Comparison of Silicon MOSFET and Silicon carbide MOSFET in EV charging application

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***Abstract*— MOSFET is an electronic device having high switching frequency which helps to attain fast operation in any circuit. Silicon carbide is a semiconductor having extraordinary behavior as compared to Si based semiconductor. Hence SiC MOSFET can be used to enhance the capability of electronic devices. In this paper, with the help of silicon carbide MOSFET, an electric vehicle charger is design and compare its result as compared with the silicon MOSFET based electric vehicle charger. Only a basic charging circuit is discussed here to compare the characteristics. The characteristics of silicon MOSFET and silicon carbide MOSFET is discussed and presented with the help of MATLAB.**

Keywords— Electrical vehicles, battery, dc-dc converter, on-board charger, off-board charger, mosfet, silicon carbide

I. INTRODUCTION

Electric Vehicle is upcoming demand of country to overcome various issues such as pollution, extinction of fossil fuels. Hence various researches are going on to make electric vehicle friendlier to life such as effective battery design, fast charging capability, low conversion and harmonics losses etc. Electric cars, rickshaw, two- wheelers are already running on road but having some drawbacks which gives it's usage a kind of limitation. And to overcome one of the drawbacks of charging capability, various research are going on, and from those research a replacement for Silicon semiconductor is made as Silicon carbide semiconductor. Hence, by replacing Silicon in electronic device, Silicon carbide can be used to enhance the capability of high switching devices. SiC is a wide band gap semiconductor device which has extra ordinary characteristics in comparison with conventional semiconductor. Wide band devices are next generation efficient power switches, these wideband devices include SiC(silicon carbide), GaN(gallium Nitride). In this paper SiC WBD are used to enhance the capability of EV charger. SiC is having around 10 times of electric field strength than silicon on minimal resistance which makes in suitable for high charging application, SiC also provide high speed operation, PFC(power factor correction), low THD, good efficiency which make it suitable of efficient ad fast charging application[1]. This Electric vehicle is today's need of transportation to overcome the energy challenges across the world but due to barriers in technicality and other factors still the acceptance of EV is challenging worldwide but as the new policies are coming various countries are taking action to encourage citizens among EV uses. Hence these charging infrastructure has to be improved and problems need to be solved or reduced [2]. In order to offer high power with enhanced efficiency while achieving dependable and low-cost operation, power converter topology design and execution are also crucial Various parts of power system such as Generation, transmission and distribution are typically not significantly impacted by the adoption of EVs; But, EV is need to be managed because it can do some changes to current infrastructure as there is a sharp increase in load in the distribution system. Hence it needs to be managed to avoid such unbalancing to the power system [3]. Additionally, damaging harmonics that lower power quality can be produced by EV chargers [4]. This problem can be reduced using the charger's ac-dc power stage's harmonic adjustment technology [5], [6]. EVs having large capacity battery with broader driving range which leads to the need of energy efficient ev charging station for fast charging operations [7]. For an effective charger the efficiency, power density, and reliability should be high and cost, weight, and volume should be low. In open loop, the temperature variation on charging of battery is not taken into consideration but if we maintain a particular temperature for battery then charging efficiency and battery life will be improved. Hence, the closed loop technique's charging current is influenced by temperature feedback and charging voltage, charging current, and battery state of charge are compared between open loop constant temperature constant voltage (CC-CV) and close loop constant temperature constant voltage (CT-CV) battery charging systems (SOC) which shows above stated temperature effect on the performance[8].

Additionally, THD needs to be extremely low because studies in [9]–[10] suggest low power EV chargers, which are inappropriate for dc fast charging. The investigations in [11], [12] have offered incredibly deep details of circuit topologies for AC and DC conversion stage. Additionally, [13] provides an excellent overview of solid-state transformer-based medium voltage ultra-fast EV chargers. Control mechanisms, however, are not covered.

A. Types of EV Charging

There are two types of charging AC charging and DC charging on the basis of supply. AC charging is possible at home, offices, and almost all the public places. For this type of charging all the converging system has to be installed in vehicle itself, hence such type of charger called on-board chargers. And on the other side DC charging based charger are off-board chargers because the system require for this charging method is bulky and of very high voltage which makes it impossible to install in the vehicle. Basically the EV charging station has this type of charging method so that they can provide ultra fast charging. Dc charging also lightens up the vehicle and DC ultra fast charging can fully charged EV in 10 min with the power rating of 400kW or higher [14]. However, this substantial increase in the amount of power to charge the battery raises challenges and research in charging infrastructure, battery performance and its reliability.

II. Topology of EV Charging

EV's are divided into 3 categories i.e. Battery electric vehicles (BEV), hybrid electric vehicles (HEV) and plug-in hybrid electric vehicles (PHEV) [18]. BEV's vehicles need a charging station facility to operate which charge both by wired technology and wireless technology. Conducted, inductive, and wireless charging are all possible types of charging; in which wireless and inductive charging still need more research to work on them physical [15], [16].

The first stage where the battery charging process starts with a rectifier in dc charging circuit. In this stage, rectifier is used to convert ac to dc and here main goal is to take a rectifier which is suitable and provide best results with low harmonics content, inductor is add in series to reduce the harmonics and boost the voltage hence by concluding a three phase boost type rectifier is used here for this type of charging as discussed.

A. AC-DC Conversion stage

This type of rectifier is perfect for Ac to dc conversion stage because it offers low THD, less number of switches, high efficiency and also high power density [17], [18]. It is a full wave rectifier which helps to attain the distortion less DC from the output. It has inductor connected in series with the circuit which helps to reduce the harmonics and also helps to boost the voltage in the circuit [19], [20].

B. DC Conversion stage

This stage is directly connected to vehicle and due to high power flow electric vehicle needed to be protected. Hence, isolation of this converter is important. Although as discussed an isolated converter perfect to include in this circuit but here for the purpose of simplicity, non isolated stage is used to show the main comparison among the electronic devices. A basic DC buck- boost converter is used here to simulate the result.

In this paper, the main concern in showing the comparative behavior of silicon MOSFET and silicon carbide MOSFET in overall basic charging circuit.

III. Material and Methods

This section shows the basic project work and the material chosen for the simulation and also covers the detailed explanation on simulation using MATLAB for the silicon and silicon carbide based charging model. The values shown in the below table I are taken from the existing MOSFET [21].

TABLE I. PARAMETER SPECIFICATION FOR SILICON ANS SILICON CARBIDE MOSFET

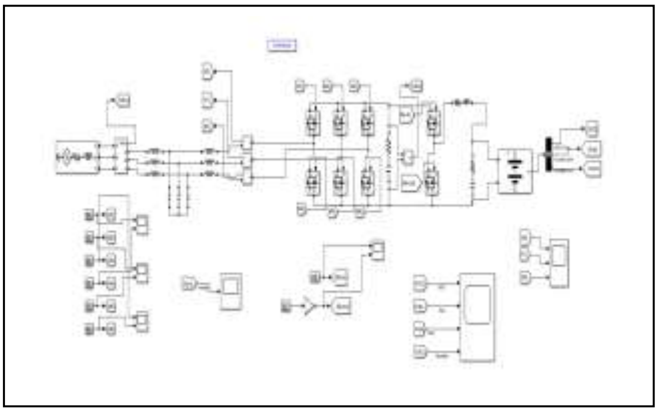
Parameter	**SiC MOSFET**	**Si MOSFET**
Static drain - source on - state resistance, RDS(ON)	0.12 ohm	0.025 ohm
Drain current, ION	10.0 A	6 A
Gate source voltage, Vgs	18.0 V	10.0 V
Gate threshold voltage	2.4 V	1.7 V
Input capacitance, Ciss	8800 pF	350pF
Reverse transfer capacitance, Crss	28pF	80pF
Output capacitance, Coss	420pF	0pF

SiC MOSFET provide low switching land conduction losses, in addition fast switching capability and low power losses which provide better performance as comapared to Si MOSFET and thus increase power device performance.

IV. Matlab Model of Charging Topology

MATLAB based model is presented below for for Silicon and Silicon carbide MOSFET based charging system.
The values of Resistor, indictor, and capacitor are taken tentively to show the final result in both cases.
A 415V of power supply is given to the circuit with 50 Hz frequency and minimal internal impedance to predict the practical condition.

Fig. 1. Simulink charging model Silicon and silicon carbide MOSFET



V. RESULTS

N-channel MOSFET characteristics are calculated with the help of below MATLAB example by which difference between silicon MOSFET and silicon carbide MOSFET.

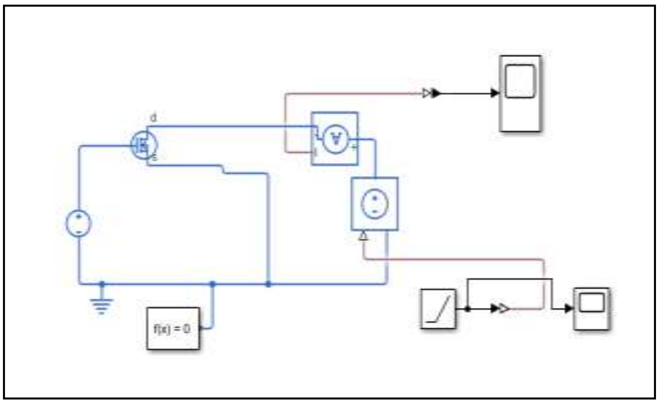


Fig. 2. Simulink model for Silicon and silicon carbide MOSFET characteristics

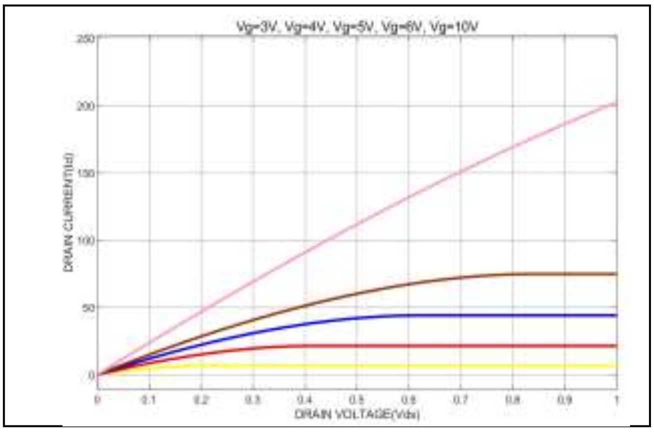
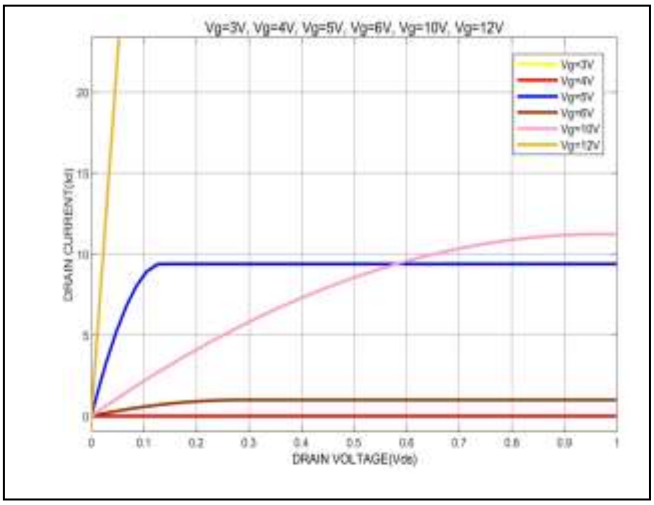


Fig. 3. Silicon MOSFET characteristics

Fig 3 shows the output characteristics of Silicon semiconductor based N- channel MOSFET where by varying the gate voltage, drain current and voltage is varied can be



shown.

Fig. 4. Silicon carbide MOSFET characteristics

Fig 4 shows the characteristics of Silicon carbide semiconductor based N- channel MOSFET where by varying the gate voltage, drain current and voltage is varied can be shown.

From the above result it can be seen that for less the Vg=5V, The drain current and voltage are zero and at 5V, the MOSFET shows constant value of current after reaching 9A drain current.

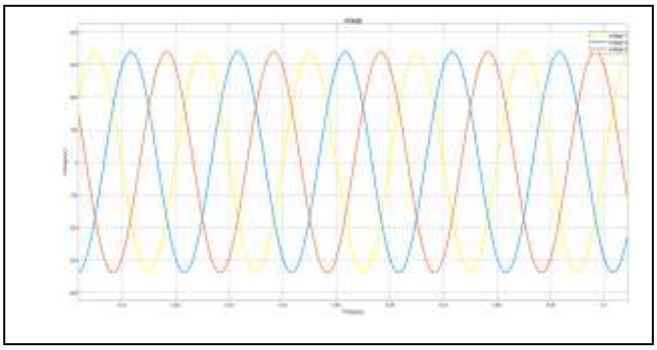


Fig. 5. Three-phase input supply

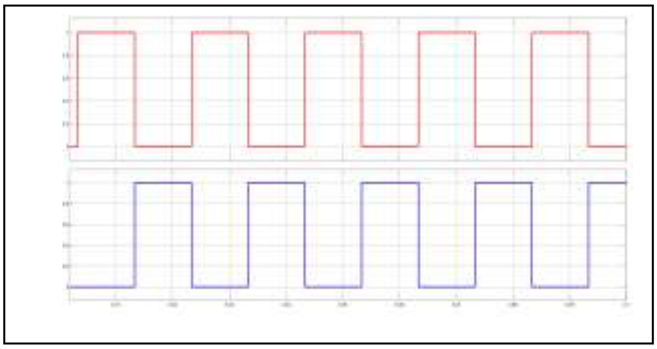


Fig. 6. Silicon MOSFET charging model output

Fig 5 and Fig 6 shows three phase supply and gate voltage respectively in the charging topology model. Gate voltage in a single leg is showing above in fig 6. 180 degree phase shift will be there in each leg.

Fig. 7. Silicon MOSFET charging model output

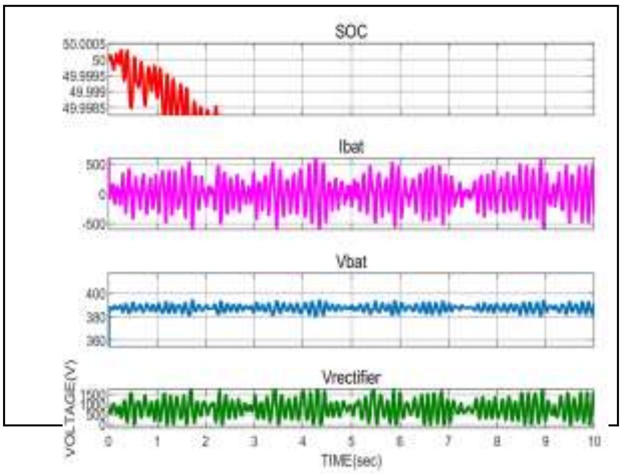


Fig 7 shows the output of silicon MOSFET based charging model, where SOC (state of charge), Ibat (Battery current), Vbat(Battery voltage), Vrectifier (voltage of rectifier).

Fig. 8. Silicon carbide MOSFET charging model output

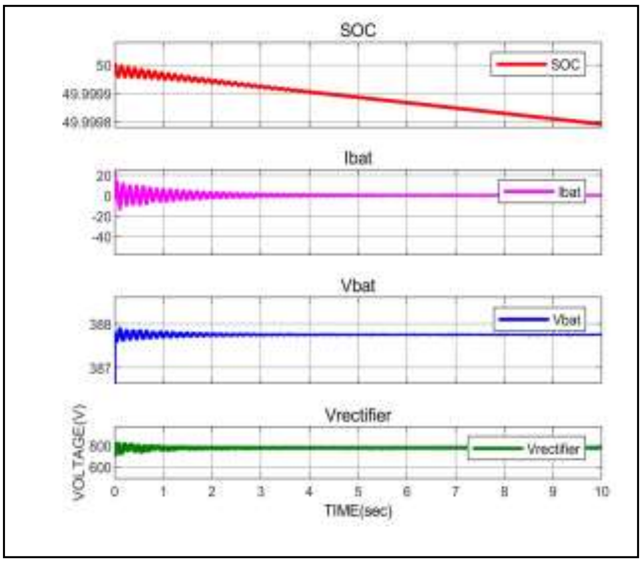


Fig 8 shows the output of silicon carbide MOSFET based charging model, where SOC (state of charge), Ibat (Battery current), Vbat(Battery voltage), Vrectifier (voltage of rectifier).

Both the above results calculated in MATLAB, and these results shows the difference between silicon and silicon carbide MOSFET based charging model. And it can be easily identify that the silicon carbide MOSFET based charging model gave the better result in comparison with silicon MOSFET based charging model. SOC of a battery shows detoriation within 3 seconds in Si MOSFET charging model where as in SiC MOSFET charging model takes 10 seconds. Ibat of a SiC MOSFET based model having low variation in comparison with Si MOSFET based model and similar with Vbat in both the cases. Vrectifier of a SiC MOSFET based model having almost constant variation in comparison with Si MOSFET based model where the variation are very high fluctuating between +1500 to -1500V.

VI. CONCLUSION

Here, it can be concluded that by using Silicon carbide MOSFET charging topology, the battery charging can be made more ideal with good efficiency and low harmonics. Further, Research can be done on advance charging model for the fast charging operation, As this model can't shows the fastest charging operation, so further research can be done on this.

REFERENCES

[1] Kaminski, N., 2009, September. State of the art and the future of wide band-gap devices. In 2009 13th European Conference on Power Electronics and Applications (pp. 1-9). IEEE.

[2] G. Krishna, ''Understanding and identifying barriers to electric vehicle adoption through thematic analysis,'' Transp. Res. Interdiscipl. Perspect., vol. 10, pp. 1–9, Apr. 2021.

[3] T. R. Board and N. R. Council, Overcoming Barriers to Deployment of Plug-in Electric Vehicles. Washington, DC, USA: Nat. Acad. Press, 2015.

[4] C. C. Chan and K. T. Chau, ''An overview of power electronics in electric vehicles,'' IEEE Trans. Ind. Electron., vol. 44, no. 1, pp. 3–13, Feb. 1997.

[5] B. Singh, B. N. Singh, A. Chandra, K. Al-Haddad, A. Pandey, and D. P. Kothari, ''A review of three-phase improved power quality AC-DC converters,'' IEEE Trans. Ind. Electron., vol. 51, no. 3, pp. 641–660, Jun. 2004.

[6] H. F. Farahani, A. Rabiee, and M. Khalili, ''Plug-in electric vehicles as a harmonic compensator into microgrids,'' J. Cleaner Prod., vol. 159, pp. 388–396, Aug. 2017.

[7] S. Srdic and S. Lukic, ''Toward extreme fast charging: Challenges and opportunities in directly connecting to medium-voltage line,'' IEEE Electrific. Mag., vol. 7, no. 1, pp. 22–31, Mar. 2019.

[8] Joshi, B., Maherchandani, J.K. and Chhipa, A.A., 2021, February. Comparison between open and closed loop battery charging technique for lithium-ion battery. In 2021 7th International Conference on Electrical Energy Systems (ICEES) (pp. 150-155). IEEE.

[9] V. Krithika and C. Subramani, ''A comprehensive review on choice of hybrid vehicles and power converters, control strategies for hybrid electric vehicles,'' Int. J. Energy Res., vol. 42, no. 5, pp. 1–24, Dec. 2017.

[10] A. Khaligh and M. D'Antonio, ''Global trends in high-power on-board chargers for electric vehicles,'' IEEE Trans. Veh. Technol., vol. 68, no. 4, pp. 3306–3324, Apr. 2019.

[11] I. Subotic, N. Bodo, E. Levi, B. Dumnic, D. Milicevic, and V. Katic, ''Overview of fast on-board integrated battery chargers for electric vehicles based on multiphase machines and power electronics,'' IET Electr. Power Appl., vol. 10, no. 3, pp. 217–229, Mar. 2016.

[12] S. F. Tie and C. W. Tan, ''A review of energy sources and energy management system in electric vehicles,'' Renew. Sustain. Energy Rev., vol. 20, pp. 82–102, Apr. 2013.

[13] H. Ramakrishnan and J. Rangaraju, ''Power topology considerations for electric vehicle stations,'' Texas Instrum. Appl. Rep., Texas Instrum., Dallas, TX, USA, Tech. Rep. SLLA497, Sep. 2020. [Online]. Available: https://www.ti.com/lit/an/slla497/slla497.pdf?ts=1633058316605

[14] S. Chakraborty, H. N. Vu, M. M. Hasan, D. D. Tran, M. E. Baghdadi, and O. Hegazy, ''DC–DC converter topologies for electric vehicles, plug-in hybrid electric vehicles and fast charging stations: State of the art and future trends,'' Energies, vol. 12, no. 8, pp. 1–43, Apr. 2019.

[15] H. Tu, H. Feng, S. Srdic, and S. Lukic, ''Extreme fast charging of electric vehicles: A technology overview,'' IEEE Trans. Transport. Electrific., vol. 5, no. 4, pp. 861–878, Dec. 2019.

[16] U.S. Department of Energy. (Oct. 2017). Enabling Extreme Fast Charging: A Technology Gap Assessment. [Online]. Available: https://www.energy.gov/eere/vehicles/downloads/enabling-extremefast-charging-technology-gap-assessment

[17] T. Friedli, M. Hartmann, and J. W. Kolar, ''The essence of three-phase PFC rectifier systems—Part II,'' IEEE Trans. Power Electron., vol. 29, no. 2, pp. 543–560, Feb. 2014.

[18] L. Huber, M. Kumar, and M. M. Jovanović, ''Performance comparison of three-step and six-step PWM in average-current-controlled three-phase six-switch boost PFC rectifier,'' IEEE Trans. Power Electron., vol. 31, no. 10, pp. 7264–7272, Oct. 2016.

[19] A. Mallik, W. Ding, C. Shi, and A. Khaligh, ''Input voltagesensorless duty compensation control for a three-phase boost PFC converter,'' IEEE Trans. Ind. Appl., vol. 53, no. 2, pp. 1527–153 7,Mar./Apr. 2017.

[20] S. Augustine, J. E. Quiroz, M. J. Reno, and S. Brahma, ''DC microgrid protection: Review and challenges,'' Sandia Nat. Lab., Albuquerque, NM, USA, Tech. Rep. SAND2018-8853, 2018.

[21] https://www.infineon.com/dgdl/Infineon-F3L8MR12W2M1HP_B11-DataSheet-v01_10-EN.pdf?fileId=8ac78c8c80027ecd0180f00090ea4e8e

[22] M. Eull, W. Wang, L. Zhou, and M. Preindl, ''Zero sequence voltage control enabling transformerless electric vehicle chargers,'' in Proc. IEEE Transp. Electrific. Conf. Expo (ITEC), Jun. 2021, pp. 861–868.

[23] R. Greul, S. D. Round, and J. W. Kolar, ''Analysis and control of a threephase, unity power factor Y-rectifier,'' IEEE Trans. Power Electron., vol. 22, no. 5, pp. 1900–1911, Sep. 2007.

[24] T. B. Soeiro and J. W. Kolar, ''Analysis of high-efficiency three-phase two- and three-level unidirectional hybrid rectifiers,'' IEEE Trans. Ind. Electron., vol. 60, no. 9, pp. 3589–3601, Sep. 2013.

[25] L. Huber, M. Kumar, and M. M. Jovanovic, ''Analysis, design, and evaluation of three-phase three-wire isolated AC-DC converter implemented with three single-phase converter modules,'' in Proc. IEEE Appl. Power Electron. Conf. Expo. (APEC), Mar. 2016, pp. 38–45.

[26] J. W. Kolar and T. Friedli, ''The essence of three-phase PFC rectifier systems—Part I,'' IEEE Trans. Power Electron., vol. 28, no. 1, pp. 176–198, Jan. 2013.