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A HIGH EFFICIENT INDUCTION HEATING USING ULTRA SPARSE MATRIX CONVERTER

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Abstract— Presenting an Ultra Sparse Matrix Converter (USMC) to achieve efficient three phase induction heating with only 9 switches without any energy storage elements and Zero DC link current commutation scheme resulting in lower modulation complexity and very high reliability. The proposed topology reduces significantly the number of devices and complexity, achieves the necessary output and maximizes the life time of the device which is leading to an efficient, versatile and cost effective solution. The analytical and simulation results have been verified by means of a prototype applied to a novel total-active-surface induction heating appliance.

Index Terms— AC-AC Converter,Space Vector Modulation,Ultra Sparse matrix Converter,Zero Commutation Scheme

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1 Introduction

Induction heating is a non-contact heating process. It uses high frequency electricity to heat materials that are electrically conductive. Since it is non-contact, the heating process does not contaminate the material being heated. It is also very efficient since the heat is actually generated inside the work-piece. This can be contrasted with other heating methods where heat is generated in a flame or heating element, which is then applied to the work-piece. For these reasons induction heating lends itself to some unique applications in industry. Static frequency converters have been extensively applied in industry as a medium –frequency power supply for induction heating and melting installations. They are applied in all branches of the military, machine-building industries, domestic heating cooking devices and other purposes.

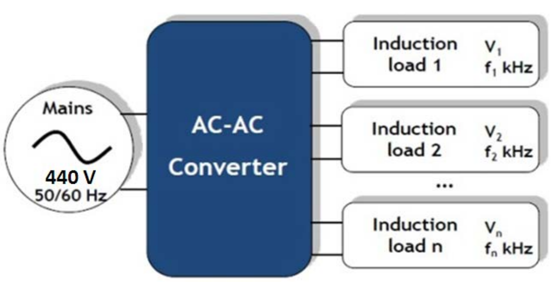

Fig 1 Conventional induction heating strategy

Increasing the frequency of operation of power converters is desirable, as it allows the size of circuit magnetics and capacitors to be reduced, leading to cheaper and more compact circuits. However, increasing the frequency of operation also increases switching losses and hence reduces system efficiency. Direct ac-ac conversion has been thoroughly studied in the past. However, the complex control scheme and higher cost has prevented it from being used in the low and medium cost applications, However to overcome this the conventional AC-DC-AC converter can be replaced to Ultra Sparse matrix converter which uses reduced number of switches and improves the efficiency.

2 Proposed modification of Induction Heating

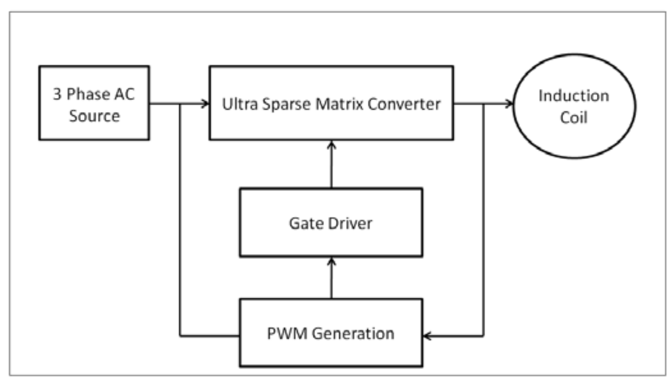

Fig 2 Proposed Modification of Induction Heating

Three-phase ultra sparse matrix converter having no energy storage elements requires only 9 IGBT to get the desired output.The modulation strategies commonly applied to control output power are based on modifying either switching frequency or duty cycle to achieve the desired output power.

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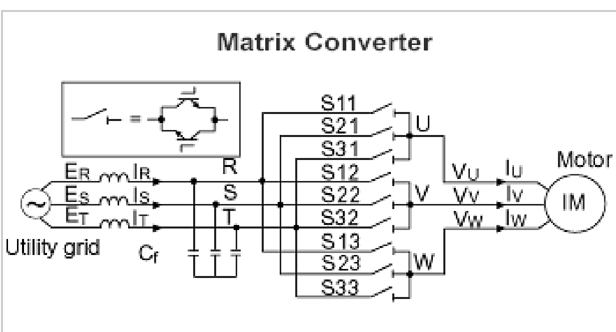
2.1 Topology

Ultra Sparse matrix converter is a indirect matrix converter with reduced number of components and a modulation scheme of low complexity and realization effort. It avoids multi-step commutation procedure of the conventional matrix converter which could impair the system reliability for operation in industrial environment.In this scheme of the AC-AC converter there are two main advantages: It is having a high power factor and a sine wave input current. Also the inverter circuit is composed with only a single controlled switch, which serves as a high-frequency generator.

3 Ultra Sparse Matrix Converter

Ultra Sparse matrix converter is a topology of Matrix converter which is used to directly convert AC to AC rather than AC to DC to AC as in conventional voltage source PWM AC Drives. Matrix converters have the capability of power regeneration and suppress input current harmonics and can be used as optimum drives for applications ranging from cranes, elevators and centrifuges where regeneration occurs, to air- conditioning fans and feed-water pumps where high harmonic countermeasures are required. Figure 3 shows the difference in the main circuit configurations of the matrix converter and the conventional voltage source PWM AC Drive. The matrix converter consists of small input filters, which in turn consists of reactors and capacitors, and 9 bi-directional switches.

Fig 3 Matrix Converter



Whereas, the voltage source PWM AC Drive is made up of a power AC Drive circuit which has a combination of a rectifying circuit on the input side, a smoothing circuit with capacitors on the intermediate part, and IGBTs on the output side.

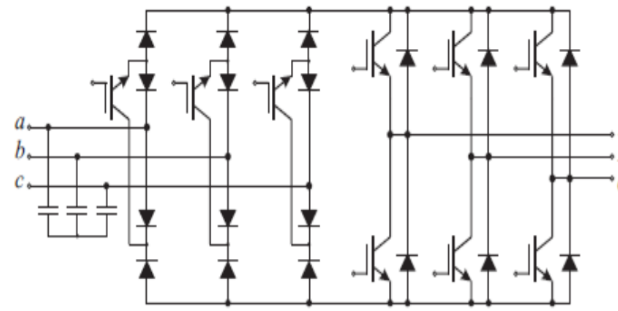


Fig 4 Ultra Sparse Matrix Converter

4 Operation of Proposed Converter

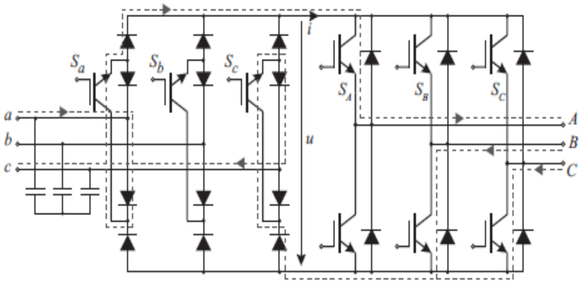
A complex, multi-step commutation strategy is employed to prevent short-circuitsbetween the input phases and open circuits in the output phases in conventional matrix converter, [3]. However, since the converter is separated into input and output stages a simpler zero dc link current commutation scheme can be used with the USMC [4].The output inverter stage is set into freewheeling mode, allowing the input stage to commutate under zero current in order to commutate the input stage. Consequently switching losses are not incurred by input stage.

A. Space Vector Modulation

A space vector modulation strategy which permits zero current commutation is used to provide sinusoidal input and output currents for the USMC [4]. The input phase having the highest absolute value is clamped for a sector that is π/6 wide while the other two phases are switched. Switching of the output stage and input stage is coordinated to ensure that the output stage is in freewheeling mode when input stage is switched.

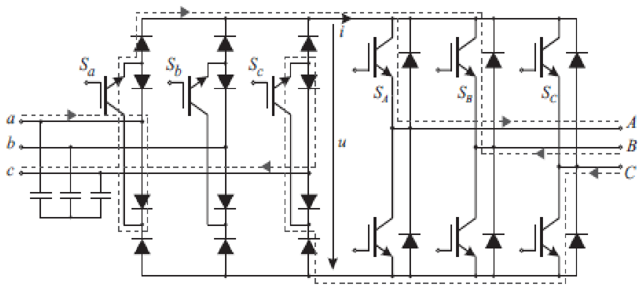
The operation of the converter with the input and output stages is shown.Both operating in sector 1, in which input phase a has the most positive value for a π/6 interval and the output stage is formed by a combination of the (100) and (110) vectors of the output stage. However under normal operation, the input and output sectors might not be synchronized. It is done under the assumption that the output current remains constant during the switching cycle due to the inductive nature of the load.

In state 1 input phase a is at its peak positive value and clamped to the positive dc link rail using input switch Sa. Switch Sc is turned on to conduct the return current. During this interval output leg SA has its high side switch active while low side switches of all other output switches are active.
In state 2, the input stage remains unchanged while the output leg SB changes from low side to high side operation.
The zero current switching of the input stage occurs in states 3 and 4. At first, output leg SC is switch to high-side operation in order to create a freewheeling state at the output. Then the input stage, under zero current commutates from Sc to Sb.

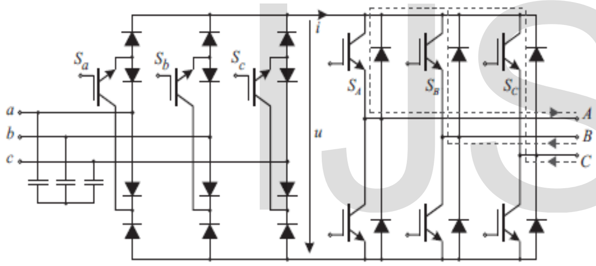


(a) State 1: $u = u_{ac}, i = i_A$

The converter then switches into state 5, which is similar to state 2 except that the dc link voltage is now uab and input switch Sb conducts the return current. In the final state (not shown in the diagram), output leg B



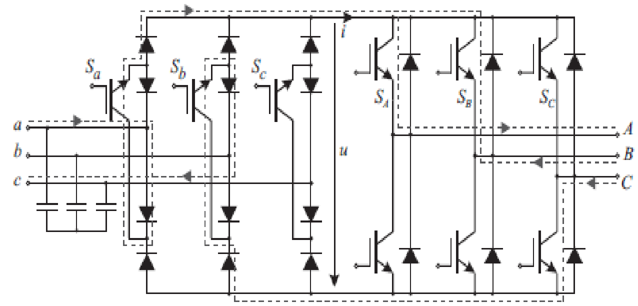
(b) State 2: $u = u_{ac}, i = -i_C$



(c) State 3, 4: u switched from u_{ac} to $u_{ab}, i = 0$

In a conventional matrix converter, a complex, multi-step commutation strategy is employed to prevent short-circuits between the input phases and open circuits in the output phases.However,with the USMC, a simpler zero dc link current commutation scheme can be used since the converter is separated into input and output stages. To commutate the input stage, the output inverter stage is set into freewheeling mode, allowing the input stage to commutate under zerocurrent. Consequently the input stage does not incur switching losses The drawback of the multistep commutation describe before is its complexity. Indirect matrix converters like the Ultra Sparse Matrix Converter provide a degree of control freedom that is not available for the Conventional Direct Matrix Converter. This can be used to simplify the complex commutation problem. It has been proposed to switch the in verter stage into a free-wheeling state, and then to commutate the rectifier stage with zero dc-link current. Fig 5 (a) shows the control of the power transistors in one bridge

switches from high to low side operation such that the output stage is the same as shown in state 1.
The time intervals of different switching states of both input and output stages, τn, are calculated based on space vector modulation to ensure sinusoidal input and output current.



(d) State 5: $u = u_{ab}, i = -i_C$

leg of the Ultra Sparse Matrix Converter. Fig 5 (b) shows the switching state sequence where s0; s7 = 1 indicates free-wheeling operation of the inverter stage. Furthermore, the dc-link current i is shown. It is interestingto note that by employing the zero dc-link current commutationstrategy the topology of the IMC could be reduced to the circuitstructure shown in Fig. (a), which is designated as the Ultrasparse matrix converter (USMC) since it has only 6 IGBTs

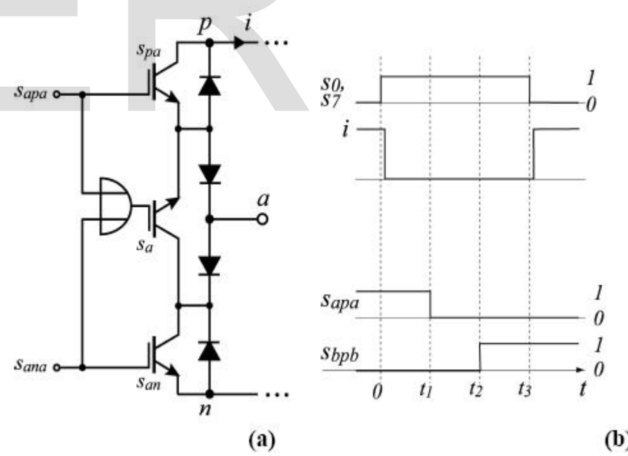


Fig 5 Zero DC link current commutation - USMC.

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Zero dc-link current commutation also allows for the circuit-topology shown in Fig. (b) to be utilized for three-phaseac-ac power conversion. The bidirectional current carrying capabilityof the input stage is achieved by combining a conventional-current dc-link rectifier and a voltage and/or current invertingswitching section, which is formed by two power transistorsand two diodes .

Accordingly, this converter is designatedas the inverting link matrix converter(ILMC). Comparedto the USMC, the ILMC

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has a similar number of power transistors,however the inversion of the inverter output stage inputcurrent has to be performed at the switching frequency whenthe phase displacement of load current and load voltage fundamentalis greater than .

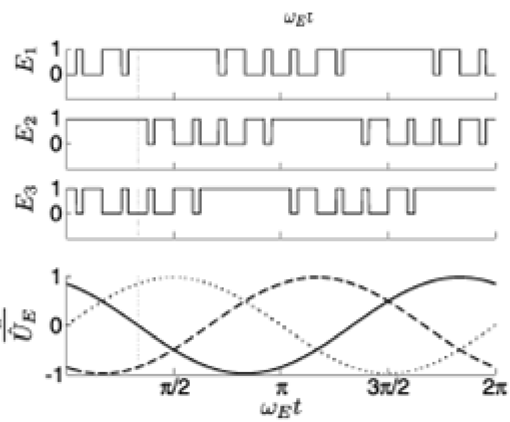

Fig 6 current commutation in 3 phases

This results in higher switchinglosses and increased control complexity, therefore the ILMC isnot further considered in this paper. In addition, the input stageof any USMC can be connected to a three-level voltage dc-link inverter output stage where in thiscase the input stage is from a VSMC .The mid pointof the three-level inverter is connected to the star point formedby the input ac filter capacitors.

A three-level output voltage can alsobe obtained from the conventional IMC by using a three-leveloutput voltage modulation method .For the USMC, since the dc-link current has to always be positive, therefore the commutation can be performed irrespectiveof the switching state of the output stage when a freewheelingdiode is provided in the dc-link.

The explicit freewheeling diode is not necessary as the outputstage can provide the required free-wheeling current path in caseof an input stage interruption. However, commutating the inputstage at a nonzero dc-link current causes additional switchinglosses. Therefore, a coordination of the switching state changesof the input and output stage is advantageous for the USMC.The use of the freewheeling diode for zero current commutationdoes potentially increase the circuit reliability because apath for the dc-link current is provided in case an input stage power transistor is not turned on due to, say, a gate drive failure.

As is obvious from Fig.(6), the switching function of the powertransistors of the USMCcan be derived from the switching functionsof the power transistors of a bridge leg of the SMCby using an OR gate.

5 Switching State Machine

For simulation and experimental verification, a state machine that performs and controls the commutation, being dependent on a superior controller, the combination of the high- frequency and the low-frequency pulse patterns, and the wanted high frequency output voltage is required. The demand of commutating not only between the main states of one interval but also between the main states of adjacent intervals first makes a general view of all possible commutations—fulfilling the conditions mentioned before—necessary.

Table 1

Parameters Details

Input voltage	420 peak voltage
IGBT Maximum Switching frequency	1Mhz
Diode reverse breakdown voltage`	1000v
PWM Reference frequency	27*BaseFrequency
Phase	-120 0 120
BaseFrequency	5KHz
Load Active Power	1KW
Load Inductor Reactive power	.1KW

As per the table details the input is given to the USMC and based on the PWM generation principle the frequency is increased to 27 times to the base frequency. According to the induction heating ,When the induction coil is placed next to or around a workpiece, the lines of force concentrate in the air gap between the coil and the workpiece. The induction coil actually functions as a trans- former primary, with the workpiece to be heated becoming the transformer secondary. The force field surrounding the induction coil induces an equal and opposing electric current in the workpiece, with the workpiece then heat- ing due to the resistance to the flow of this induced electric current.

By eddy current and hysteresis loss the heat is generated and The rate of heating of the workpiece is dependent on the frequency of the induced current, the intensity of the induced current, the specific heat of the material, the magnetic permeability of the material, and the resistance of the material to the flow of current.

The induced currents are sometimes referred to as eddy-currents, with the highest intensity current being produced within the area of the intense magnetic fields.

6 Performance Results

6.1 Input Voltage

Below Screenshot shows the given Input voltage 230V and 50 Hz for each phase with a phase shifting of 120 degree difference.

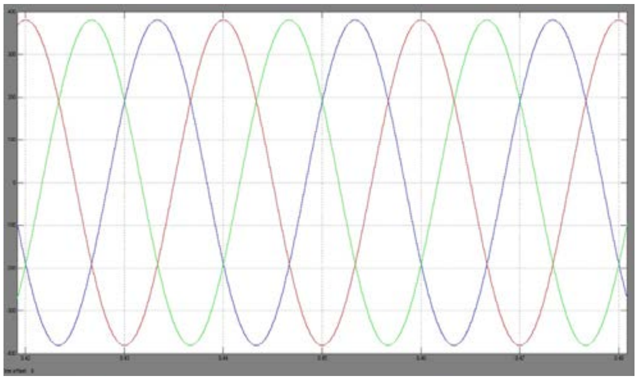

Fig 7 Input Voltage

6.2 PWM with Reference Signal

Shows the high frequency carrier wave signal with the input voltage .

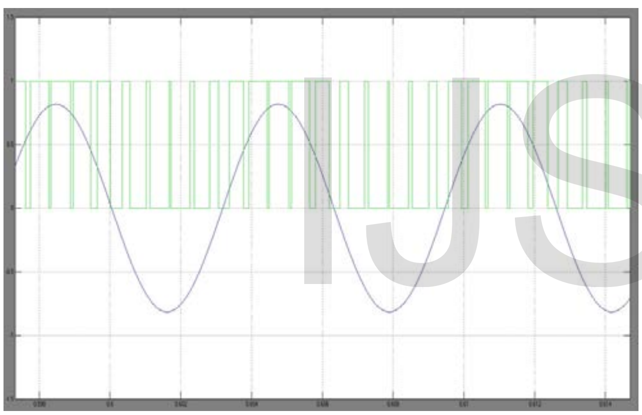

Fig 8 PWM Reference Signal.

6.3 Output Voltage

Shows the output voltage for the three phase Ultra sparse matrix converter which we got as 390V.

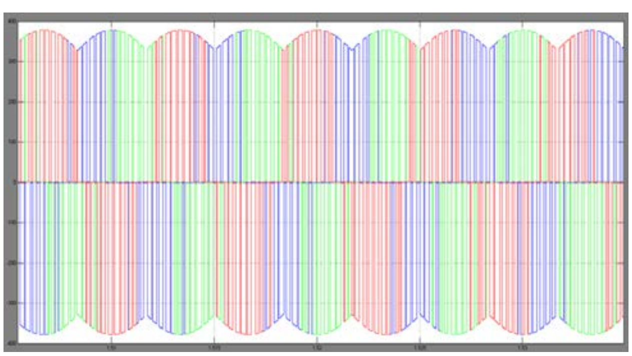

Fig 9 Output Voltage waveforms

7 Advantages

Ultra Sparse Matrix converter circuits have following effects compared to conventional AC Drive circuits.

7.1 Power harmonics suppression

Less than 7% THD of input current and more than 98% input power factor is realized without any specific measures taken

7.2 Longer operating life

Main circuit does not have endurableparts like an electrolytic capacitor. This accounts for longer operating life of the main circuit and less maintenance.

7.3 Elimination of derating

Reduced operation during low-frequency operation is unnecessary with the elimination of current constriction on any specific device.

7.4 Regeneration of Power

Continuous regeneration of power is possible due to unique bi-directional switches for directly connecting the power supply and loads.

7.5 High-efficiency

Only bi-directional switches are used to connect the power supply and loads, leading to higher efficiency in operation

8 Conclusion

Direct ac-ac conversion has proven to be a convenient technique which can be extended to the ubiquitous dc-link inverters present in most household appliances. It combines higher power density with a reduced number of conversion stages and energy-storage elements. However, the higher number of switching devices and complex control scheme has prevented it from being widely used Thus in this paper Induction heating has been carried out using Ultra sparse Matrix converter and it has proven the better performance with the its experimental results.

The USMC is the most reduced form of the indirect matrix converter that is well-suited for applications demanding unidirectional power flow. The USMC has minimal semiconductor requirements, comprising only 9 unidirectional switches and 18 diodes. Like the other converters in the indirect matrix family, the USMC uses a simple zero dc-link current commutation scheme to reduce the switching losses of the rectifier stage.Both simulation and experimental results have demonstrated that the USMC produces sinusoidal cur rents of a high quality at both the input and output which proves the efficiency.

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