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An Efficient Power Factor Correction Converter for Low Voltage Applications

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***Abstract*—A single-stage three-level isolated ac/dc power factor correction (PFC) converter for high dc-link voltage low- power application with increased efficiency is presented in this paper. For achieving this, both ac/dc and dc/dc stages are effectively integrated. The efficiency is increased by the method of synchronous rectification. Using this method, all the switches are shared. The bus voltage regulation and output voltage regulation can be achieved without introducing additional switches with the proposed converter and switching scheme. Two independent PI controllers are used for this. This converter is used for low voltage applications such as laptop chargers, mobile chargers, lamps, etc.**

***Index Terms*— power factor correction; dc-link voltage; synchronous rectification; PI controller.**

I. INTRODUCTION

Power Factor represents the fraction of total power that is used to do the useful work. The aim of any electric utility company is unity power factor because low power factor has many limitations .These include : large line losses, large KVA rating and size of electrical equipment, greater conductor size and cost, poor voltage regulation and large voltage drop, low efficiency, and penalty from power supply company.
Different methods of power factor correction are avail- able. The simplest method of power factor improvement is a Passive PF correction (PFC) circuit which consists of inductive and capacitive filters which makes it bulky and heavy. High frequency two-stage active PFC converters have been proposed to operate at high frequency and reduce the size of the circuit. It consists of ac/dc PFC converter to shape the input current close to sinusoidal waveform in phase with the grid voltage and the second stage dc/dc converter provides the galvanic isolation and output voltage regulation. Moreover, constant switching losses associated with power switches reduce the efficiency of the converter. To overcome the drawbacks of the two stage approach, many single-stage ac/dc converters have been developed by integrating the PFC circuit and the dc/dc converter [5]-[6],[8].
Single-stage ac/dc converters are available which reduces the number of switching elements and is a cost-effective approach [3].In these converters, the front-end PFC stage and dc/dc stages are integrated and their operations are performed in a single-stage by sharing some of the switches and control scheme [4].A boost converter is a common front-end PFC interface due to its simple structure, good THD reduction performance and unity power factor operation capability [2]. To provide sufficient hold up time and to act as a buffer ,an

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energy storage unit such as inductor or capacitor is located in between two stages.

This study proposes a single stage three level isolated ac-dc PFC converter for high dc-link voltage and low-power applications. It is achieved through the effective integration of ac/dc and dc/dc stages where all the switches are shared between input current shaping and output voltage regulation. When comparing with existing three-level single-stage topologies, the proposed converter offers minimum number of components and does not require any auxiliary circuit except a diode bridge and an inductor. The middle two switches are turned ON under zero current in DCM operation and the upper and bottom switches under zero voltage. This increases the efficiency of the converter. Also, high PF can be achieved at high line-voltage due to the flexible dc-link voltage structure.

II. Existing System

A. Three-Level Single-Stage PFC Converter

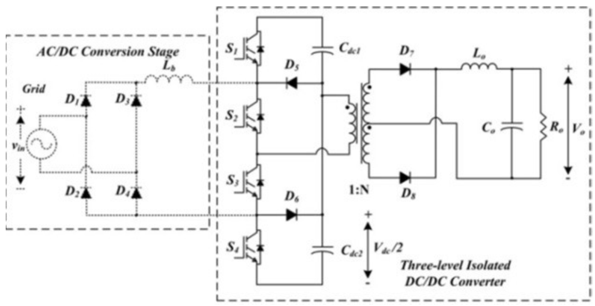

Fig. 1. Existing System Topology

The existing single-stage three-level isolated power factor correction converter[1] is an integrated version of a boost PFC circuit and three-level isolated dc-dc converter. The two stages include the ac/dc conversion stage which is basically a boost PFC circuit and the second stage is a three-level isolated dc/dc converter which consists of a diode bridge and an inductor. This converter is called as A Fully Integrated Three- Level Isolated Single-Stage PFC Converter. In this converter, all the switches are shared between the two-stages which makes it a fully-integrated single-stage converter without any additional auxiliary switches. It is called as three-level since three different voltages appear across the primary side of the transformer which include Vdc/2,-Vdc/2 and 0 voltages. The switches S1 to S4 applies these voltages at the primary.

III. Switching Scheme

The switching scheme[1] of both existing system and modified system remains the same.There is a phase shift of 180 for switches S2-S3 and S1-S4.For the two signals to overlap,the duty ratios of S2-S3 should be greater than 0.5.The input inductor current is considered discontinuous. The switching scheme is as follows: S1 is turned ON right after S3 is turned OFF, and similarly,S4 is turned ON when S2 is turned OFF.To avoid short-circuit,a dead-time should be inserted in between the turning ON instant of S1 and turning OFF instant of S3.

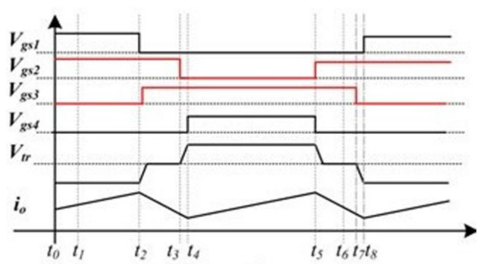

Fig. 2. switching scheme

IV. OPERATION MODES

The operation modes[1] is explained as follows: Mode 1 [t0 ¡ t ¡ t1]:
Switches S1 and S2 are turned ON in this mode.The upper dc-link capacitor Cdc1 starts discharging and applies Vdc/2 to the primary side of the transformer so that primary current increases linearly.Diode D8 conducts at the secondary side of the transformer.The voltage across the output inductor is Vlo=Vdc/2N Vo.In this mode,there is no role for the boost inductor Lb.

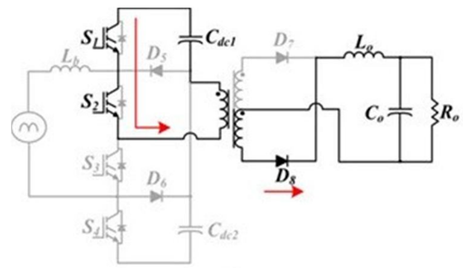

Fig. 3. Mode 1

Mode 2 [t1 ¡ t ¡ t2]

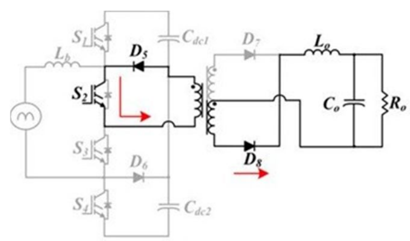

Fig. 4. Mode 2

At t=t1,S1 is turned OFF and S2 is turned ON.Diode D5 conducts due to the current in the leakage inductance and the primary side current freewheels.Hence, zero voltage is applied across the primary.The voltage across the output inductor is Vo and the output inductor current decreases linearly.
Mode 3 [t2 ¡ t ¡ t3]
At t=t2,S3 is turned ON and S2 still remains ON. The primary current continuous to freewheel and zero voltage is applied across the primary side; hence, the output inductor current continuous to decrease under output voltage. Mean- time, Vin is applied across Lb , and input current increases linearly storing energy in the inductor.

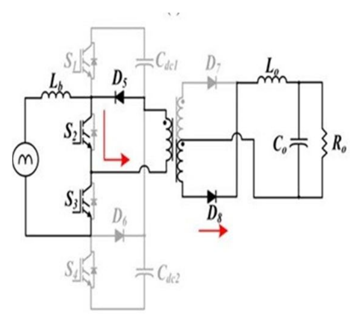

Fig. 5. Mode 3

Mode 4 [t3 ¡ t ¡ t5]
In the beginning of this mode, S2 is turned OFF and S4 is turned ON, while S3 is kept on. Within this time interval, two operations are completed. The energy stored in the input inductor is transferred to the dc-link

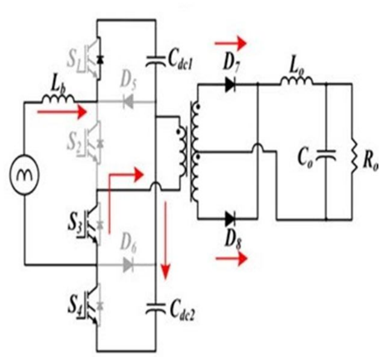

Fig. 6. Mode 4A

capacitors. The inductor current decreases linearly under Vin Vdc. Meantime, Vdc/2 is applied across the primary side of the transformer. The current in the leakage inductance is transferred to the lower dc-link capacitor Cdc2.

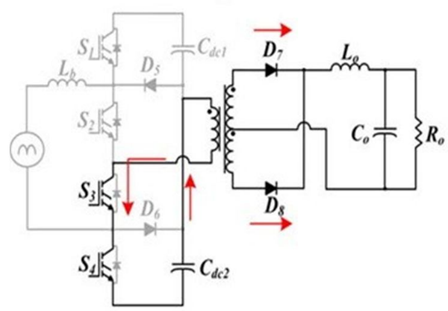

Fig. 7. Mode 4B

This causes the output current to commute from D8 to D7 . At the end of this time interval, the energy in the input inductor is completely transferred to the dc-link capacitors and the commutation of the output diodes is completed.Depending on the dc bus voltage, and input current, one of these operations ends earlier than the other one. In this case, the energy stored in Lb is transferred to the dc-link at t = t5 . Then, the current commutation from D8 to D7 is completed at t = t6 .

Mode 5 [t5 ¡ t ¡ t6]

Cdc2 discharges over to the load and Vdc/2 is applied across the primary side of the transformer. The voltage across the output inductor is VLo = Vdc/2N Vo. The input current remains at zero in DCM mode.

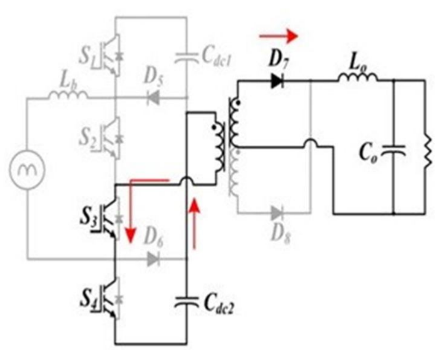

Fig. 8. Mode 5

Mode 6 [t6 ¡ t ¡ t7]
At t = t6, S4 is turned OFF, and only S3 is on. This allows leakage current to freewheel through D6, and zero voltage is applied to the primary side. The output current decreases linearly under Vo.

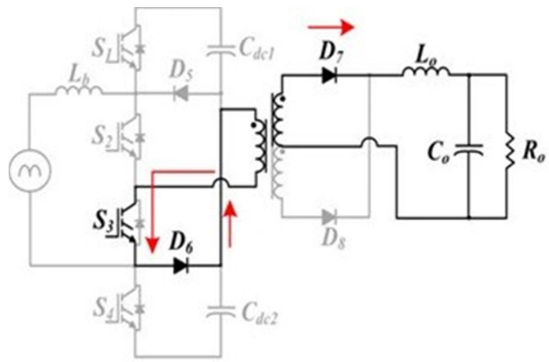

Fig. 9. Mode 6

Mode 7 [t7 ¡ t ¡ t8]
At t = t7, S2 is turned ON. The energy from the input is

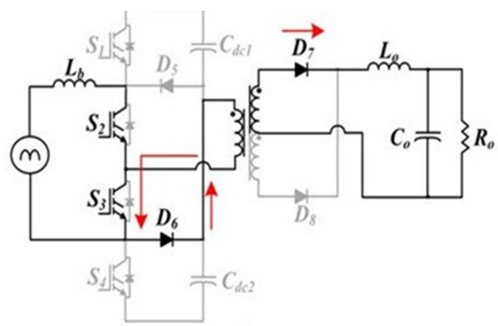

Fig. 10. Mode 7

stored in the inductor. This is similar to Mode 3, except that this time the primary side current is opposite to that in Mode 3 and freewheels through D6 .
Mode 8 [t8 ¡ t ¡ t10]
At the beginning of this interval, S3 is turned OFF, S1 is turned ON, and S2 remains ON. This mode is similar to Mode 4, where the stored energy in the inductor is transferred to the dc bus capacitors, and Vdc/2 is applied to the primary wind- ings. In the meantime, the output inductor current commutates from D7 to D8.

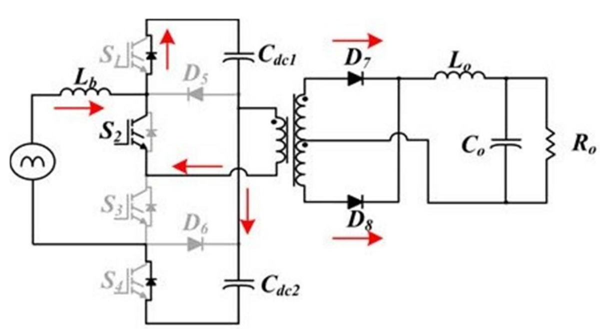

Fig. 11. Mode 8A

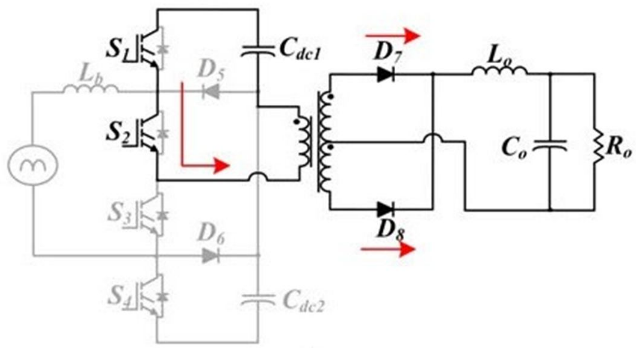

Fig. 12. Mode 8B

V. Simulation Results

The simulation of the proposed converter is performed and the following results are obtained.The input voltage and input current obtained as a result of closed loop simulation is given in fig 13.The input inductor current is shown in fig 14.The waveform for dc-link voltage is shown below fig 15.

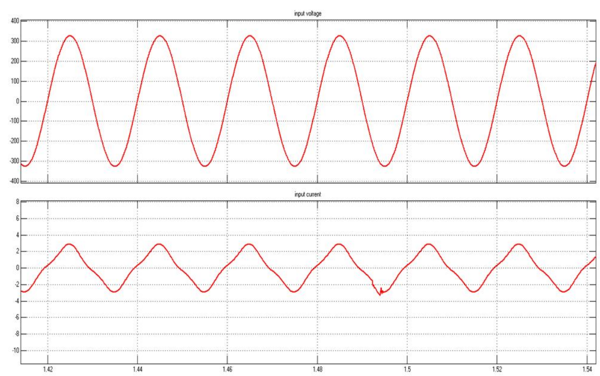

Fig. 13. Input Voltage and Input Current

VI. Modified System

The existing system has a flexible dc-link voltage struc- ture.So, when dc-link voltage increases,power factor in- creases and therefore efficiency decreases.So,modification is be done to increase the efficiency using synchronous recti- fication.So,the existing single stage three level isolated PFC converter is modified to improve the efficiency of the system.In this case,the diodes present at the output diode rectifier can be replaced with MOSFETs.The drop across diode is 0.7V.

A. Synchronous Rectification

Synchronous Rectification is the process used for im- proving the efficiency of rectification by replacing diodes with actively controlled switches. The constant voltage drop of a standard p-n junction diode is between 0.7 V and 1.7 V which causes significant power loss in the diode. When conducting, MOSFETs have a constant very low resistance known as on-resistance (Rds(on)). This can be made with an on-resistance as low as 10 m or even lower. The voltage drop across the transistor is then much lower thus, reducing power loss and improvement in efficiency.

B. Circuit Diagram

The modified system is shown in fig 17.The operation modes of the modified system is similar to the existing system operation.

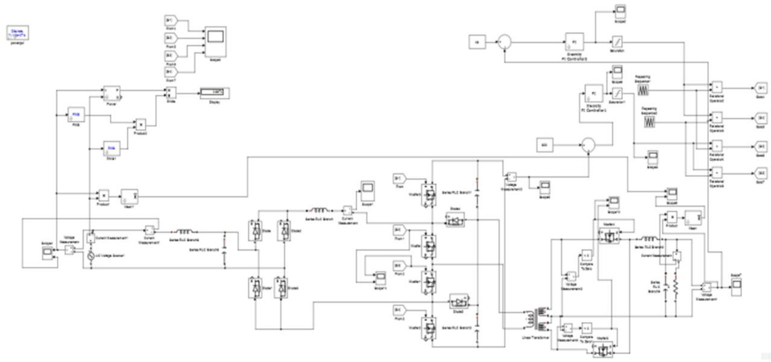

Fig. 16. Modified System

VII. COMPARISON OF EFFICIENCY

The existing system and the modified system has been simulated and the results obtained is compared and presented in the form of a table and is shown in fig 18.

PROPOSED CONVERTER	MODIFIED CONVERTER
Output Power = 384.8W	Output Power = 384W
Input Power = 407W	Input Power = 397W
Efficiency = 94%	Efficiency = 97%

Fig. 17. Comparison Table

VIII. CONCLUSION

In this paper, a three-level single-stage PFC ac/dc converter with increased efficiency is proposed for low-power applica- tions. A PFC inductor and a diode bridge are added to the conventional three-level isolated dc/dc converter,with suitable switching scheme to be compatible with single-stage operation. Two independent controllers for shaping the input current and regulating the output voltage, are adopted which simplifies the design and control of the circuit.The results of the analyses show that under 265 V line voltage, the PF can be increased to 0.9 with dc-link voltage of 600 V. On the other hand, the efficiency of the converter is 0.97.

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