Design and Implementation of Five Levels to Seven Front End Converter for Electric Vehicle

P.RAJKUMAR[1], S. VIVEK SINGH[2], AAKASH. J. PARIKH[3], M. VISHWANATHAN[4], M. VISHAL[5], G. MARIYA SUNDARI[6]

[1, 2, 3, 4, 5] UG Students Department of Electrical and Electronics Engineering, DMI College of Engineering
[6]Assistant Professor, Department of Electrical and Electronics Engineering, DMI College of Engineering

***Abstract* - The increasing consumption of conventional energy in the world with increasing costs of fossil fuel is justifiable reason for using fuel cell technology with high performance. However, the output voltage of fuel cell stack is very low and it is not sufficient to drive the electric vehicle. The three level hybrid boost dc-dc converter, which can be step-up the fuel cell output voltage with high voltage gain. The working principle of the converter is based on the traditional neutral clamped multi-level inverter. Here, MOSFET based three level converter is designed and the steady state of filtering capacitors are simulated with MATLAB software. Fuel cell stack is designed in the place of normal dc battery. Hybrid boost dc-dc converter is connected to Multi level inverter for AC output to drive the Electric Vehicle (EV). The hardware of the above converter as a laboratory setup is implemented and the results are obtained.**

***Indexed Terms*— Front end converter, Fuel Cell, DC-DC Converter, Seven-Level, Electric Vehicle, Battery.**

I. INTRODUCTION

In the recent years, the energy consumption from the renewable energy resources is increasing compared to that of conventional sources due to demand for clean power. According to environmental summits, the fossil fuels are may be completely exploited by the year 2050. So we have to reserve these sources for next generations and give importance to the renewable resources for generating electrical energy. Renewable energy resources include photovoltaic systems, wind energy systems, fuel cells and others. Fuel cells are efficient, reliable and ease to generate on board electricity for automobiles.[1] Block diagram of an electrical vehicle powered with fuel cell. The output voltage of a single cell is not enough to connect directly to the alternate current utility system. Therefore, each cell is connected with others in series and parallel to obtain high level dc voltage.[2] However, with above topology, the efficiency of the fuel cell gets deteriorated. So, the dc to dc converters with high voltage gain are used. These converters boost the low voltages (23 – 68 V) to high voltages (300 – 500 V).[3] The salient features of this converter are large transfer gain and high efficiency with low duty ratio. According to theoretical calculations, classical boost converters have high voltage gain with extreme duty ratio.[4] However, functioning of the converters is devolved with high duty ratio because of low efficiency, reverse recovery and electromagnetic interference problems. Some of the converters are isolated type like forward, fly-back and push-pull can accomplish with high voltage gain by changing the turns ratio of transformer[5].The isolated converters have a leakage inductor, which can cause serious problems such as voltage stress on the power switches and high power dissipation.

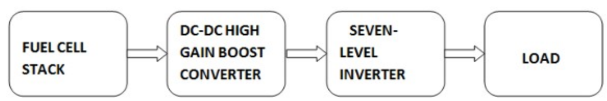

Fig.1 Block diagram

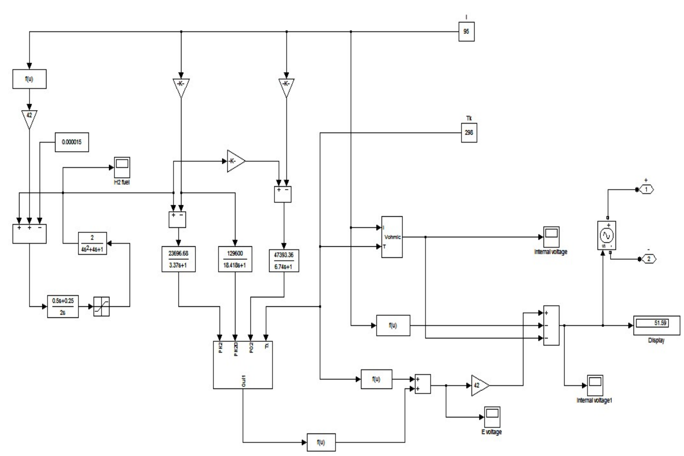

Fig.2 Overall model of fuel cell stack

In recent days, the application of fuel cell energy is the most well-known energy than other renewable sources [6]. It is electro-chemical device, which directly converts chemical energy into electrical energy. In this, cell produces electro-motive force when hydrogen is chemically reacts with atmospheric air. Proton Exchange Membrane Fuel Cells are suitable for research activities than other topologies. This type of fuel cell stack has an advantage that they operate under low temperature. Reaction at anode and cathode is given byThe terminal voltage of fuel cell in the model shown in Figure 2 is expressed in where ENerst is the thermodynamic potential of the cell, Vact is the portion of voltage drop due to activation losses across the anode and cathode, Vohmic is the voltage drop due to series resistance, Vcon is the voltage drop due to the concentrations equations .Generally, the output power of the fuel cell is high when the output voltage is high. The PEMFC consists of solid polymer as dielectric material in between anode and cathode electrodes. Actually the ions are distributed on the surface of the electrolyte but there is no chance to conduction. The flow of electrons is possible with an external circuit in between two electrodes. Identification of the load for power conditioning.

II. MODES OF OPERATION

According to the Figure 3, the output voltage is achieved by the following equation
Vab =Vag – Vbg

Where Vag and Vbg are the voltages of two half bridges and Vo be the output voltage of the boost converter. This voltage can be achieved by using filtering capacitors C1 and C2. Coming to the storage elements, inductor and capacitors are playing vital role in the converter design.

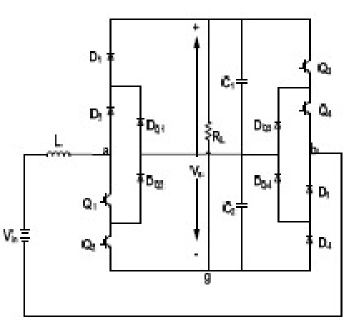

Fig. 4

When the transistors Q1 – Q4 are switched off, then the capacitors C1 and C2 are in series and charged together by input voltage Vin and energy stored boost inductor L through diodes D1 – D4. Then the output voltage Vo is equal to Vab. When the transistor Q4 is switched on, then C1 is charged by input voltage Vin and energy through diodes D2, D1 and DQ3 transferred from the boost inductor. In the moment, C2 is discharged through load resistor and the output voltage is observed as Vo/2, which is appeared across the capacitor C1. And, the instantaneous voltage Vab = Vo/2 is appeared across theC2 is charged by input voltage Vin and energy transformed from the inductor L through diodes DQ2, D4 and D3, when Q1 is switched on and energy is discharged from the C1 to load. When both the transistors Q1 and Q2 are turned on, the energy stored in inductor L through diodes D4 and D3. Meanwhile, the capacitors C1 and C2 are discharged togetherfor the load. According to the conduction paths shown in the Figure 4, the phase to ground voltages Vag and Vbg for both half bridges are described as

$$V_{ab} = (1 - S_1 \times S_2)\ (V_{c1} + V_{c2}) - (S_1 - S_2) \times V_{c1}$$

$$V_{bg} = S_3 \times V_{c1} + S_4 \times V_{c2}$$

Where S1, S2, S3, S4 are the function of the switching states. By equating 1, 2 & 3 equations and Vab is derived as

$$V_{ab} = \left[(1 - S_1)\ (1 + S_2) - S_3\right] \times V_{c1} + (1 - S_1 \times S_2 - S_4) \times V_{c2}$$

According to the switching actions of thyristors, pulse width modulation (PWM) control method can be implemented. Charging and discharging of capacitors can be decided by the action of power switches with respect to pulse generations. Here, the term modulation index can be defined as the ratio of amplitude of modulation wave and amplitude of carrier wave. The modulation indices are represented with ma and mb can be used to modulate the reference signal to required level and carrier signals Carrier_ 1 and Carrier_2 are provided with 1800 phase shifted to the control logic then according to respective modulated values, turn on and turn off time of power switches canbe decided. PWM control technique can be described as,

$$m_b > V_{carrier\_1},\ S_1 = 0$$
$$m_a < V_{carrier\_2},\ S_2 = 0$$
$$m_a < V_{carrier-\_1}, | S_3 = 0$$
$$m_b > V_{carrier\_2},\ S_4 = 0.$$

According to the Figure 5 shown, the modulated wave is compared with carrier signal can be achieved switching states of the power switches Q1-Q4.

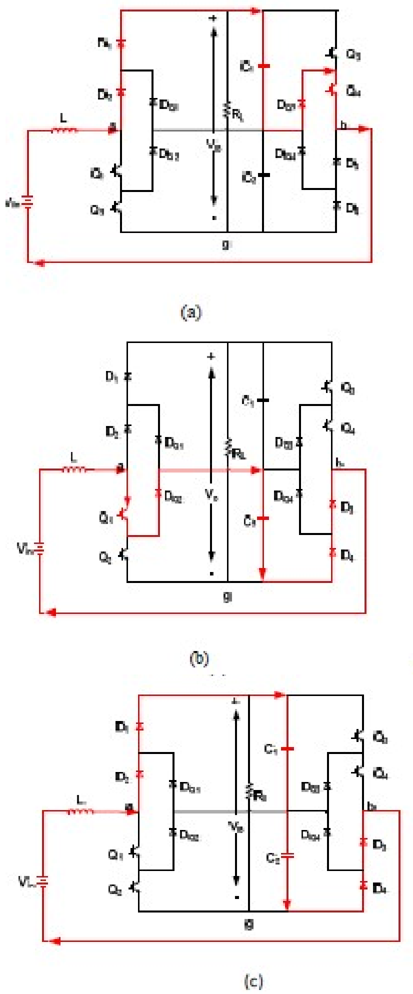

Fig. 5 Operation states of suggested Converter.
(a) D1, D2, Q4,
DQ3 = ON and Vab = Vo/2 = VC1;
(b) Q1, DQ2, D3, D4 = ON and
Vab = Vo/2 = VC2;
(c) D1, D2, D3, D4 = ON and Vab = Vo = VC1+VC2

Based on respective states, the charging and discharging of capacitors are balanced. When iL is decreasing, the C1 is starts discharging and C2 is going to charging state and the corresponding voltage is Vag = Vo/2, Vbg = 0. Alternatively, the states are changing with respect to modulated indices. The discharging time of capacitors are mentioned below

$$t_1 = t_2 = \frac{t_{on1} - t_{on2}}{2}$$

$$t_3 = t_4 = \frac{t_{on4} - t_{on3}}{2}$$

Here, t1-t4 is represented as discharging and charging times of capacitors C1 and C2. The discharging time of C1is (t1 + t2) and for C2 is (t3 + t4).

III. DIODE CLAMPED MULTILEVEL INVERTER (DCMI)

DCMI inverter came into existence when Nabae, Takahashi, and Akagi introduced a three level DCMI inverter in 1981. This inverter uses diodes to limit the power devices voltage stress. Fig. 4 shows a three-phase 5-leveldiode clamped inverter. Each phase consists of one DC source, four Capacitors (called DC bus capacitors), 12 diodes (called clamping diodes),and 8 switches (like SCR, MOSFET, IGBT etc.). The capacitors associated with the DC voltage source Vdc such that the voltage across every capacitor is equal to Vdc /4. The power losses of diode clamped inverter are more than that of cascaded H-bridge inverter but less than flying capacitor inverter.

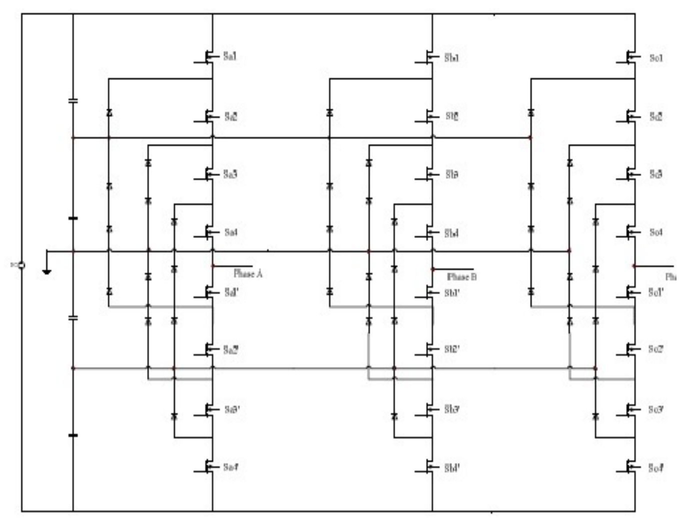

Fig.6 Diode Clamped Multilevel Inverter

TABLE12: SWITCHING SEQUENCE OF 5-LEVEL DCMLI INVERTER

Switch state								Output
S_1	S_2	S_3	S_4	S_1'	S_2'	S_3'	S_4'	V_{an}
1	1	1	1	0	0	0	0	$V_{dc}/2$
0	1	1	1	1	0	0	0	$V_{dc}/4$
0	0	1	1	1	1	0	0	0
0	0	0	1	1	1	1	0	$-V_{dc}/4$
0	0	0	0	1	1	1	1	$-V_{dc}/2$

IV. PULSE WIDTH MODULATION (PWM)

When the width of the carrier signal is varies in accordance with the modulating signal then the signal is called as pulse width modulation (PWM) signal. To generate PWM signal we compare two signals called modulating signal and a carrier signal. Generally, we take modulating signal as sinusoidal signal and carrier signal as triangular or saw tooth signal to generate PWM signal. The amplitude modulation index is given by,

$$m_a = \frac{A_m}{A_c}$$

Where Am is amplitude of modulating signal and Ac is the amplitude of the carrier signal. The frequency modulation index is given by,

$$m_f = \frac{f_s}{f_1}$$

Where fs is frequency of the PWM signal and f1 is the fundamental frequency. The value of mf must be an odd integer, else DC component might exist, and even harmonics will present at the output voltage. There are several Modulation techniques used to control the inverter switches that are as follows:

(1) Phase disposition (PD)
(2) Phase opposition disposition (POD),
(3) Alternative phase opposition disposition (APOD)
(4) Variable Frequency (VF)
(5) Carrier Overlapping (COPWM)

Natural sampling of a single modulating signal (generally sinusoidal signal) through several carrier signal (generally triangular or saw tooth signal) generates multicarrier PWM. An n-level inverter requires n-1 carrier signal with the same frequency (assume fc) and same peak-to-peak amplitude (assume Ac). Let us assume that the modulating signal has amplitude Am and frequency fm with zero offset. The modulating signal is continuously compared with every carrier signals. When the modulating signal is more than the carrier signal, than the active device corresponding to that carrier signal is switched ON else device is switch OFF. For Multi-carrier PWM the amplitude modulation indexis defined as,

$$m_a = \frac{2A_m}{(n-1)A_c}$$

Where Am is amplitude of modulating signal and Ac is amplitude of carrier signal. For Multi-carrier PWM the frequency modulation index is defined as,

$$m_f = \frac{f_c}{f_m}$$

Where fc is frequency of carrier signal and fm is frequency of modulating signal. In this paper we use 4 KHz carrier signal frequency and 50Hz modulating signal frequency. The generation of gate pulses for DCMLI is shown in table. Natural sampling of a single modulating signal (generally sinusoidal signal) through several carrier signal (generally triangular or saw tooth signal) generates multicarrier PWM.

V. SIMULATION RESULTS

SIMULATION DIAGRAM AND RESULTS

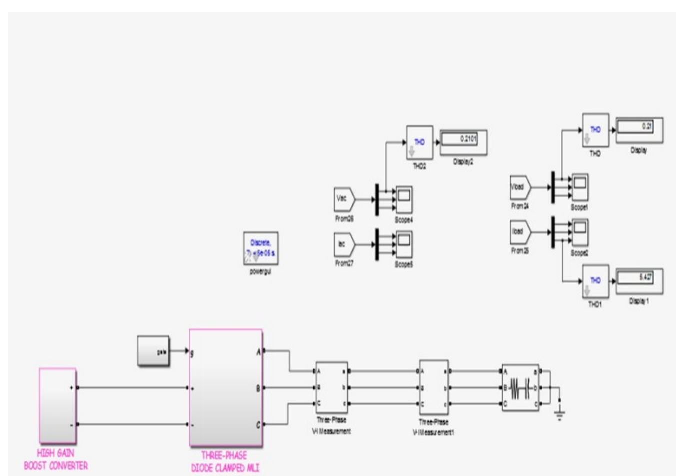

Fig.7 Simulation diagram

MULTILEVEL INVERTER OUTPUT VOLTAGE

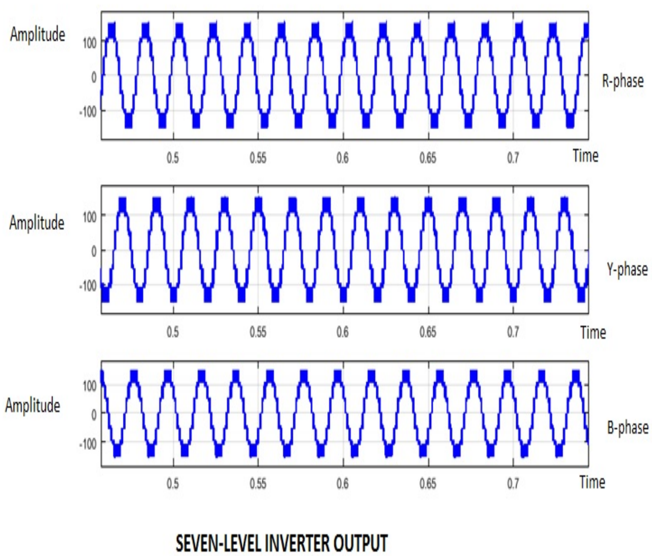

Fig.8 Wave form

VI. HIGH GAIN BOOST CONVERTER OUTPUT

EXPECTED INPUT AND EXPECTED OUTPUT
Here the Input: 230V AC, 0.5A
Output: 280V AC, 12V DC

The number of major components is reduced by the integration. In case of the transformer, the total volume of the magnetic core is increased.

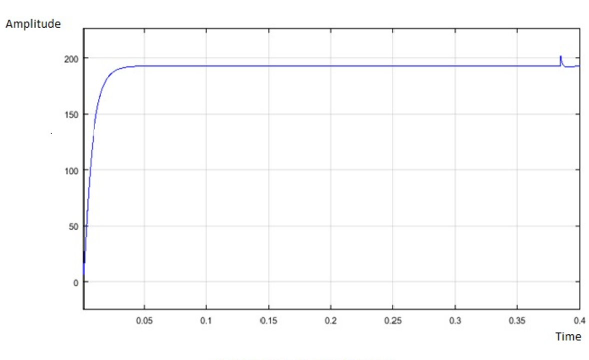

Fig.9 DC Wave form

VII. HARDWARE DESCRIPTION

The hardware system of the proposed converter is implemented using a PIC micro-controller. The software system like Proteus, Mplab, and Micropro is used for the system design for coding the pulses in to the PIC controller. The power supply circuit is designed that will control the PIC and driver circuit to drive the pulses to the MOSFET.

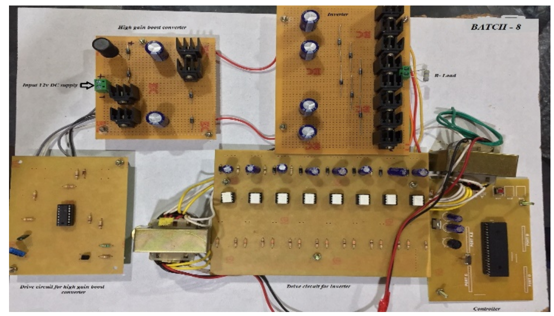

Fig 10 Hardware Setup

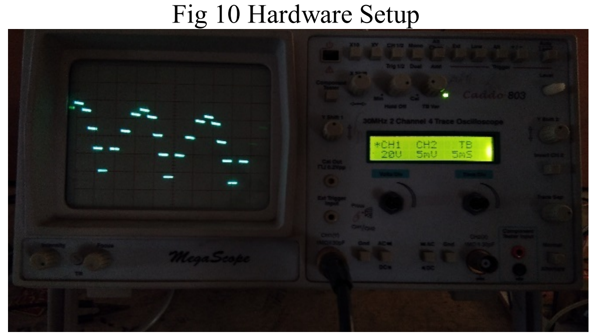

Fig 11 Hardware Result

VIII. CONTROLLER UNIT

A Microcontroller is a small computer on a single integrated circuit containing a processor core, memory, and programmable input/output peripherals. Neither program memory in the form of NOR flash or OTP ROM is also often included on chip, as well as a typically small amount of RAM. Microcontrollers are designed for embedded applications, in contrast to the microprocessors used in personal computers or other general purpose applications.

REQUIREMENTS (HARDWARE PART)
MOSFET GATE DRIVER

The High And Low Side Driver (IR2112) is a high voltage; high speed power MOSFET and IGBT driver with independent high and low side referenced output channels. Proprietary HVIC and latch immune CMOS technologies enable ruggedized monolithic construction. Logic inputs are compatible with standard CMOS or LSTTL outputs, down to 3.3V logic. The output drivers feature a high pulse current buffer stage designed for minimum driver cross conduction. Propagation delays are matched to simplify use in high frequency applications. The floating channel can be used to drive an N-channel power MOSFET or IGBT in the high side configuration which operates up to 600 volts.

MOSFET

A cross section through an n-MOSFET when the gate voltage VGS is below the threshold for making a conductive channel; there is little or no conduction between the terminals source and drain; the switch is off. When the gate is more positive, it attracts electrons, inducing an n-type conductive channel in the substrate below the oxide, which allows electrons to flow between the n-doped terminals; the switch is on.

LOAD

If an electric circuit has a well-defined output terminal, the circuit connected to this terminal (or its input impedance) is the load. (The term 'load' may also refer to the power consumed by a circuit; that topic is not discussed here). Load affects the performance of circuits that output voltages or currents, such as sensors, voltage sources, and amplifiers. Mainspower outlets provide an easy example: they supply power at constant voltage, with electrical appliances connected to the power circuit collectively making up the load. When a high-power appliance switches on, it dramatically reduces the load impedance. If the load impedance is not very much higher than the power supply impedance, the voltage will drop. In a domestic environment, switching on a heating appliance may cause incandescent lights to dim noticeably.

IX. CONCLUSION

The suggested converter Topology consists of three level hybrid boost dc-dc converter and Three phase 5- level DCMLI, In hybrid boost dc-dc converter, step-up the fuel cell output voltage with high voltage gain. It is not only improving the converter's performance but also controls the duty ratio to minimum value. Here, boost inductor, ripple current and voltage are derived with respect to converter parameters. The dynamic and steady state performance of both the capacitors are verified and voltages across the filtering capacitors are balanced by the PWM control technique. The major advantage with this converter, the voltage across the power switches is half of the output voltage. The output of DC voltage is again converted in to AC by using multilevel inverter. This converter topology is better for fuel cell based electric vehicle. Electric Vehicles Boost ac–dc line-side converter for charging/discharging is the application.

REFERENCES

[1] L. Müller and J. W. Kimball, "High gain DC–DC converter based on the Cockcroft–Walton multiplier," IEEE Trans. Power Electron., vol. 31, no. 9, pp. 6405–6415, Sep. 2016.

[2] S. A. Arshadi, B. Poorali, E. Adib, and H. Farzanehfard, "High step-up DC–AC inverter suitable for AC module applications," IEEE Trans. Ind. Electron., vol. 63, no. 2, pp. 832–839, Feb. 2016.

[3] M. Das and V. Agarwal, "Design and analysis of a high-efficiency DC-DC converter with soft switching capability for renewable energy applications requiring high voltage gain," IEEE Trans. Ind. Electron., vol. 63, no. 5, pp. 2936–2944, May 2016.

[4] U. R. Prasanna, A. K. Singh, and K. Rajashekara, "Novel bidirectional single-phase single-stage isolated AC–DC converter with PFC for charg-ing of electric vehicles," IEEE Trans. Transport. Electrific., vol. 3, no. 3,pp.536–544, Sep. 2017.

[5] F. Shang, H. Wu, G. Niu, M. Krishnamurthy, and A. Isurin, "Dynamic analysis and control approach for a high-gain step-up converter for

electrified transportation," IEEE Trans. Transport. Electrific., vol. 3, no. 3, pp. 656–667, Sep. 2017.

[6] M. I. Shahzad, S. Iqbal, and S. Taib, "A wide output range HB-2LLC resonant converter with hybrid rectifier for PEV battery charging," IEEE Trans. Transport. Electrific, vol. 3, no. 2, pp. 520–531, Jun. 2017.

[7] D. Vinnikov, A. Chub, E. Liivik, and I. Roasto, "An implementation of solar PV array based multifunctional EV charger," IEEE Trans. Power Electron., vol. 32, no. 5, pp. 3634–3650,Jan 2018.

[8] M. A. Saket, N. Shafiei, and M. Ordonez, "LLC converters with planar transformers: Issues and mitigation," IEEE Trans. Power Electron., vol. 32, no. 6, pp. 4524–4542, Feb. 2018.

[9] Navid Shafiei, Martin Ordonez, Member, IEEE, Mohammad Ali Saket Tokaldani, Student Member, IEEE, and Seyed Ali Arefifar, Senior Member, IEEE Transactions on transportation electrification, Vol. 4, No. 1, MARCH 2018