**A Magnetically Coupled Converter Connected Three Phase Voltage Source Inverter for EV Applications**

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| **Article Info** |  | **ABSTRACT** (10 PT) |
| ***Article history:***  Received Jun 12, 201x  Revised Aug 20, 201x  Accepted Aug 26, 201x |  | *The Electrical Vehicle (EV) is an obligatory segment is current era due the shortage of fossil fuel and increasing CO2 emissions. In EV the vehicles drive is consuming more energy than other part of vehicle appliances. The EV drives mainly are induction motor, permanent magnet synchronous motor, or BLDC motor. These motor are normally either in low voltage machines or high voltage machine. The high voltage machines are high cheap. However those motor drives need 600V DC-link for their full range operation. Hence, the high step DC to DC converter fed VSI is need for such a applications, which is need to give a voltage gain higher range since vehicle battery is only in the arrange of 24 V to 48 V. With this aim a non-isolated DC to DC converter is propose here with VSI. The referred DC to DC converter is operating based on transformer coupled and contains only one capacitor with tightly-coupled 3 winding transformer inductor arrangement. The inverter can increase the boost factor through changing shoot-through duty ratio and varying the amount of turns in the three-winding transformer. The proposed DC to DC converter more control degrees of freedom in terms its voltage gain, and therefore, improving the drive versatility is high. The PWM switching techniques are introduced to this converter fed VSI topology to control drive. The working principle of the proposed transformer based DC to DC Source fed VSI is analysed and simulated using MATLAB/Simulink system software. The laboratory based small scale 200W power circuit is designed and developed and the control algorithm is implemented in PIC microcontroller platform. The Analysis, simulation and experimentation validating the proposed converter fed VSI drive system for EV applications.*, |
| ***Keyword:***  Transformer based in high step DC to DC converter, impedance networks, voltage source inverter. |
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1. **INTRODUCTION**

The Electrical Vehicle (EV) is a more focused electrical load for the future electrifies per capita for the world. The XX association is estimated 20% IC engine vehicles is migrated EVs and they are going to play in the road in 2020. In EV the vehicles drive is consuming more energy than other part of vehicle appliances [1]. The EV drives mainly are induction motor, permanent magnet synchronous motor, or BLDC motor. These motor are normally either in low voltage machines or high voltage machine. There many literatures on DC to DC converter fed VSI drive for variable DC bus voltage [2, 3]. These research papers are mainly focused power converters design and its controller arguments to improve system efficiency of the EV. The aim of a variable DC- bus voltage for VSI is to get better the system controllability and efficiency by boosting the DC-bus voltage for the period of flux-weakening in the motor drive. In flux-weakening operation state, a restricted DC-bus voltage results in involving a negative d-axis current to weaken the flux. To achieve this high voltage gain DC-DC converter employed with inverter [4, 5, 33]. As a result of the variable DC-bus voltage no d-axis current is compulsory in the mid-range high speed. Thus, the copper losses get reduced which getting better system efficiency. The High step voltage gain DC to DC converter is a principle follows Z-source network [6]. The attempt is made for involving multilevel inverters for PV connected stand alone and grid connected applications as well [7-10]. There are many research has been reported in Z-source network, which are mainly developed to offer an efficient power conversion with an extensive voltage gain [11]. The upgrading to the impedance networks realizing for higher voltage boosting through the coupled magnetic circuit. These power circuits control is variant based on their inductor arrangement and shoot-through time [12]-[14]. The coupled magnetic circuit based DC to DC conversion, verity of converter is proposed (Γ [15], T [16], trans-Z [17], TZ [18], LCCT-Z- [19], transformer-isolated [20], and Y [21]) and they are mainly structured based on inductors and capacitors. The work is also carried out for maintain the voltage stability for adding the battery across the capacitor. Through these idea is improving the system stability, the cost and size does not comprehend [22]. The authors, Y. P. Siwakoti et.al in [23] suggested the interesting high step voltage conversion DC to DC converter for distributed power system which improves overall system reliability. In this work the authors varying the voltage gain by changing the transformer ratio. The converter is designed and operated for the specific duty-cycle interval and hence the converters maintain their controllability. For controlling inverter along with Z-source network many PWM techniques are developed which are mainly giving interest to create a short through (ST).These ST attempt has been done for both sine PWM (SPWM) and space vector PWM (SVPWM) [ 24,25,31-39]. Among SPWM is simple and easy to implement. The selective harmonics eliminations and 3rd order harmonics elimination is a next candidates to addressing the inverter performance with respect to harmonics cancelations [26]. The paper dealt the converter with 3rd order harmonics in a PV application including ST creations [27, 28]. Normally magnetic coupled converter fed VSI drive suffered with higher voltage and current harmonics, which are main causes of the EV drive non-smoother performances [32]. This dreadful behaviour VSI DC-link voltage is supplied through the front end converter circuit inductor. Hence the special attendance is necessary for taking care of the input voltage and current harmonics components [29,34]. .

Based on the clear discussion on the EV drive requirements, the high step DC to DC converter fed VSI drive is needed with lesser harmonics spectra for their voltage and current. The converter is needs to prove a high voltage gain to meet out the VSI DC-link requirement. Hence, in this paper the proposes the magnetically coupled transformer structure converter fed three phase voltage source inverter for EV drive. The suggested power circuitry is able to provide a continuous DC-voltage to the VSI for the full range of vehicle drive curve requirements. The paper also deals the design and circuit operation of the proposed power circuitry. The working principle of the proposed transformer based DC to DC Source fed VSI is analysed and simulated using MATLAB/Simulink system software. The laboratory based small scale 200W power circuit is designed and developed and the control algorithm is implemented in PIC microcontroller platform. The Analysis, simulation and experimentation validating the proposed converter fed VSI drive system for EV applications.

**2. EV DRIVE SYTEMSOVERVIEW**

A typical EV motor drive system consists of a three-phase VSI and a motor as shown in Fig 1.



Fig 1. Classical EV drive power system

In an EV the DC- bus voltage of the VSI is generated from the EV inbuilt battery in a straight line through a DC to DC boost converter [3]. The battery connected EV is another cost is maintain the battery energy management and power handling. Precisely determining the SOC of a battery over time is crucial for the performance of intellectual battery management approaches. There are numerous methods to establish the SOC, including: capacity of the terminal voltage, specific gravity, and technique based on ampere-hour (Ah) examination. The DC to DC converter selection is other method since they need to fix the DC –link voltage for the inverter. The main section for any EV drive is motor control to maintain the torque-speed characteristic.

# 3. DC TO DC CONVERTER

* 1. **Magnetically coupled DC to DC converter**

A typical magnetic coupled DC to DC converter system as shown in Fig 1. The converter is consist of three magnetic coupled with different winging and inductor range. The input diode is used to connect input DC source and three magnetic coupled inductors. The capacitor is used to source the supply to output inductor in non-ST states. The converter is shaped as Y-shape consists of a DC input supply, a Y-source impedance network (a three winding coupled inductor / transformer and a capacitor) in addition to an inverter bridge. Y-source network comprises of a passive diode, D, a winding coupled inductor (N1:N2:N3) along with a capacitor, C. The effectiveness of the inverter depends on the magnetic coupling tightness between the coupled inductors to keep away from any losses through leakage inductances.



Fig 2. Magnetically coupled DC to DC converter [23]

The Y-source impedance function can be explained by a simple single switch converter as shown in the Fig 2. Considering the network working in ideal operating conditions the converter will either be in its shoot-through state or non-shoot-through state while ignoring their leakage inductances. For the shoot-through state, switch S is turned ON to short terminals 1 and 2, which in turn, sources diode, D in the association to reverse bias. The converter is bring back to the non-ST state by turned OFF the switch, S with the diode, D conducting. Averaging voltage across the magnetizing inductance for these two states results in the peak DC-link voltage V12’ across terminals 1 and 2 in terms of input DC voltage to the VSI. Nevertheless this can be accomplished only with ideal operating situation where the leakage inductances, Ll of the network is nullified or significantly reduced. The Minimization of Ll is not constantly feasible or cost-effective as it needs more superior core as well as windings. Consequently effects caused by the leakage inductances must be studied thoroughly.

* 1. ***Modes of operation***

An intermediate equivalent circuit is introduced when the impedance source transits from non-ST state to ST state as shown in Fig. 4. During non-ST state inductances are all discharging energies as well as current is therefore decreasing. The shunt switch S in the ﬁg.3 is next shorted, which ideally, will lead to the ST circuit shown in Fig. 5. Nevertheless, for the non-ideal case, an intermediate circuit shown Fig. 5 will be inserted for a short time interval, sourced by the rapid fall of the current through leakage inductance,L1 in N1, and rapid increases of currents during leakage inductances N2and N3



Fig 3. At Non-ST , D forward Biased



Fig 4. At ST , D forward Biased, )Intermediate state



Fig. 5. At ST , D reversed Biased

. The intermediate state ends only as the leakage current through N1and diode D reduced to zero.For ST to non-ST transition, the network is in its ST state, when the switch, S is turned OFF, the network attached the source to the load and transits to non-ST state. Unlike the forward conduction, there is no intermediate state and the network enters its non-ST state directly with diode, D conducting, though its current may rises rapidly in excess of a short duration slightly than step-increased. No reduction of the ST duration is therefore introduced by the reverse transition.

The current strained via this capacitive load be able to adapt to leakage current at instantaneous commutation, therefore neither voltage spikes nor limitations are practiced with capacitive loads. At less inductive nature, during the commutation from ST state to non-ST state, leakage currents caused by leakage inductance in N3 will be draped down to current directly, ensuing in high voltage in the circuit. Beside this momentary is not mitigated, it may affect N1 and N2 the leakage currents. Therefore a capacitive-snubber may be additional in order to transport downward between the load current and leakage current.

At the ST state interval dST,while the switch S is “ON” and diode, D is reverse-biased, the expression as,

 (1)

Where, n13 = N1/N3, n12= N1/N2, as well as voltage across the inductor is given as,

 (2)

At non-ST state, the interval (1 -dST), diode, D is conducting is conducting source to the load, the KVL expression for VL,

 (3)

 (4)

The voltage across the capacitor, VC can be derived as,

 (5)

From the Eq.(6), the capacitor voltage across, VC,

 (6)

At the non­ST states,

 (7)

 ; (8)

N1 + 2 N2 > N3; N3 – N2 > 0; N2 < N3 ; N3 > 1

 ; 

 (9)

Table 1 – converter parameter F, dST, voltage gain, N1: N2: N3

|  |  |  |  |
| --- | --- | --- | --- |
| K | 0<dst<dstmax | Voltage Gain,Gv | N1:N2:N3 |
| 2 | 0 ≤ dST ≤ 1/2 | 0.5M(1-2dST )-1 | 1:1:3, 2:1:4, 1:2:5, 3:1:5 |
| 3 | 0 ≤ dST ≤ 1/3 | 0.5M(1-2dST )-1 | 1:1:2, 3:1:3, 2:2:4, 1:3:5 |
| 4 | 0 ≤ dST ≤ 1/4 | 0.5M(1-2dST )-1 | 2:1:2, 1:2:3, 5:1:3, 4:2:4 |
| 5 | 0 ≤ dST ≤ 1/5 | 0.5M(1-2dST )-1 | 3:1:2, 2:2:3, 1:3:4, 7:1:3 |
| 6 | 0 ≤ dST ≤ 1/6 | 0.5M(1-2dST )-1 | 4:1:2, 3:2:3, 2:3:4, 1:4:5 |

The Magnetically coupled DC to DC converter voltage gain varies with different winding factors, F and ST duty cycles dST. The desired converter gain with various different arrangements of F and dST. Table 1. illustrates K and dST for selection of converter voltage gain. The table shows the clear combination of F, dST, voltage gain, N1: N2: N3.

The gain produced by the Y -source network is thus a combination of those expected from the T - or trans-Z-source and Γ -source networks. This either creates a higher gain or allows merits of the other networks to be flexibly merged. The latter can be helpful when subject to size and type availabilities while choosing magnetic core, wire and coupling method for winding the transformer. The goal is to maximize coupling, and hence minimize leakage, which if not ensured, will lead to higher switching voltage in addition to a reduction in gain.

**4. SIMULATION STUDY**

The magnetic coupled DC to DC converter with six switch three phase voltage source inverter for EV drive. The PMSM motor has chosen for EV motor. The table -3, shows the simulation parameter for converter, VSI and PMSM motor. The simulation is developed with MATLAB/Simulink software simulations. The three winding transfer is designed by variable number of winding and inductance values. The converter is designed with 460V DC –link voltage. The battery voltage is considered as 24V to 36V range. The winding ratios N1:N2:N3 = 1:4:8 at a higher modulation index, Ma= 0.9 while maintaining the ST duty ratio at DST = 0.236.

Table 3. Simulation parameters

|  |  |
| --- | --- |
| Parameters | values |
| Battery voltage, VB  Transformer Turns, N1,N2,N3  Power (P) | 36V, 2.5KW  1:8:16  2 kW |
| Line to Line voltage (VL) | 400 V |
| DC-link voltage ( VDC)  Frequency (f) | 460V  50Hz |
| Stator resistance (Rs) | 0.7 Ω |
| Stator inductance (Ls) | 0.0047 H |
| Rotor resistance (Rr) | 1.35 Ω |
| Speed | 1300 rpm |
| Irms | 5A |
| Vrms | 400V |
| Torque(T) | 8 Nm |

The Fig.8, shows the converter side output voltage for 48V input with F=6. From the figure, result it could understand that the converter side able to maintain the converter outside voltage ( VDC , DC-link for VSI). The converter able to maintain the 460V. Fig.9 shows the inverter voltage line-voltage. From the results it seen that the VSI is able to give a stater voltage for the drive and giving the suitable voltage for the desired torque –speed. The voltage percentage THD is shown for the line –voltage. From the THD result is it could understand that, the proposed 3rd harmonics is reduced the THD well below.



(a)



(b)

Fig. 8. Simulation results: (a). Input Battery voltage ( Vin), (b). output voltage ( VDC)



Fig. 9. Simulation results: inverter line – voltage for all three phases VAB,VBC, VCA

**4. EXPERIMENTAL RESULTS AND DISCUSSIONS**

For the investigation of the experimental verification for the proposed magnetic coupled DC to DC converter with six switches three phase VSI, the 200W show six switch VSI is designed and collaborated with PIC microcontroller digital implementation platform. The PWM is developed in assembly code and implemented in the 3 kHz switching frequency with 6 mircosec dead time. Fig.10.shows the experimental setup of the three-phase VSI connected RL load.



Fig.10.shows the experimental setup of the three-phase VSI connected RL load.



Fig. 11. Simulation results: Input Battery voltage ( VB), output voltage ( VDC)



Fig.12. Experimental Line voltage for 0.5 Ma

The 1000mcroF capacitor and 10 ohm, 4 mH RL load used for the DC-link and load respectably. The TLP250 gate driver circuit is used for six MOSFETs. The voltage and THD waveforms are measured using 2-channel DSO. The three winding transfer is designed is for fixed variable number of winding and inductance values to provide a F=4. The converter is designed with 60V DC –link voltage. The battery voltage is considered as 12V range. The winding ratios N1:N2:N3 = 1:4:8 at a higher modulation index, Ma= 0.9 while maintaining the ST duty ratio at DST = 0.236. The Fig.11, shows the converter side output voltage for 12V input with F=4. From the figure, result it could understand that the converter side able to maintain the converter output voltage as 60V ( VDC , DC-link for VSI). Fig.12 shows the inverter voltage line-voltage, VAB. From the results it seen that the VSI is able to give a stater voltage for the drive and giving the suitable voltage for the desired torque –speed.

**6. CONCLUSION**

The proposed magnetic coupled DC to DC converter inverter can produce a very high voltage gain while operating at a higher modulation index. Voltage gain of different impedance networks in literature has been compared. The working principle of the proposed transformer based DC to DC Source fed VSI is analysed and simulated using MATLAB/Simulink system software. The laboratory based small scale 200W power circuit is designed and developed and the control algorithm is implemented in PIC microcontroller platform. The Analysis, simulation and experimentation validating the proposed converter fed VSI drive system for EV applications.

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