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PV based Isolated DC-DC Converter Fed Induction Motor Drive for Railway Applications

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Abstract-The dual active bridge (DAB) topology as an attractive alternative to full-bridge topology. In comparison with the conventional full bridge topology, the output inductor is transferred to the ac side, and is in series with the leakage inductance. Consequently, the energy in the leakage inductance is transferred to the load without causing reverse recovery losses in the output diodes. This allows higher switching frequencies and, therefore, an increase in power density. In this project three-phase dual active bridge (DAB) topology used as high-power-density dc–dc converter for railway applications. The three-phase DAB is analyzed concerning the current intervals, the output power, and soft switching region, including the impact of zero-voltage switching capacitors. Furthermore, two measures are proposed to achieve soft-switching in the entire operating range, being auxiliary inductors and a straightforward switching strategy called the burst mode. Optimal component values are calculated to minimize losses in the complete operating range and to assess which measure is best suited. The simulation results are presented by using Matlab/Simulink software.

Index Terms—DC–DC power conversion, power electronics, power supplies, rail transportation electronics.

I. INTRODUCTION

Solar energy is the most low cost, competition free, universal source of energy as sun shines throughout. This energy can be converted into useful electrical energy using photovoltaic technology. The steady state reduction of price per peak watt and simplicity with which the installed power can be increased by adding panels are attractive features of PV technology. Among the many applications of PV energy, pumping is the most promising. In a PV pump storage system, solar energy is stored, when sunlight is available as potential energy in water reservoir and consumed according to demand. There are advantages in avoiding the use of large banks of lead acid batteries, which are heavy and expensive and have one fifth of the lifetime of a PV panel. A number of simulation DC motor driven PV pumps are already in use in several parts of the world, but they suffer from maintenance problems due to the presence of the commutator and brushes. Hence a pumping system based on an induction motor can be an attractive proposal where reliability and maintenance-free operations with less cost are important. The effective operation of Induction motor is based on the choice of suitable converter-inverter system that is fed to Induction Motor.

For PV applications like pumping these converters could do a good job as pumping is carried out at high power. Thus a new push pull converter which is two switch topology can do justice by giving a high power throughout. The Induction Motors are the AC motors and hence from converter, an inverter system is also required to obtain an AC voltage. This inverter is chosen based on its advantages and it is fed to induction motor.

Photovoltaic technology is one of the most promising for distributed low-power electrical generation. The steady reduction of price per peak watt over recent years and the simplicity with which the installed power can be increased by adding panels are some of its attractive features. Among the many applications of photovoltaic energy, pumping is one of the most promising. In a photovoltaic pump-storage system, solar energy is stored, when sunlight is available, as potential energy in a water reservoir and then consumed according to demand. There are advantages in avoiding the use of large banks of lead-acid batteries, which are heavy and expensive and have one-fifth of the lifetime of a photovoltaic panel. It is important, however, that the absence of batteries does not compromise the efficiency of the end-to-end power conversion chain, from panels to mechanical pump. Photovoltaic panels require specific control techniques to ensure operation at their maximum power point (MPP). Impedance matching issues mean that photovoltaic arrays may operate more or less efficiently, depending on their series/parallel configuration.

II. TOPOLOGY OVERVIEW

The field of high-power-density dc–dc converters has beenaddressed often in the last decades. From the beginning,the conventional full-bridge converter topology has been thepreferred choice to realize a high-power dc–dc converter [1].However, due to problems with the leakage inductance of thetransformer and, consequently, reverse recovery losses of theoutput diodes, the maximum switching frequency is limited.To solve this problem, several solutions were presented,including active clamps and/or auxiliary circuits [2]–[4]. Thesesolutions enable higher switching frequencies at the expense ofadditional components and could lead to higher device stress.The additional components impede the increase in powerdensity and increased complexity, while the efficiency is oftennot better compared to other zero-voltage switching (ZVS) andzero-current switching (ZCS) techniques.Resonant converter topologies offer possibilities for ZVS orZCS, enabling high efficiencies and power densities [5]–[7]. Theseries resonant or LLC converter provides a load independentoperating point with unity voltage gain at a switching frequencynear the resonance frequency [6], [8]–[10]. However, this loadindependent operating point is lost when the input and/or outputvoltage changes, and switching frequency control is necessary toregulate the output voltage. Therefore, a boost converter can beused to regulate the input voltage in order to guarantee operationin the load independent operating point [10], [11]. Alternatively,the resonance circuit can be influenced by a switch-controlledcapacitor, resulting in fixed frequency operation [12]. Despitethe provided solutions, the LLC converter still suffers from highrms phase currents, requiring a relatively large series resonantcapacitor that leads to a decreased power density. The additionalboost converter or switch-controlled capacitor also deterioratesthe power density and efficiency.

The dual active bridge (DAB) topology introduced in [1]is an attractive alternative to the problems with the classicalfull-bridge topology. In comparison with the conventional fullbridge topology, the output inductor is transferred to the ac side,and is in series with the leakage inductance. Consequently, theenergy in the leakage inductance is transferred to the load without causing reverse recovery losses in the output diodes. Thisallows higher switching frequencies and, therefore, an increasein power density. Furthermore, the use of an active output bridgealso increases the power density of the transformer [1]. Whenthe desired inductance can be incorporated in the transformer,again the power density can be increased. In [13], very highpower densities, up to 11.13kW/L, are reported.A three-phase DAB, also proposed in [1], has some advantages in comparison to the single-phase DAB. The three-phaseDAB has lower turn-off currents in the switches and lowerrms currents per phase. Also, the VA ratings for the input andoutput filters are significantly lower and can even go to zerodue to the three-phase characteristics. Besides the lower VAratings, the effective ripple frequency of the filter currents isthree times higher, allowing to use smaller filters. Comparedto the single-phase DAB, the currents through the transformerwindings are much more sinusoidal, resulting in reduced highfrequency losses in the transformers [14]. A comprehensivecomparison of single-phase and three-phase DAB topologies isgiven in [1].Both the single-phase and three-phase DAB topologies sufferfrom a limited soft-switching range in case the input voltage andthe reflected output voltage are not equal. For the single-phaseDAB, there exist switching strategies or modulation schemes forincreasing the soft-switching range are described. Here, the soft-switching operating range is increased andalso the overall efficiency can be increased with a minimum lossmodulation strategy. The three-phase DAB does notpossess these advantageous switching possibilities. The phaseshift angle φ between the bridge voltage is the only controlvariable as the symmetrical properties of the three-phase systemhave to be maintained [14].Although the three-phase DAB has less switching possibilities, compared to the single-phase DAB, and includes fourextra switches, the topology has the most preferred propertiesfor designing a high-power density isolated dc–dc converter. Ithas the lowest component ratings and is capable of achievinghigher output powers with possibly the highest power density.For APU applications in light rail vehicles, high-power capability and power density are decisive. Therefore, the three phaseDAB topology is selected in this study.

III. THREE-PHASE DAB DC–DC CONVERTER

The three-phase DAB, shown in Fig. 1(a), consists of twothree-phase bridges coupled with a three-phase transformer connected in Y–Y. The bridges are operated in six-step mode at aconstant frequency. By applying a phase shift between the inputand Output Bridge, the power flow can be controlled. Becausethe converter is symmetrical from input to output, bidirectionalpower flow is possible. The transformer leakage inductances areused as current transfer elements and, therefore, not consideredas parasitic. If the magnetizing inductance Lm is neglected, anequivalent circuit can be used for analysis. In this circuit, onlythe total leakage inductance Ls seen from the primary side isconnected between the phase legs from the input and outputbridge. The corresponding idealized waveforms are shown inFig. 1(b).

A. Analysis

To analyze the soft-switching region, the current of phase Ais defined for the first six intervals as depicted in Fig. 1(b). Thecurrent iA in the different intervals is given in (3) for phaseshifts of 0 ≤ φ ≤ π 3 . For phase shifts of π 3 ≤φ ≤ 23π , a secondset of equations, not given here, is utilized for further analysisof the soft-switching region. The magnetizing inductance Lmof the transformer is neglected in the analysis.Furthermore, the angular frequency is defined as ω = 2πfs,with fs the switching frequency in Hertz. The transformer'sleakage inductance is indicated with Ls and the input and outputvoltage are defined as Vi and Vo, respectively. The reflected output voltage is given by Vo= VoN, with N the turns ratio ofthe transformer.Because the phase current is symmetric, the current iA(0) canbe found by solving the set of equations, assuming steady-state

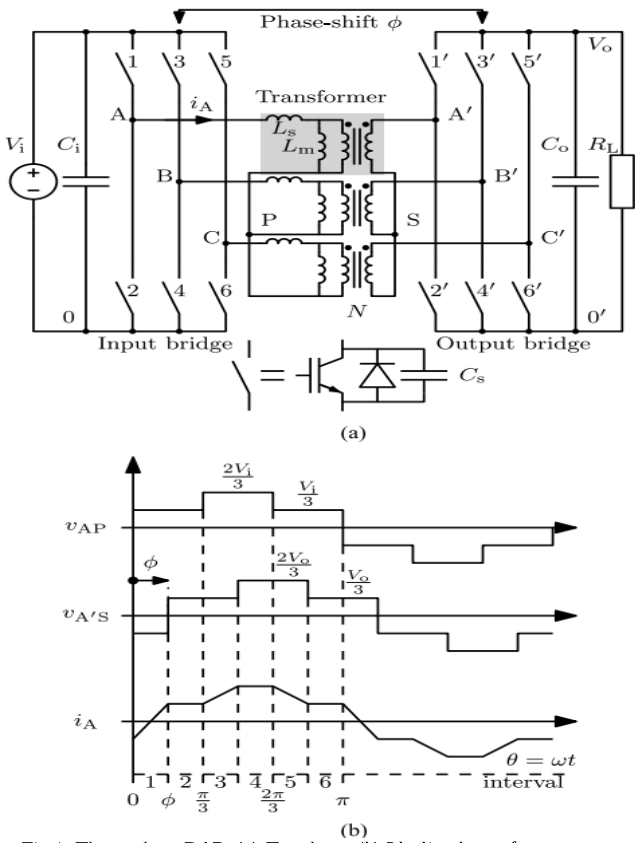

Fig.1. Three-phase DAB. (a) Topology. (b) Idealized waveforms, gatingsignals can be found in [1].

ConditioniA(0) = −iA(π). This results in

$$i_A(0) = \frac{1}{3\omega L_s}\left[\frac{2\pi}{3}(V_o' - V_i) - V_o'\phi\right] \quad (1)$$

B. Output Power

Under the assumption of a lossless converter, the output powerPocan be found with

$$P_o = P_i = \frac{3}{\pi}\int_0^{\pi} v_{AP}(\theta) i_A(\theta) d\theta \quad (2)$$

$$i_A(\theta) = \begin{cases} i_A(0) + \frac{V_i + V_o'}{3\omega L_s}\theta & \forall \quad 0 \le \theta \le \phi & \text{:interval 1} \\ i_A(\phi) + \frac{V_i - V_o'}{3\omega L_s}(\theta - \phi) & \forall \quad \phi \le \theta \le \frac{\pi}{3} & \text{:interval 2} \\ i_A(\frac{\pi}{3}) + \frac{2V_i - V_o'}{3\omega L_s}(\theta - \frac{\pi}{3}) & \forall \quad \frac{\pi}{3} \le \theta \le \frac{\pi}{3} + \phi & \text{:interval 3} \\ i_A(\frac{\pi}{3} + \phi) + \frac{2V_i - 2V_o'}{3\omega L_s}(\theta - \frac{\pi}{3} - \phi) & \forall \quad \frac{\pi}{3} + \phi \le \theta \le \frac{2\pi}{3} & \text{:interval 4} \\ i_A(\frac{2\pi}{3}) + \frac{V_i - 2V_o'}{3\omega L_s}(\theta - \frac{2\pi}{3}) & \forall \quad \frac{2\pi}{3} \le \theta \le \frac{2\pi}{3} + \phi & \text{:interval 5} \\ i_A(\frac{2\pi}{3} + \phi) + \frac{V_i - V_o'}{3\omega L_s}(\theta - \frac{2\pi}{3} - \phi) & \forall \quad \frac{2\pi}{3} + \phi \le \theta \le \pi & \text{:interval 6} \end{cases} \quad (3)$$

Finally, the expression of the output power for 0 ≤ φ ≤ 23π is

$$P_o = \begin{cases} \frac{V_i V_o'}{\omega L_s}\phi\left[\frac{2}{3} - \frac{\phi}{2\pi}\right] & \text{for } 0 \le \phi \le \frac{\pi}{3} \\ \frac{V_i V_o'}{\omega L_s}\left[\phi - \frac{\phi^2}{\pi} - \frac{\pi}{18}\right] & \text{for } \frac{\pi}{3} \le \phi \le \frac{2\pi}{3} \end{cases} \quad (4)$$

C. Soft-Switching Region

Minimizing the switching losses is the key to achieve a highswitching frequency. The turn-on losses are of main interestbecause excessive losses in the switch and the antiparallel diodecan arise when the antiparallel diodes experience the reverserecovery process. The input bridge faces this problem wheniA(0) > 0. Therefore, the current has to fulfill iA(0) ≤ 0 toensure soft-switching in the input bridge. During the switchingtransient, the current iA is considered constant. Rewriting (1)to the required constraint gives the phase shift for ensuring softturn-on of the switches in the input bridge, this is found to be

$$\phi_i \ge \frac{2\pi(V_o' - V_i)}{3V_o'} \quad (5)$$

A similar derivation can be made for the output bridge, wherethe output bridge is soft-switching for iA(φ) ≥ 0. Using (3) and(1) gives the required phase shift to ensure soft turn-on of theswitches in the output bridge, resulting in

$$\phi_o \ge \frac{2\pi(V_i - V_o')}{3V_i} \quad (6)$$

1) Impact of ZVS Capacitors: ZVS capacitors, or snubbercapacitors, are used to reduce turn-off losses. These are connected in parallel to the switches and supplement the output capacitance, as can be seen in Fig. 1(a). After a switch turns OFF,there is a small blanking time tb before the opposite switch ofhe same leg turns on. During tb, the current commutates to theZVS capacitors

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and divides equally over the two capacitors ofthe phase leg. In this transition, one capacitor is charged whilethe other is discharged. This implies that the load current must behigh enough to enable a full charge or discharge of the ZVS capacitors for a given tb. Assuming a constant current during theswitching transient, the soft-switching constraint for enablingsoft turn-on of the switches in the input bridge is changed to

$$i_A(0) + \frac{2C_s V_i}{t_b} \le 0 \tag{7}$$

and for the output bridge to

$$i_A(\phi) - \frac{2C_s V_o}{t_b N} \ge 0 \tag{8}$$

Where Cs represents a ZVS capacitor connected in parallel tothe switch, and tb is a fixed blanking time. A more accurate, current depending charge-based ZVS analysis is reported.However, to investigate the impact of the ZVS capacitors andapproximate the soft-switching region, the presented currentbased method is sufficient.Solving (7) and (8) for the phase-shift φ gives the softswitching region for the input bridge and the output bridge,respectively. These are given by

$$\phi_i \ge \frac{2\pi_i(V_o' - V_i)}{3V_o'} + \frac{2C_s V_i}{V_o' t_b} 3\omega L_s \tag{9}$$

$$\phi_o \ge \frac{2\pi(V_i - V_o')}{3V_i} + \frac{2C_s V_o}{V_i t_b N} 3\omega L_s \tag{10}$$

D. Extension of the Soft-Switching Region

Auxiliary power converters for railway applications have tobe able to operate from no-load to full-load conditions overthe whole input voltage range. This means that the converterhas to operate outside the soft-switching region. Therefore, twomethods to extend the soft-switching operation of the converterhave been investigated.

1) Auxiliary Inductors: The first method is based on addingreactive currents to fully charge or discharge the ZVS capacitorsduring the switching transient. The reactive currents are injectedwith three star-connected auxiliary inductors per bridge. This has the same effect as the magnetizinginductances of the transformers, which are also connected instar. However, separate auxiliary inductors are preferred tohave more design flexibility.The peak current, injected by the auxiliary inductors duringthe switching transient, is calculated from the voltage waveforms shown in Fig. 1(b). For the input bridge, the peak currentis calculated as

$$\hat{i}_{a-i} = \frac{2\pi V_i}{9\omega L_{a-i}} \tag{11}$$

and for the output bridge as

$$\hat{i}_{a-o} = \frac{2\pi V_o}{9\omega L_{a-o} N} \tag{12}$$

Next, the soft-switching constraints from (7) and (8) can beextended to

$$i_A(0) + \frac{2C_s V_i}{t_b} - \frac{2\pi V_i}{9\omega L_{a-i}} \le 0 \tag{13}$$

and for the output bridge to

$$i_A(\phi) - \frac{2C_s V_o}{t_b N} + \frac{2\pi V_o}{9\omega L_{a-o} N} \ge 0 \tag{14}$$

Then, the soft-switching region can be calculated with the minimum phase shift for the input bridge

$$\phi_i \ge \frac{2\pi(V_o' - V_i)}{3V_o'} + \frac{2C_s V_i}{V_o' t_b} 3\omega L_s - \frac{2\pi V_i L_s}{3V_o' L_{a-i}} \tag{15}$$

and for the output bridge

$$\phi_o \ge \frac{2\pi(V_i - V_o')}{3V_i} + \frac{2C_s V_o}{V_i t_b N} 3\omega L_s - \frac{2\pi V_o L_s}{3V_i L_{a-o} N} \tag{16}$$

As shown with (15) and (16), the auxiliary inductance decreases the required phase-shift for operating in a soft-switchingmanner. To achieve soft-switching in the whole operating range,(15) and (16) should be solved for zero phase-shift, i.e., no-loadcondition. The corresponding values. Forrelatively low- and high-input voltages, the required values forLa−i and La−o are low and, therefore, also causing high reactive currents. The use of auxiliary inductors presents a cleardisadvantage due to the reduced efficiency and power density.

2) Burst Mode: The second method does not use any extracomponents but relies on a straightforward switching strategy.When the required output power Po is lower than the minimumload for soft switching, the converter switches from continuousmode to burst mode. In the burst mode, the converter operateswith an output power Pb high enough to enable soft-switching.An example of the burst mode with the corresponding waveforms is shown in Fig. 2(a). The average output power is definedas

$$< p_o > = \frac{n}{m} P_b, \qquad \forall \quad 1 \le n \le m \tag{17}$$

Where n is the amount of switching cycles operating with po =Pb and m is the total amount of switching cycles of one burstcycle. The value of Pb depends on the soft-switching region ofthe converter.When nTs< t ≤ mTs, the output power po = 0 W, thus theoutput capacitor delivers

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the required current to the load, introducing a small voltage ripple. The output voltage ripple can becalculated with

$$\Delta v_o = \frac{I_o \Delta t}{C_o} \tag{18}$$

Where Io =<po>Vo=nPbmVoand Δt = m−nfs . This results in

$$\Delta v_o = \frac{n(m-n)P_b}{mV_o C_o f_s} \tag{19}$$

An example of the output voltage ripple with n ≥ 2 is shownin Fig. 2(b).

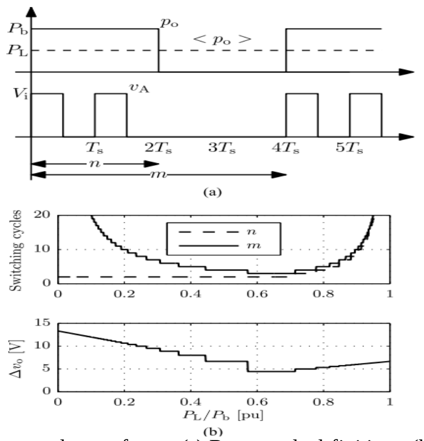

Fig. 2. Burst-mode waveforms. (a) Burst-mode definitions. (b) Output voltageripple with n ≥ 2, Pb = 80 kW, Vo = 600 V, Co = 1 mF, and fs = 20 kHz.

The downside of this method is the need for a larger outputcapacitance for the same voltage ripple requirements in normal operation without the burst mode. Furthermore, while theswitching frequency is unchanged, the converter becomes audible due to the discontinuous operation.

IV. INDUCTION MOTOR (IM)

An induction motor is an example of asynchronous AC machine, which consists of a stator and a rotor. This motor is widely used because of its strong features and reasonable cost. A sinusoidal voltage is applied to the stator, in the induction motor, which results in an induced electromagnetic field. A current in the rotor is induced due to this field, which creates another field that tries to align with the stator field, causing the rotor to spin. A slip is created between these fields, when a load is applied to the motor. Compared to the synchronous speed, the rotor speed decreases, at higher slip values. The frequency of the stator voltage controls the synchronous speed. The frequency of the voltage is applied to the stator through power electronic devices, which allows the control of the speed of the motor. The research is using techniques, which implement a constant voltage to frequency ratio. Finally, the torque begins to fall when the motor reaches the synchronous speed. Thus, induction motor synchronous speed is defined by following equation,

$$n_s = \frac{120 f}{P}$$

Where f is the frequency of AC supply, n, is the speed of rotor; p is the number of poles per phase of the motor. By varying the frequency of control circuit through AC supply, the rotor speed will change.

A. Control Strategy of Induction Motor

Power electronics interface such as three-phase SPWM inverter using constant closed loop Volts l Hertz control scheme is used to control the motor. According to the desired output speed, the amplitude and frequency of the reference (sinusoidal) signals will change. In order to maintain constant magnetic flux in the motor, the ratio of the voltage amplitude to voltage frequency will be kept constant. Hence a closed loop Proportional Integral (PI) controller is implemented to regulate the motor speed to the desired set point. The closed loop speed control is characterized by the measurement of the actual motor speed, which is compared to the reference speed while the error signal is generated. The magnitude and polarity of the error signal correspond to the difference between the actual and required speed. The PI controller generates the corrected motor stator frequency to compensate for the error, based on the speed error.

V.MATLAB/SIMULATION RESULTS

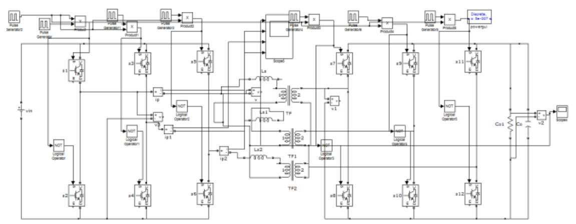

Fig 3 Matlab/simulation conventional circuit of three-phase DAB dc-dc converter Topology.

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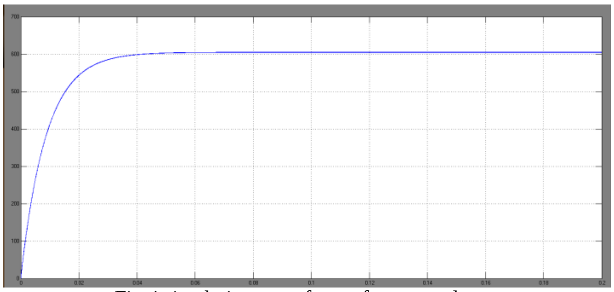

Fig 4 simulation wave form of output voltage

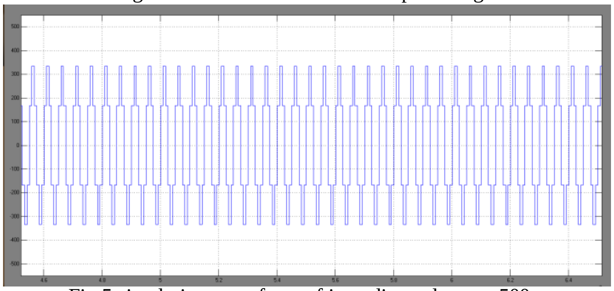

Fig 5 simulation wave form of input line voltage at 500v

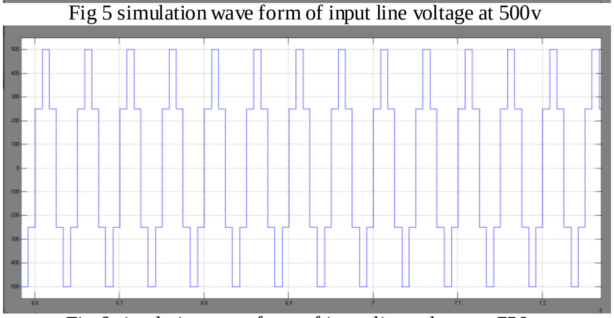

Fig 6 simulation wave form of input line voltage at 750 v

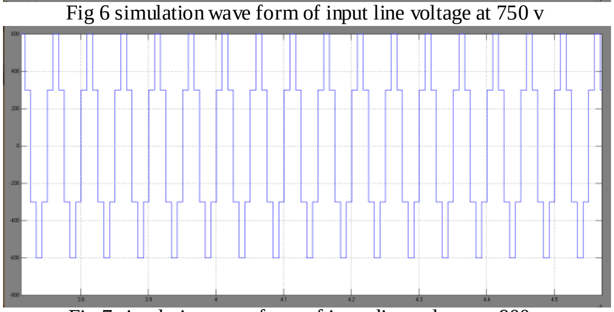

Fig 7 simulation wave form of input line voltage at 900v

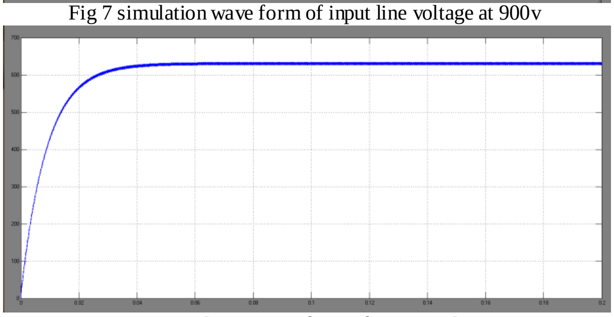

Fig 8 simulation wave form of output voltage

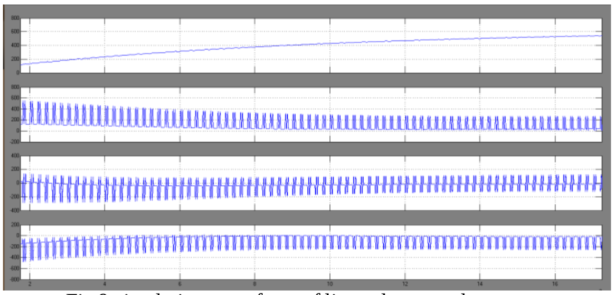

Fig 9 simulation wave form of line voltages and currents

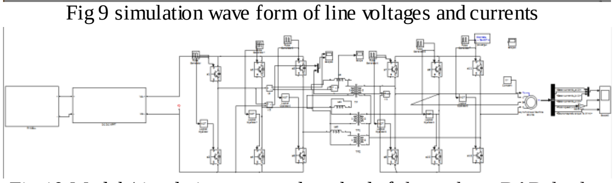

Fig 10 Matlab/simulation proposed method of three-phase DAB dc-dc converter Topology with Induction Motor

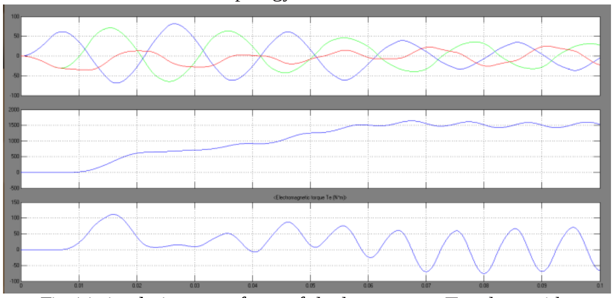

Fig 11 simulation wave form of dc-dc converter Topology with Induction Motor torque, speed and voltage

VI.CONCLUSION

This work has evaluated the strategy for utilization of PV Cells for induction motor pumping. The electricity bill gets reduced since solar energy is utilized for agriculture pumping. The Photo Voltaic powered three phase induction motor drive system is successfully designed, modelled and simulated using Matlab/Simulink. The concept of Photo Voltaic pumping is proposed. The simulation results of three phase induction motor for Photo Voltaic pumping are presented. The simulation results are in line with the theoretical results. The scope of this work is the simulation and implementation of three phase PV Powered Induction motor drive system.

REFERENCES

[1].Nico H. Baars, Student Member, IEEE, Jordi Everts, Member, IEEE, Henk Huisman, Jorge L. Duarte, Member, IEEE, and Elena A. Lomonova, Senior Member, IEEE"A 80-kW Isolated DC–DC Converter m for Railway Applications"IEEE Transactions On Power Electronics, Vol. 30, No. 12, December 2015.

[2] R. De Doncker, D. Divan, and M. Kheraluwala, "A three-phase softswitched high-power-density dc/dc converter for high-power applications," IEEE Trans. Ind. Appl., vol. 27, no. 1, pp. 63–73, Jan. 1991.

[3] J. Dudrik, P. Spanik, and N.-D. Trip, "Zero-voltage and zero-current switching full-bridge dc-dc converter with auxiliary transformer," IEEE Trans. Power Electron., vol. 21, no. 5, pp. 1328–1335, Sep. 2006.
[4] J.-G. Cho, C.-Y. Jeong, and F. Lee, "Zero-voltage and zero-currentswitching full-bridge PWM converter using secondary active clamp," IEEE Trans. Power Electron., vol. 13, no. 4, pp. 601–607, Jul. 1998.
[5] O. Patterson and D. Divan, "Pseudo-resonant full bridge dc/dc converter," IEEE Trans. Power Electron., vol. 6, no. 4, pp. 671–678, Oct. 1991.
[6] R. Steigerwald, "A comparison of half-bridge resonant converter topologies," IEEE Trans. Power Electron., vol. 3, no. 2, pp. 174–182, Apr. 1988.
[7] A. Bhat and R. Zheng, "Analysis and design of a three-phase LCC-type resonant converter," IEEE Trans. Aerospace and Electron. Syst., vol. 34, no. 2, pp. 508–519, Apr. 1998.
[8] R. Steigerwald, "High-frequency resonant transistor dc-dc converters," IEEE Trans. Ind. Electron., vol. IE-31, no. 2, pp. 181–191, May 1984.
[9] X. Li, "A LLC-type dual-bridge resonant converter: Analysis, design, simulation, and experimental results," IEEE Trans. Power Electron., vol. 29, no. 8, pp. 4313–4321, Aug. 2014.
[10] J.-W. Kim and G.-W. Moon, "A new LLC series resonant converter with a narrow switching frequency variation and reduced conduction losses," IEEE Trans. Power Electron., vol. 29, no. 8, pp. 4278–4287, Aug. 2014.
[11] S. De Simone, C. Adragna, C. Spini, and G. Gattavari, "Design-oriented steady-state analysis of LLC resonant converters based on FHA," in Proc. Int. Symp. Power Electron.,Electr. Drives, Autom. Motion,, May 2006, pp. 200–207.
[12] B.-C. Kim, K.-B. Park, C.-E. Kim, B.-H. Lee, and G.-W. Moon, "LLC resonant converter with adaptive link-voltage variation for a high-powerdensity adapter," IEEE Trans. Power Electron., vol. 25, no. 9, pp. 2248– 2252, Sep. 2010.
[13] Z. Hu, Y. Qiu, L. Wang, and Y.-F. Liu, "An interleaved LLC resonant converter operating at constant switching frequency," IEEE Trans. Power Electron., vol. 29, no. 6, pp. 2931–2943, Jun. 2014.
[14] M. Pavlovsky, S. de Haan, and J. Ferreira, "Reaching high power density in multikilowatt dc-dc converters with galvanic isolation," IEEE Trans. Power Electron., vol. 24, no. 3, pp. 603–612, Mar. 2009.