,output and inference block representation

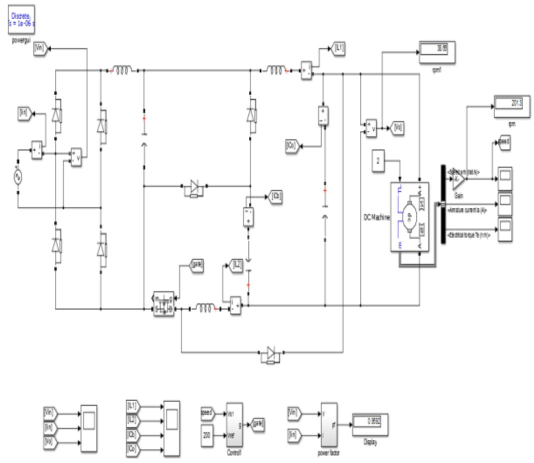

Fig. 14. Integrated Buck-Buck Boost AC-DC converter with PFC with DC motor load

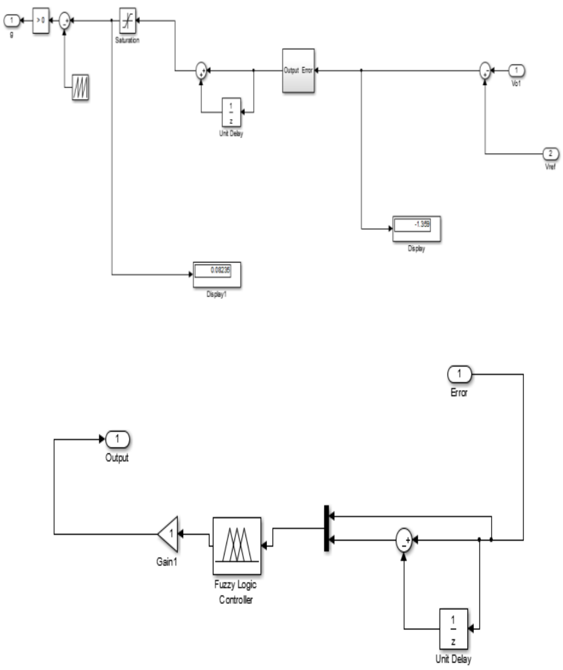

Fig. 15. Simulink model of control part

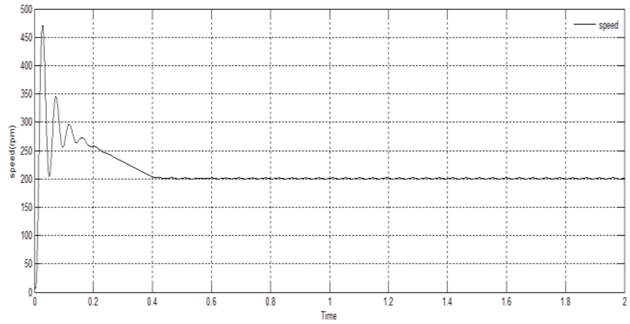

Fig. 16. Resultant speed waveform

Simulation results shows that by using proposed integrated buck- buck boost converter with fuzzy logic controller speed of permanent magnet dc motor can be regulated to a reference speed of 200 rpm with high power factor of about 0.96.

V. CONCLUSION

Proposed integrated buck-buck boost converter and its application in permanent magnet dc motor speed control using fuzzy logic controller is simulated using MATLAB/SIMULINK. Regulated output voltage of about 19V is obtained by using PI controller. Speed control of dc motor is achieved using fuzzy logic controller. Results shows that high power factor,low intermediate bus voltage and speed control of dc motor can be obtained for universal line application(90rms-270rms).

APPENDIX

Input Voltage=90-270Vrms
Output Voltage=19V
Power Output=100W
Switching Frequency=20kHz
L_1=106µH
L_2=46µH
C_B=5mF
C_o=5mF
Input filter inductor,L_f=2mH
Input filter capacitor,C_f=2µF
DC motor reference speed=200rpm

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