A NOVEL UNITY POWER FACTOR INPUT STAGE WITH RESONANT DC LINK INVERTER FOR AC DRIVES

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Abstract: *This work describes a novel method in improving the input current total harmonic distortion as well as power factor of a three-phase resonant DC link inverter circuit. In this method, three bidirectional switches comprising MOSFET and four diodes are used across the three-phase supply and load. Also, resonant circuit with small inductor and capacitor is used to reduce the switching losses of the inverter. In a three-phase rectifier only two diodes conduct at any given time. As a result, the current in the third phase is zero. But in this method, the bidirectional switch corresponding to the third phase is turned ON. Once the input voltage crosses zero-voltage axes, the corresponding switch will be triggered. Each bidirectional switch receives a pulse of 30° in width following the zero-crossing point of corresponding phase voltage. The closing of bidirectional switches provides an alternate path for the input current to flow. The analysis and simulation of three phase rectifier with bi directional switches, experimental results of the inverter are also presented in this paper.*

Key words: *DC link inverter, MOSFET, three phase inverter, AC drives.*

1. Introduction

Traditionally, three-phase ac-to-dc high power conversion is performed by diode or phase-controlled rectifiers. Due to the commutation of these structures at the zero crossing of the current, they are also called "line-commutated" rectifiers. These rectifiers are robust and present low cost, but draw non sinusoidal currents or reactive power from the source, which deteriorate the power quality. To compensate for the harmonic distortion generated by the standard diode rectifiers, passive linear filters or power factor correction structures can be employed [1–3]. The multi pulse three-phase rectifiers achieve harmonic cancelation by introducing phase shift by means of special three-phase transformers [4-5]. Moreover, the simplicity and reliability ability of the diode rectifiers are preserved. However, they are heavy, bulky, and expensive.

Three-phase pulse width modulation (PWM) rectifiers are widely employed in low- and medium-power drive applications where the requirements established by international standards should be satisfied [6–9]. These structures are the most promising rectifiers from a power quality viewpoint [10-12] since they can present low harmonic distortion and unity power factor.

Recent trends in high-power rectifiers have introduced a new class of three-phase rectifiers, the hybrid rectifiers [13–15]. The term "hybrid rectifier" denotes the series and/or parallel connection of a line-commutated rectifier and a self-commutated converter. The line-commutated rectifier operates at low frequency and has a higher output power rating. The active rectifier is designed to operate with a small power rating and at a high switching frequency [16].

The sub harmonic pulse width modulation strategy reduces the THD and switching frequency optimal pulse width modulation strategies enhances the fundamental output voltage. The multilevel inverter improves output voltage, reduces output total harmonic distortion and voltage stress on semiconductors switches. These schemes are confirmed by simulation results and experimental results [17].

THD analysis and distortion factor have been estimated for different modulation indices. From the analysis we can say that the THD for PS technique for MI =1 is less when compared with APOD, PD, POD and Hybrid control techniques. In that PS technique also, bipolar mode of operation has given less THD values compared to uni-polar [18].

The basic features of a feedback control systems are insensitivity to parameter variations and robustness. The proposed scheme is capable of producing nearly perfect sinusoidal voltage. The closed-loop controller helps to reduce the harmonic content more when compared to the open loop controller. Moreover, the zero-voltage switching reduces the dv/dt and di/dt of each switching device; this in turn decreases the EMI effect and switching losses. The fourth leg of the topology adds to its ability to handle unbalance loading conditions. The proposed scheme gives better results relative to the previous methods [19].

In this paper, the new approach uses the circuit employed in [20] along with modified resonant rear end inverter. By controlling the conduction period of bidirectional switches, power delivered to the load and then the power factor is increased and input current harmonics can be eliminated. The resonant inverter is formed by using one small inductor and one capacitor. An inverter is turned ON and turned OFF when the voltage across it or current through it is zero. So the switching losses and high voltage stresses are reduced.

2. Analysis

For the circuit analysis, six topological stages are presented, corresponding to the 0 to 180 half period. Two main situations can be identified:

1. In the stage I, III and V, there are only two conducting diodes. As a result, on a conventional three-phase rectifier, the current on the third phase remains null during that interval. In the proposed circuit, the switch associated with the third phase is gated on during that interval. For instance, during the 0 to 30 stage, the bidirectional switch is gated on, so the input current evolves from zero to a maximum value.
2. In the stage II, IV and VI, there are three conducting diodes, one associated with each phase. The three switches are off, so the converter behaves like a conventional rectifier with input inductors.
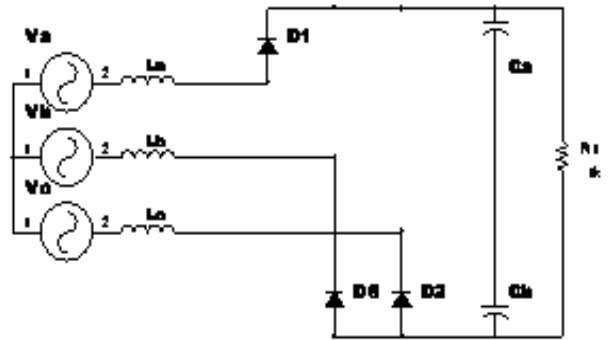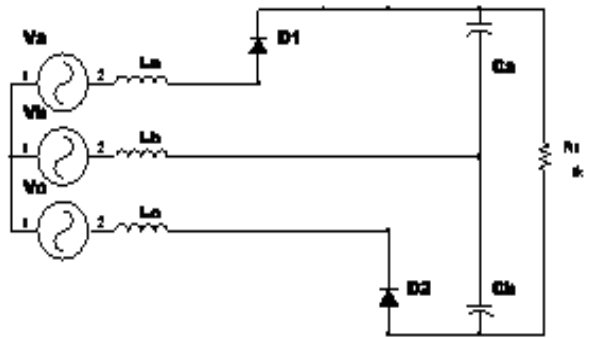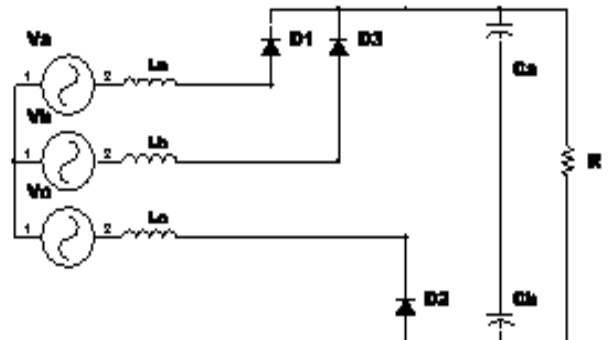
(c)

(d)

(a)

(e)

(b)
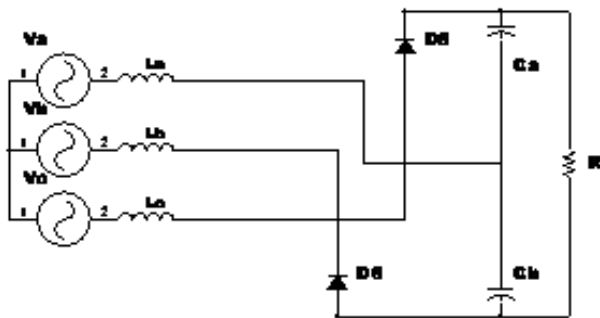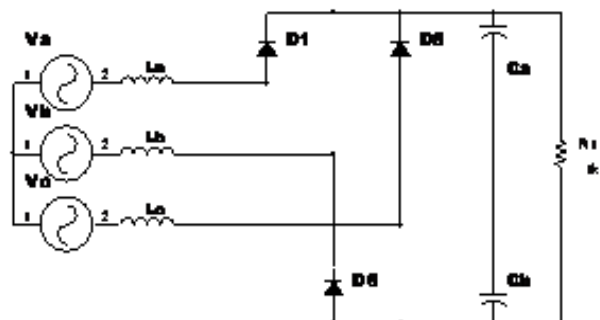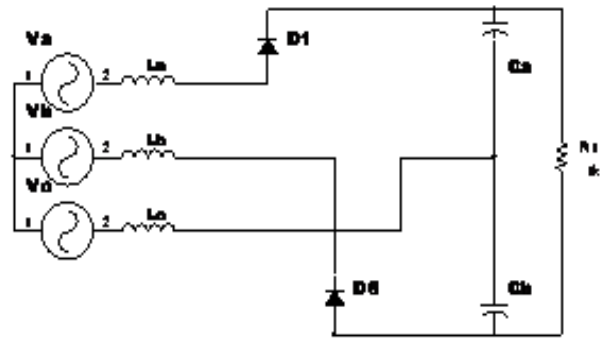
(f)

2.1 Bidirectional Switches

When gate circuit is open and V_{dd} is present, no current flow from drain to source. When gate terminal is made positive with respect to source, current flows from drain to source.

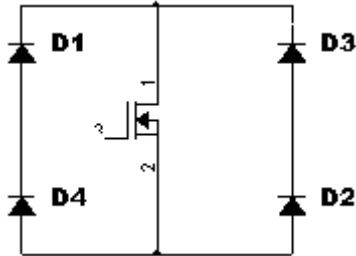The construction of bi-directional switch using four diodes and MOSFET is shown in Fig 2.

Fig 2. Bi-directional switch

During positive half cycle of the input voltage, diodes D1 and D2 are forward biased. When gate signal is applied with respect to source, current flow from drain to source. So the input current is supplied to the load through D1, MOSFET and D2.

During negative half cycle of the input voltage, diodes D3 and D4 are forward biased. When gate signal is applied with respect to source, current flow from drain to source. So the input current is supplied to the load through D3, MOSFET and D4.

2.2 Block Diagram

The block diagram of a novel unity power factor input stage with resonant dc link inverter for ac drives is shown in Fig. 3.
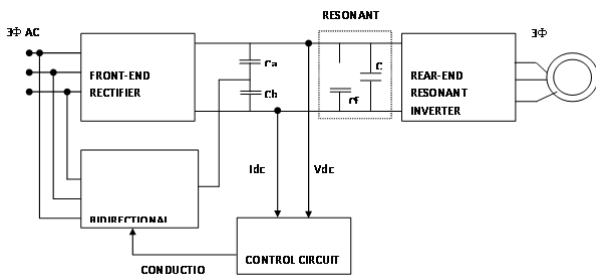

Fig. 3 Block diagram of a dc-link inverter

Where,

Ca, Cb – Two identical capacitors to provide a balanced central node
L, C – Resonant elements
Cf – Electrolytic capacitor for resonant dc link operation
Idc – dc link current
Vdc – dc link voltage

2.3 Circuit Diagram

The circuit diagram of a novel unity power factor input stage with resonant dc link inverter for ac drives is shown in Fig. 4.
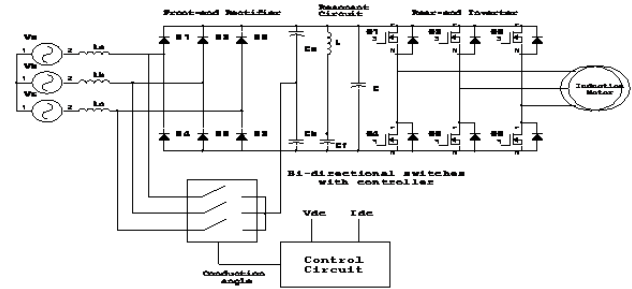

Fig. 4 Resonant Dc Link Inverter

3. Simulation Results

The source voltage and source current waveforms are shown in Fig. 5. The diode connected in the first phase is conducts from 30 degree to 150 of the input voltage. The diode will not conduct from 0 to 30 degree and 150 to 180 degree. During this period source current become zero and source voltage slightly reduced. The main objective of this paper is to make source current continuous and sinusoidal.

The waveform for source voltage and source current and output voltage of diode rectifier was simulated with and without bi directional switches is shown in Fig. 6. Without bi directional switches, the diode connected in the first phase of rectifier conducts only 30 to 150 degree of input supply voltage. So the input current is connected to the load during this period only. From 0 to 30 degree and 150 to 180 degree input current is not connected to the load. Due to this source current become discontinuous and non sinusoidal and also input voltage is slightly reduced. Therefore input supply power factor is reduced and load regulation and load performance is also reduced.
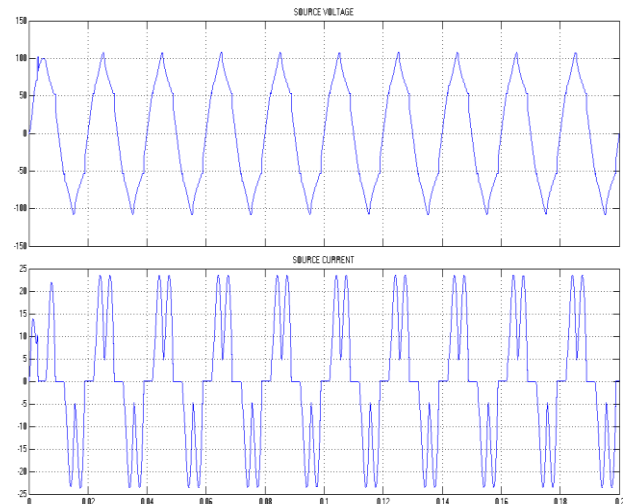

Fig. 5 Simulation Results of three phase rectifier

With bi directional switches, the source current is connected to the load continuously through the rectifier and bi directional switches. During the period 30 to 150 degree, the load is connected through the rectifier. During period 0 to 30 degree and 150 to 180 degree, the load is connected through bi directional switches. Therefore, the entire period 0 to 180 degree, the load is connected. So the source current waveform is improved and become sinusoidal and also source voltage is also improved. Due to this load voltage and load performance is also improved.
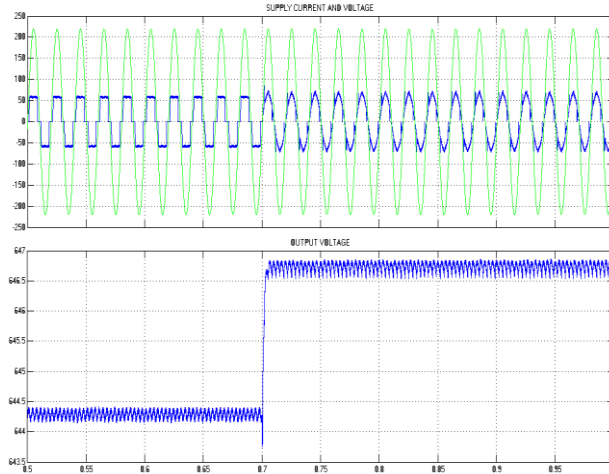

Fig. 6 Simulation Results of rectifier with bi directional switches with and without bi directional switches

4. Hardware Description

4.1 Hardware Circuit Diagram

The hardware circuit diagram of a novel unity power factor input stage with resonant dc link inverter for ac drives is shown in fig 7.
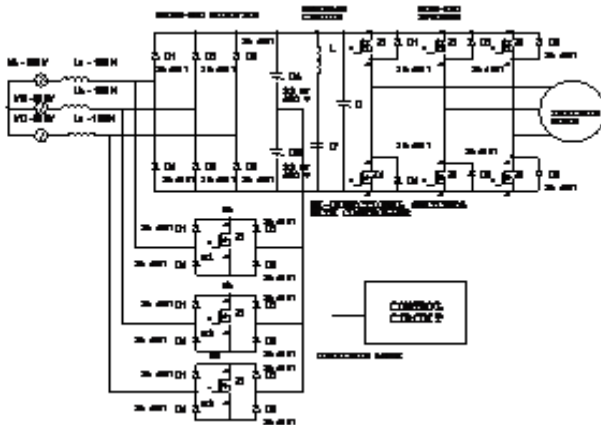

Fig 7. Hardware Circuit Diagram

5. Experimental Analysis and Result

For the purpose of experimental analysis, three-phase induction motor with the following specifications is chosen:

Power : 3 HP
Current : 4.8 A
Voltage : 440 V
RPM : 1440

Power factor is calculated by conducting the load test on three-phase induction motor. Load test on three-phase induction motor is conducted with dc-link inverter. For analyzing the improvement in the power factor, the same load test is repeated by dc-link inverter with bi-directional switches.

5.1 Load Test Using Dc-Link Inverter

The circuit diagram for conducting load test on three-phase induction motor is shown in Fig 8.
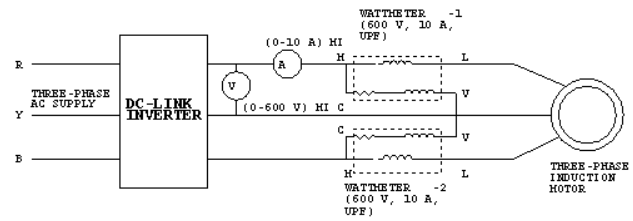

Fig. 8. Load test using dc-link inverter

Connections are given as per circuit diagram. The load is increased steps by steps and ammeter, voltmeter and wattmeter readings are noted and tabulated in the Table 1.

Table 1. Load Test Using DC-Link Inverter

S. No	Line voltage Volts	Line current Amps	Speed RPM	Input power Watts	Spring balance S1~S2	Torque N-m	Output power Watts	Power factor
1	440	1	1474	320	0	0	0	0.419
2	440	1.5	1450	800	5	4.75	721.25	.699
3	440	2	1436	1200	7	6.66	1001.51	.787
4	435	2.5	1416	1560	8.8	8.37	1241.13	.828
5	435	3	1404	1880	10.4	9.89	1454.09	.831
6	435	3.5	1384	2200	12	11.412	1653.96	.834
7	430	4	1384	2560	13.6	12.93	1855.01	.859
8	430	4.5	1370	2880	14.6	13.88	1947.7	.859

The input power, output power, torques and power factor are calculated by the following formulas:

1) Input power Pi = W1 + W2
   W1, W2 – Wattmeter readings

2) Output power Po = $\dfrac{2\pi Nt}{60}$ watts

3) Torque T = (S1 ~ S2).g.r N-m
   S1, S2 – Spring balance readings in Kg
   g – Acceleration due to gravity in m / sec2-9.81
   r – Radius of the brake drum in m

4) Power factor cosϕ = $\dfrac{W1 + W2}{\sqrt{3}.VL.IL}$

   VL – Line voltage in volts

IL – Line current in amps
Radius of the brake drum = 0.097 m
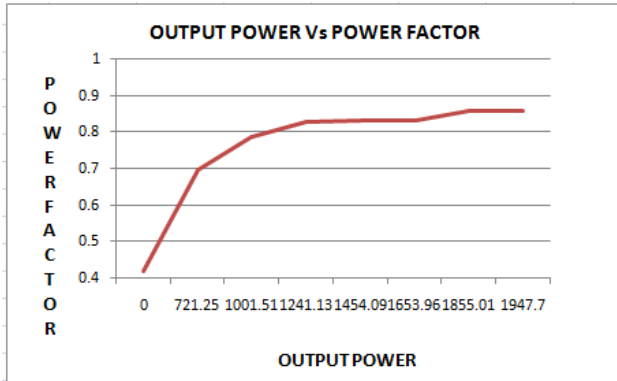Multiplication factor = $\dfrac{600 \times 10}{4}$
= 1500

Fig. 9. Input Power factor with variation in output power for Load test using dc-link inverter

The relationship between input power factor and output power for Load test using dc-link inverter is shown in Fig. 9.
The relationship between input power factor and line current for Load test using dc-link inverter is shown in Fig. 10.
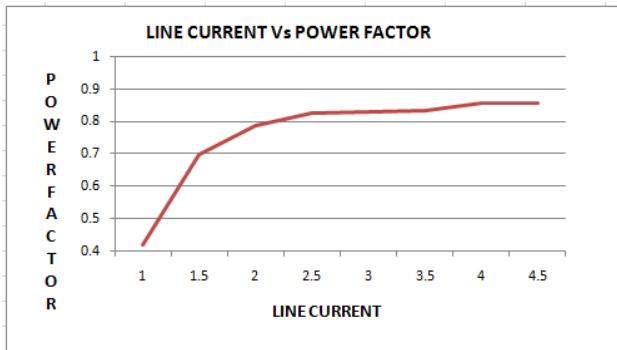

Fig. 10. Input Power factor with variation in output power for Load test using dc-link inverter

5.2 Load Test Using Dc-Link Inverter with Bi-Directional Switches

Connections are given as per circuit diagram. The load is increased steps by steps and ammeter, voltmeter and wattmeter readings are noted and tabulated in the Table 2.
The relationship between input power factor and output power for Load test using dc-link inverter with bi-directional switches is shown in Fig 11.
The relationship between input power factor and line current for Load test using dc-link inverter is shown in Fig. 12.
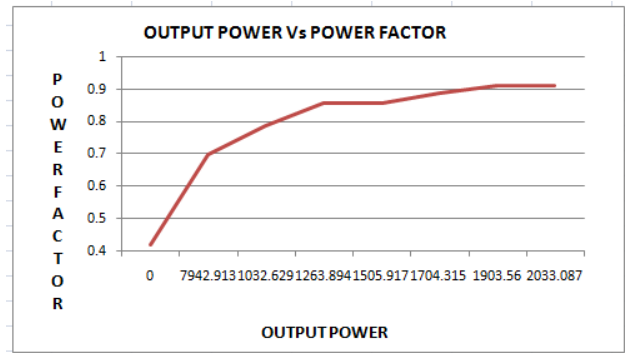

Fig. 11. Input Power factor with variation in output power for Load test using dc-link inverter with bi-directional switches

Table 2. Load test using dc-link inverter with bidirectional switches

| S. No	Line voltage Volts	Line current Amps	Speed RPM	Input power Watts	Spring balance S1~S2	Torque N-m	Output power Watts	Power factor
1	440	1	1474	320	0	0	0	0.4199
2	440	1.5	1450	800	5.5	5.2336	794.2913	0.6998
3	440	2	1440	1200	7.2	6.8513	1032.629	0.7873
4	435	2.5	1410	1620	9	8.5641	1263.894	0.8601
5	435	3	1400	1940	10.8	10.277	1505.917	0.8583
6	435	3.5	1380	2350	12.4	11.799	1704.315	0.8912
7	430	4	1375	2720	13.9	13.227	1903.56	0.9130
8	430	4.5	1370	3060	14.9	14.178	2033.087	0.9130
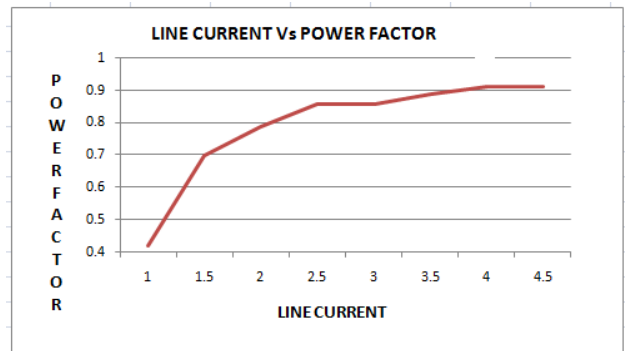
Fig. 12. Input Power factor with variation in line current for Load test using dc-link inverter with bi-directional switches

The power factor of the front-end rectifier is calculated using the equation mentioned with and without bidirectional switches. Before using bi-directional switches, the input power factor was 0.859. After using bi-directional switches, the input power factor is 0.9130. So the power factor is improved by 12%.
Each bi-directional switch receives a pulse of fixed 30 degree in width following the zero-crossing point of corresponding phase voltage. Since the bi directional switches are operated independent of load on the rectifier bridge, this method cannot provide optimum input power factor as well as THD under varying load conditions. So the input power factor after using bi-

directional switches is only 0.9130, about 12% improvement. Unity power factor can be achieved by varying the conduction period of bi-directional switches according to the load condition. The pulse width of the bi-directional switches is determined by the dc link current and dc link voltage.

6. Conclusion

The simulation results are obtained for three phase rectifier with and without bi directional switches show that sinusoidal input supply current waveform presents at the input stage. Experimental results obtained from three phase dc link inverter shows that improved power factor presents at the input stage. A power factor and input current THD improvement scheme for a suppressed-link delta modulated rectifier-inverter structure has been suggested in this paper and is verified to be functional over an extended operating range. Due to the low-frequency operation of the front bi-directional MOSFET switches, the gating circuit is simple, and more reliable. The low-frequency operation provides low switching losses. The MOSFET based bi-directional switches conducts only a small fraction of the total cycle, yielding a negligible switch KVA rating. Absence of series inductor at the dc link ensures fast converter response to any unexpected load changes. With these excellent rectifier power factor and inverter output voltage boosting capabilities, the proposed converter will be an excellent energy saver in a clean power environment.

7. References

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