J. Integr. Sci. Technol. 2024, 12(1), 705 Article

Integrated Science

Journal of Integrated
SCIENCE & TECHNOLOGY

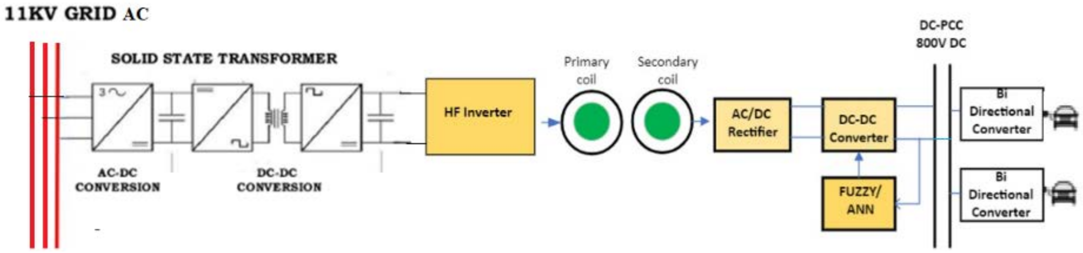
Application of Solid State Transformer in Wireless charging system of EV and voltage profile enhancement by using AI techniques

Dinakar Yeddu, B. Loveswara Rao*

Department of Electrical and Electronics Engineering, Koneru Lakshmaiah Education Foundation, Vaddeswaram, AP, India.

Received on: 08-Apr-2023, Accepted and Published on: 07-Aug-2023

ABSTRACT



The paper describes a novel approach to wireless charging in electric vehicle design. The development of solid-state transformers (SSTs) is based on silicon carbide devices that are able to block higher voltages and switch faster than silicon (Si) power devices. The wireless charging system makes charging very easy and reliable. LFT is replaced by SST in wireless charging. maintaining a constant DC bus voltage for EV and any load requirements. Two AI controllers were proposed for regulating the voltage. For battery charging, a dual-active bridge is used. Since it charges in constant current and constant voltage (CC-CV) modes. The fuzzy and ANN regulated the DC bus voltage and were implemented in MATLAB and Simulink. However, fuzzy has a long computational time. This article proposes a new design that is based on solid-state transformer-based wireless charging technologies for EVs and control strategies based on ANN and fuzzy logic for voltage profile enhancement. Finally, for battery charging, the proportional plus integral controller-based dual active bridge allows the user to specify the desired current, enabling constant current mode.

Keywords: Solid State Transformer (SST), Electric Vehicles (EV), Artificial Neural Network (ANN), Fuzzy Logic, Battery Pack, Wireless Power Transfer (WPT), Proportional plus integral controller (PI).

INTRODUCTION

The ever-increasing number of fossil-fuel-powered automobiles, such as motorcycles, cars, trucks, buses, and other vehicles, is the primary source of environmental pollution, degrading air quality and contributing to global warming by emitting harmful air pollutants. The environment is spoiled by these gases, and the human body's organ systems also have harmful effects. Scientists have expressed worry about the environmental issues, and the solution is to put a strong focus on reducing dependency other than on electric vehicles. There was no pollution in the environment and no greenhouse gases emitted over the last few decades. These characteristics make us select EVs, and their demand is growing day by day.[1] Different load profiles are used to analyze the chargers' effects on the distribution network, which results in the development of the infrastructure and the planning of investments.[2]

Future electric mobility will focus on static charging via wireless power transfer systems.[3] Amperes and the laws of Faraday are used in inductive wireless power transfer (IPTS). Humans and any electronic equipment exposed to leakage flux must be protected in accordance with ICNIRP guidelines.[4] To be commercialized, EMC tests must be successful.[5] As energy demand rises, solar energy is a source of electricity for wireless power transfer today and in the future.[6] Hybrid microgrids can be interconnected with a solid-state transformer.[7] SSTs are the foundation for a future smart grid that can remove harmonics and correct the power factor. Compared to LFT, which lacks the aforementioned benefits,[8] flexible and reliable hybrid ac-dc grids can be constructed using the multiple terminals of SST.[9] The development of solid-state transformers resulted in weight and volume reductions.[10] A low-frequency transformer is substituted by an SST, and its application is in EV charging. PI and PID controllers are used by industry vastly. It can't handle the non-linearity.[11] For FLC mathematical model not required. Response is obtained from predefined rules and it works

---

*Corresponding Author: B. Loveswara Rao
Department of Electrical and Electronics Engineering, Koneru Lakshmaiah Education Foundation, Vaddeswaram, AP, India
Tel: +91 9866290922, Email: loveswararao@kluniversity.in

Cite as: *J. Integr. Sci. Technol., 2024, 12(1), 705.*

ISSN: 2321-4635
http://pubs.thesciencein.org/jist

on if - then logic and the capacity to handle non linearity in power system.[12] ANN based methods which are data driven or model free controllers.[13] For achieving the optimal switching state of the power converter ANN is trained and having good accuracy.[14] To keep the voltage constant at 800 VDC at the DC bus. AI techniques such as fuzzy and artificial neural network controllers were proposed in WPT and implemented in MATLAB/Simulink. Both performed well and regulated the voltage at 800 volts. The bidirectional DC/DC converter regulated the current of the battery pack during charging. The input line current THD is very high due to nonlinear loads.[15] Herein, we report the analysis of the solid state transformer, conventional and proposed wireless power transfer (WPT) system, their control strategies namely ANN & fuzzy-based, simulation results and bidirectional charger for battery charging.

SOLID STATE TRANSFORMER

The efficiency is 98% for SST, and it has provisions for DC.[17] Figure 1 shows the block diagram for SST implementation.

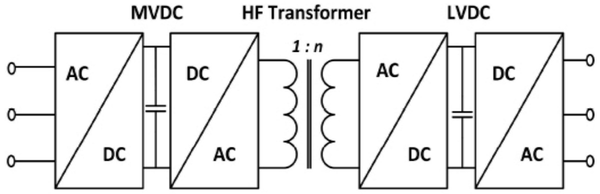


Figure 1. SST three stages diagram [16]

2.a. Conventional wireless charging system

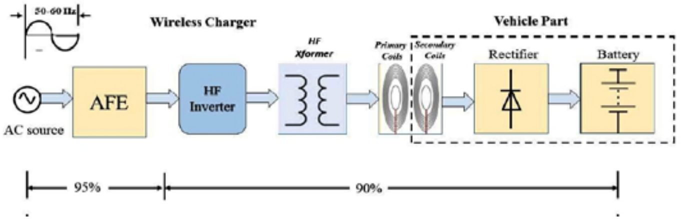


Figure 2. Block diagram of WPT[18]

Static wireless chargers charge the battery while the EV is still running,[19] as illustrated in figure 2. Wireless power transfer (WPT) systems send power from the receiver to the batteries or the motor mechanism via power electronic converters.[20]

2.b. SST –Based EV wireless power transfer system.

The designed SST-based EV wireless charging station is shown in Figure 3a. SSTs' function is to offer a shared DC link. The active rectifier, of the modular type, will connect this system to a distribution network for high voltage power of 11 KV. The DAB (dual active bridge) receives the high-voltage DC produced by this rectifier through its input. As shown in abstract section Figure each H-bridge produces a DC voltage, which is fed to DAB. The stage contains a dual active bridge or other bidirectional converter (DAB).It provides isolation . Due to the transformer's location in the high-frequency portion, it is not very large. The secondary side DC bus connects to the wireless charging system. The 800V DC bus output will charge the EV via DAB.

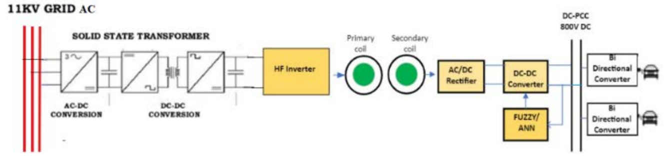


Figure 3a. Designed SST

2.c. SST internal structure

The internal structure of a SST is shown in figure 3b.

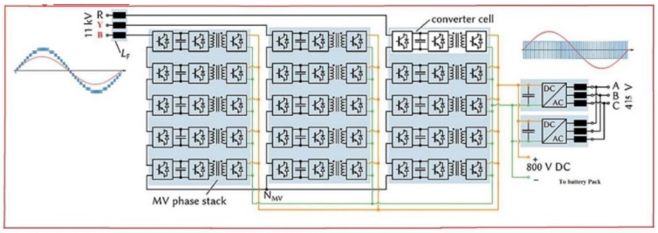


Figure 3b. SST internal structure[21]

AI CONTROL STRATEGIES

Artificial neural network (ANN)

Input (x) and weight (w) are multiplied ,next add to the bias(b) as mathematically shown in equation (1). It can be used to simulate the representation of an ANN .The transfer function of a non-linear type gets the summation output. For successful online learning, neural networks typically require independent ,uniformly dispersed data. How ever in this case ,the artificial neural network makes use of comparable training samples (ANN). ANN gets trained online. No need of minihardware.Optimal duty cycle D is provided by a memory-based ANN learning technique. The technique makes D values change from one value to another in a multi dimenstional measurement space.

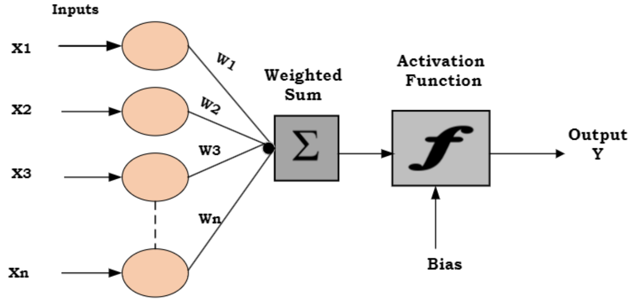


Figure 4. Artificial Neuron diagram[22]

$$y=f(<w,x>+b) \tag{1}$$

The output layer, summation layer, a pattern layer and the input layer ($P_{pv} = x(t)$) comprises an ANN. The ANN's output (t) is the duty cycle $D(x) = y$.[23]

Fuzzy logic controller Design in DC-DC Converter

In figure 6, three parameters are explained below. Fuzzy sets called membership functions are used to represent fuzzy variables, and they have a range of 0 to 1.

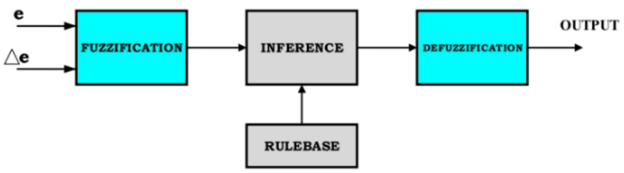
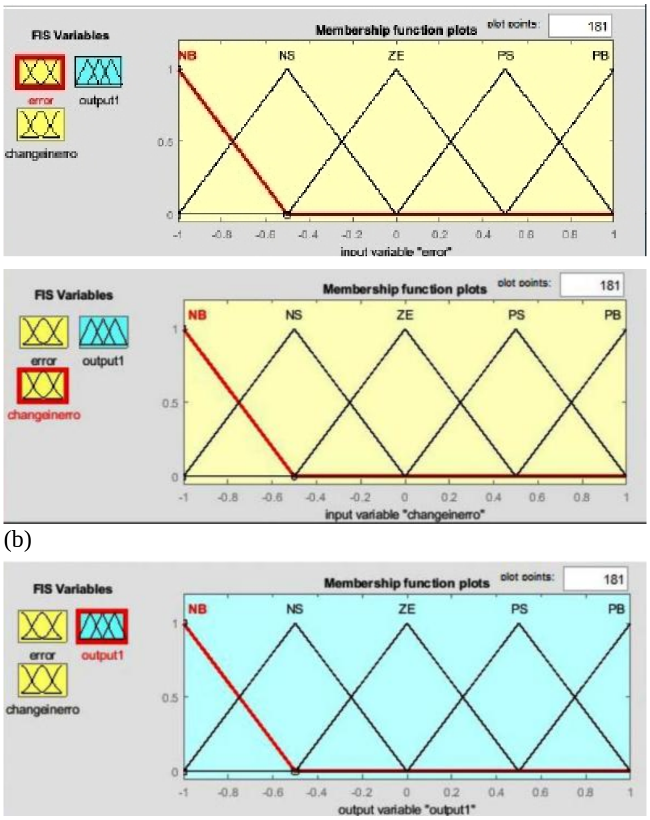


Figure 5. Fuzzy logic states Block diagram[24]

Table 1.Fuzzy if-then rules

Error/Change of Error	NB	NS	ZE	PS	PB
NB	PB	PB	PB	PS	PS
NS	PB	PS	PS	PS	ZE
ZE	PS	PS	ZE	NS	NS
PS	ZE	NS	NS	NS	NB
PB	NS	NB	NB	NB	NB



(a)

(b)

(c)

Figure.6. (a) Membership function Error (b) Membership function change in error (c) Membership Function Output

Five linguistic variables are given as input and output variables. Figures 6(a),6(b) and 6(c), which result in the generation of the optimal duty cycle for regulating the output voltage and controlling mosfet switch.[25]

Fuzzification: The crisp value will be transformed into a fuzzy value. The two inputs are error and change of error. See equations 2 and 3.

$$E = V_{out} - V_{ref} \tag{2}$$

$$\Delta E = E(s) - E(s-1) \tag{3}$$

Fuzzy Inference engine (Fuzzy rule base):

The creation of 25 rules is shown in Table 1.It is decided using the Mamdani max-min method.

Defuzzification:

It applies the centroid approach, separates the physical value from the linguistic value ,and sends the switch the best duty value.

Block diagram of designed ANN controller on DAB plus DC/DC boost converter

Figure.7 depicts the block diagram of a DC/DC boost converter. That is ANN-controlled.

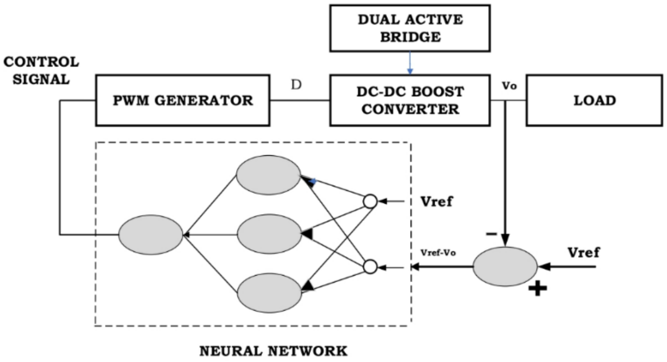


Figure 7. Dual active bridge (DAB)+Boost converter with ANN controller

Block Diagram of proposed Fuzzy logic controller on DAB plus DC/DC Boost Converter

The block diagram of a fuzzy–controlled DC/DC boost converter is shown in figure 8.

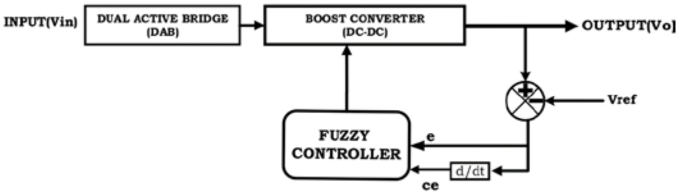


Figure 8. DAB plus Boost converter with fuzzy controller.[26]

4 SIMULATION AND ANALYSIS

Proposed wireless charging system results

As depicted in abstract figure ,the proposed system (11KV/1MW/800V) was simulated in MATLAB/simulink.[27] 800v DC is the solid state transformer based WPT's output.They are now prepared to charge the electric vehicles. Figure 9 displays the waveform of the output voltage.

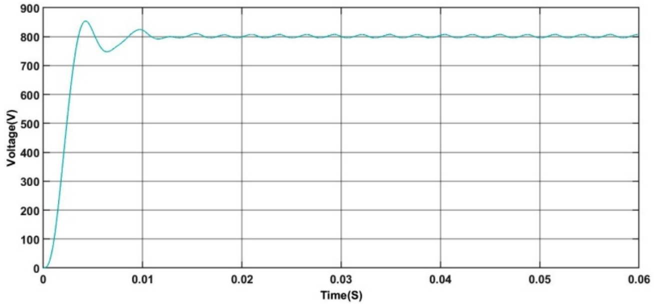


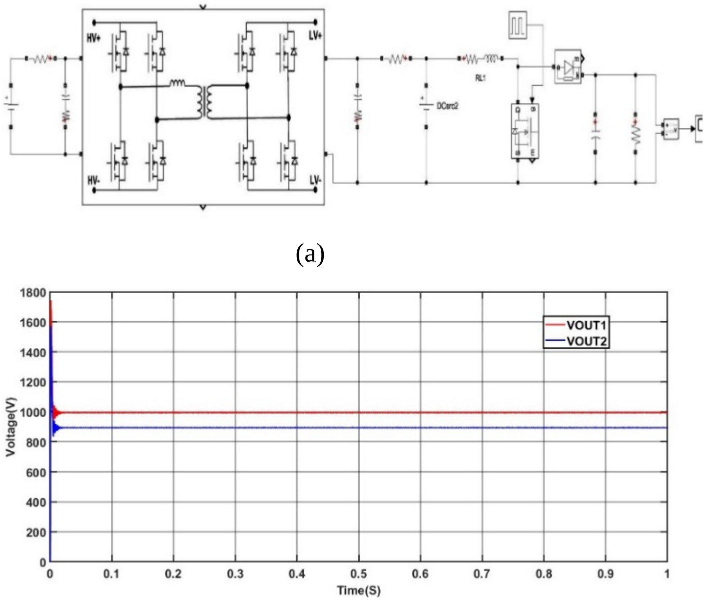
Figure 9. Output voltage vs time.

Dual Active Bridge plus Boost converter output results

The output voltage of the wireless charging system is 800V DC Bus. To analyse the various parameters from line side variations and load side variations, implemented AI techniques. Taken 10KW dual active bridge with boost converter

Table.2. Specifications of Dual active bridge

Parameter	Specifications
Input Voltage	800V DC
Output Voltage	500V DC
Output Power rating	10KW
Output current	20-A
PWM Switching frequency	100KHZ



(a)

(b)

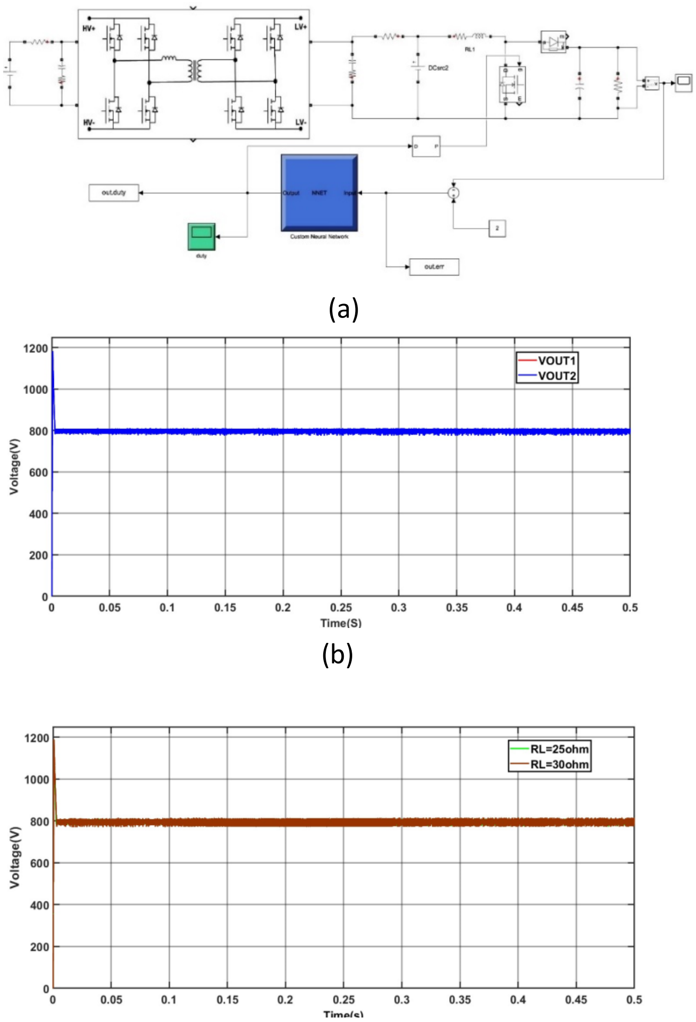
Figure10. (a) Model and (b) DAB plus Boost converter (DC-DC) output voltage for line variations

Table 3. Source side variations and its output voltage

S.No	Voltage(V_{in})	Voltage(V_{out})	voltage (V_{ref})
1	450V	895V	800V
2	500V	995V	800V

From table 3 it is very clear that for input line variations we got voltage other than 800V. So we are going for AI controllers like ANN &Fuzzy to regulate the voltage of (DAB plus Boost converter)

4.c. DAB plus Boost converter with Artificial neural network(ANN) results.



(a)

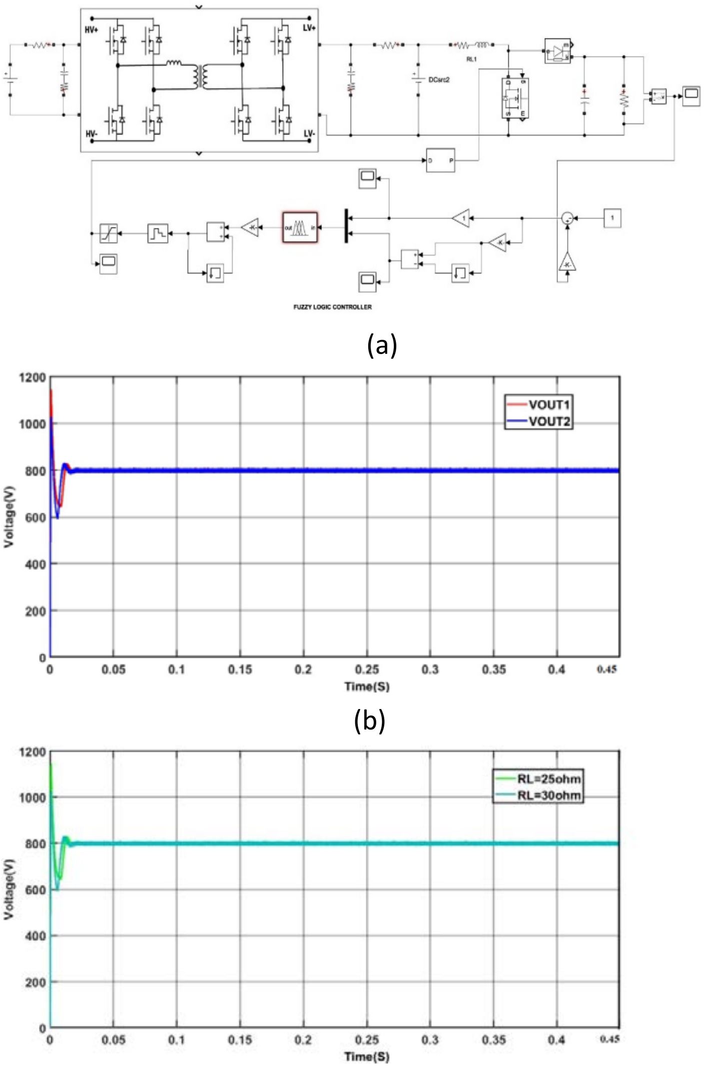
(b)

(c)

Figure11.(a) model (b)Source side variations ,ANN voltage output and (c) Load side variations ANN voltage output.

From 11(b) and (c) figures the ANN controller regulated the voltages to 800V DC as desired with respect to line and load variations

DAB plus Boost converter with Fuzzy logic controller results



(a)

(b)

(c)

Figure.12. (a) .model (b) Source side variations ,Fuzzy voltage output(c) Load side variations,Fuzzy voltage output

From 12(b), and 12(c) figures it is clear that for variations in input voltage for 500V and 450V DC and (RL=25ohms,30ohms) different load resistance values the fuzzy logic controller made the boost converter to regulate the voltage to 800V DC as desired.

Table 4.Computational Time in Simulation

S.No	Line/Load variations	Fuzzy	ANN
1	450V/500V	30min	10min
2	20/30 Ω	30min	10min

Table5 Mathematical results & comparision of AI controllers for line side variation

Vin=500V					
AI techniques	*V_{in1}*	*V_{out1} (regulated)*	*Rise time (micros sec)*	*Over shoot (%)*	*Settling time (millisec)*
Fuzzy controller	500V	800V	365.458	44.203	15.215
ANN controller	500V	800V	383.797	48.507	18.508
Vin=450V					
AI techniques	*V_{in2}*	*V_{out2} (regulated)*	*Rise time (micros)*	*Over shoot (%)*	*Settling time (millis)*
Fuzzy controller	450V	800V	392.319	29.221	13.198
ANN controller	450V	800V	383.647	48.507	19.714

From the above Tables 4 and 5, it is very clear that both the controllers have regulated the voltage. But computation time is high for fuzzy compared to ANN. An Artificial neural network has the robustness of fuzzy, but the computational time is less.

We maintain the constant DC bus voltage for Ev's and any other load requirements. But since the battery pack cannot charge with constant voltage thereby charge with CC-CV mode ,the battery charges.

WIRELESS CHARGING SYSTEM PLUS BIDIRECTIONAL DUAL ACTIVE BRIDGE FOR CHARGING THE BATTERY PACK OF EV

The wireless charging system(WCS) will have a fixed output voltage of 800V DC.But charging involves the constant current and constant voltage (CC plus CV) method .To achieve this, we selected dual active bridge(DAB)at the 800V DC bus.

Design of 10KW DAB for battery charging

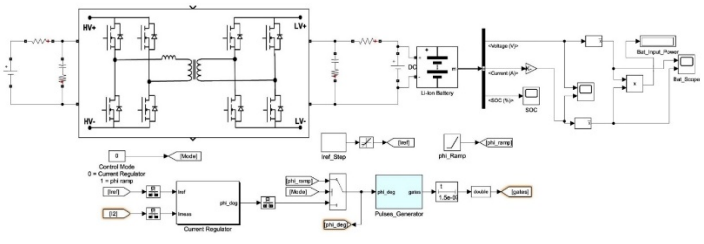


Figure 13: DAB with pi controller for current control

The DAB supplies a power of 10KW with 500V Dc and 20A current as output. Figures 14 and15 shows the results .

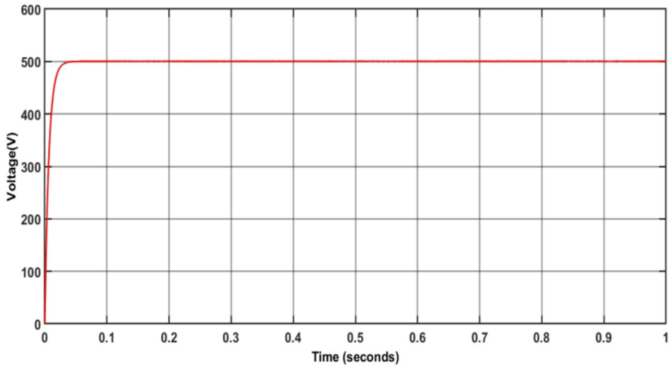


Figure14: DAB output voltage

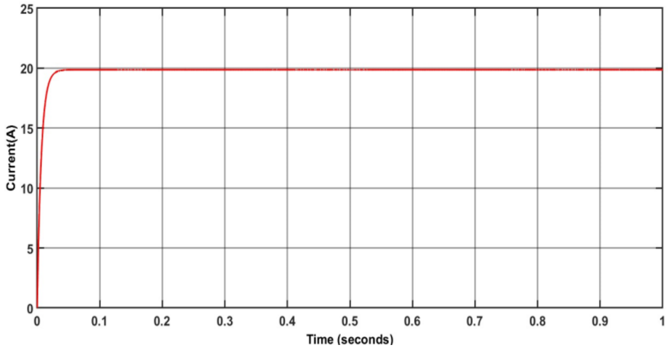


Figure15: DAB output current

Table 6. Dual Active Bridge results.

OUTPUT CURRENT (A)	OUTPUT VOLTAE (V)	POWER (W)	LOAD RESISTANCE (ohms)	PHASE SHIFT (deg)
16.5	420	6920	26	16
19	480	9038	26	21
19.7	500.5	9860	26	23

The resistive loads used to change the output power from light load to full load .At 800 Volts, the input voltage is maintained at a constant level. As can be seen from the Table 6,the phase angle is changed while maintaining the load resistance constant at 26 Ω to accomplish a power transfer of 10KW.

Block diagram of proportional plus derivative controller for Dual active bridge (DAB) converter for charging of EV.

To enable constant current charging, initially proportional plus derivative controller is taken for DAB .It provides current ranging from 10A to 20A for battery pack charging

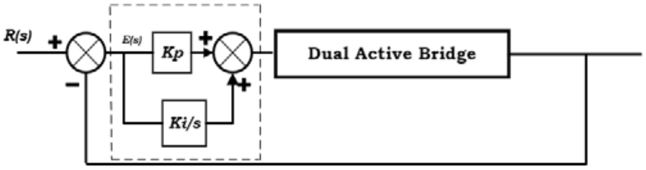


Figure16. Dual Active bridge with PI controller

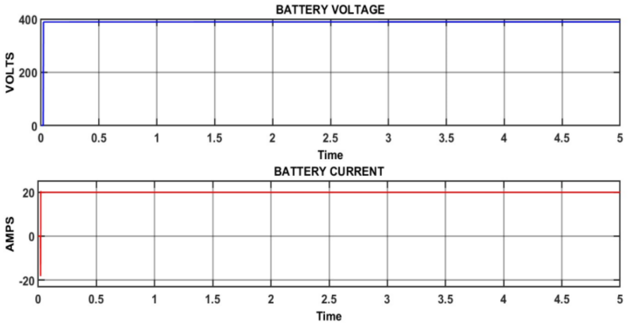


Figure.17. Battery output voltage & output current

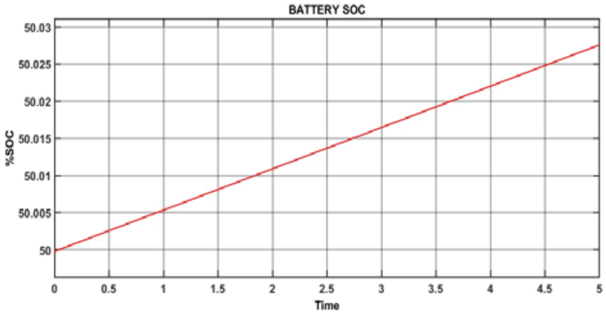


Figure18. Battery SOC

Since the battery operates in CC-CV mode, a constant voltage output dc bus is not needed. So a bidirectional charger is used for charging the battery pack. The required current can be set using the PI controller. From the figures 17 & 18, it is clear that the battery voltage is 360 volts and the current is set at 20A. The model is simulated for 5 seconds, and results are shown. We can set the desired current because of the PI controller in Dual Active Bridge (DAB).

CONCLUSION

In this article, a novel SST-based wireless charging system design is discussed, which leads to a compact size and flexibility of control. WPT makes charging easy and reliable. Secondly, to maintain constant dc bus voltage at the EV charging port, ANN and fuzzy controllers are used for line and load variations. ANN computes faster than fuzzy and has the same robustness as a fuzzy controller. A bidirectional converter is used for battery charging applications. The PI controller enables the use of constant current and constant voltage (CC-CV modes). Finally, an SST-based wireless charging system is simulated in MATLAB/Simulink and the results are presented.

CONFLICTS OF INTEREST

Authors declare no conflict of interest is there for publication of this work

REFERENCES

1. S. Mohammed, J. Jung. A Comprehensive state of the art review of wired /wireless charging technologies for battery electric vehicles Classification/common topologies /future research issues. *IEEE access* **2021**, 27 (9), 19572–85.
2. M. Akil, E. Dokur, R. Bayindir. Impact of electric vehicle charging profiles in data-driven framework on distribution network. In *9th International Conference on Smart Grid, icSmartGrid 2021*; **2021**; pp 220–225.
3. C.C. Mi, G. Buja, S.Y. Choi, C.T. Rim. Modern Advances in Wireless Power Transfer Systems for Roadway Powered Electric Vehicles. *IEEE Transactions on Industrial Electronics*. 2016, pp 6533–6545.
4. Guidelines for limiting exposure to time varying electric and magnetic fields (up to 300GHZ). *CNIRP Guidel.* **1998**.
5. Guidelines for limiting exposure to time varying electric and magnetic fields (upto 100KHZ), ICNIRP guidelines. 2010.
6. G. Bal, S. Oncu, N. Ozturk, K. Unal. An Application of PDM Technique for MPPT in Solar Powered Wireless Power Transfer Systems. *10th IEEE Int. Conf. Renew. Energy Res. Appl. ICRERA 2021* **2021**, 305–309.
7. S.M. Malik, Y. Sun, J. Hu. A novel solid state transformer based control topology for interconnected MV and LV hybrid microgrids. *Energy Reports* **2022**, 8, 10385–10394.
8. Q. Ye, R. Mo, H. Li. Impedance Modeling and DC Bus Voltage Stability Assessment of a Solid-State-Transformer-Enabled Hybrid AC-DC Grid Considering Bidirectional Power Flow. *IEEE Trans. Ind. Electron.* **2020**, 67 (8), 6531–6540.
9. J. Zhou, J. Zhang, X. Cai, J. Wang, J. Zang. Family of Modular Multilevel Converter (MMC) Based Solid State Transformer (SST) Topologies for Hybrid AC/DC Distribution Grid Applications. In *Proceedings - 2018 IEEE International Power Electronics and Application Conference and Exposition, PEAC 2018*; IEEE, **2018**; pp 1–5.
10. M.A. Hannan, P.J. Ker, M.S.H. Lipu, et al. State of the art of solid-state transformers: Advanced topologies, implementation issues, recent progress and improvements. *IEEE Access* **2020**, 8, 19113–19132.
11. I.S. Mohamed, S.A. Zaid, M.F. Abu-Elyazeed, H.M. Elsayed. Classical methods and model predictive control of three-phase inverter with output LC filter for UPS applications. In *2013 International Conference on Control, Decision and Information Technologies, CoDIT 2013*; IEEE, **2013**; pp 483–488.
12. S.J. Jawhar, N.S. Marimuthu. An intelligent controller for a non linear power electronic boost converter. In *International Journal of Soft Computing*; IEEE, **2008**; Vol. 3, pp 69–73.
13. B.R. Lin. Power converter control based on neural and fuzzy methods. *Electr. Power Syst. Res.* **1995**, 35 (3), 193–206.
14. H.S. Khan, I.S. Mohamed, K. Kauhaniemi, L. Liu. Artificial Neural Network-Based Voltage Control of DC/DC Converter for DC Microgrid Applications. In *2021 6th IEEE Workshop on the Electronic Grid, eGRID 2021*; IEEE, **2021**; pp 1–6.
15. A. Yadav, P. Tiwari. Simulation of a model DC-DC converter with cascaded via improvement PFC with boost converter and THD using multiple loads. *2018 Int. Conf. Sustain. Energy, Electron. Comput. Syst. SEEMS 2018* **2019**, 4 (1–3), 147–170.
16. M.S. Poojari, P.M. Joshi. Advance technology using solid state transformer in power grids. *Mater. Today Proc.* **2022**, 56, 3450–3454.
17. J. Burkard, J. Biela. Hybrid transformers for power quality enhancements in distribution grids - Comparison to alternative concepts. In *NEIS 2018 - Conference on Sustainable Energy Supply and Energy Storage Systems*; **2020**; pp 112–117.
18. A. Ahmad, M.S. Alam, R. Chabaan. A Comprehensive Review of Wireless Charging Technologies for Electric Vehicles. *IEEE Trans. Transp. Electrif.* **2017**, 4 (1), 38–63.
19. S. Lukic, Z. Pantic. Cutting the Cord: Static and Dynamic Inductive Wireless Charging of Electric Vehicles. *IEEE Electrif. Mag.* **2013**, 1 (1), 57–64.
20. P. Geetha, S. Usha. Critical Review and Analysis of Solar Powered Electric Vehicle Charging Station. *International Journal of Renewable Energy Research*. 2022, pp 581–600.
21. J.E. Huber, J.W. Kolar. Applicability of Solid-State Transformers in Today’s and Future Distribution Grids. *IEEE Trans. Smart Grid* **2019**, 10 (1), 317–326.
22. S. Sebbane, N. El Akchioui. A Novel Hybrid Method Based on Fireworks Algorithm and Artificial Neural Network for Photovoltaic System Fault Diagnosis. *International Journal of Renewable Energy Research*. 2022, pp 239–247.
23. N.L. Diaz, J.J. Soriano. Study of two control strategies based in fuzzy logic and artificial neural network compared with an optimal control strategy applied to a buck converter. In *Annual Conference of the North American Fuzzy Information Processing Society - NAFIPS*; **2007**; pp 313–318.
24. P.R. Choube, V.K. Aharwal. Development of suitable closed loop system for effective wind power control using different ZSC topologies and different switching techniques. *J. Integr. Sci. Technol.* **2022**, 10 (2), 156–167.
25. D. Yeddu, B.L. Rao. Design of Hybrid Controller for Voltage Profile Enhancement at Battery Energy Storage System Terminal of Solid State Transformer Based Charging of Electric Vehicles. *International Journal of Renewable Energy Research*. 2022, pp 1151–1163.
26. N.D. Bhat, D.B. Kanse, S.D. Patil, S.D. Pawar. DC/DC buck converter using fuzzy logic controller. In *Proceedings of the 5th International Conference on Communication and Electronics Systems, ICCES 2020*; **2020**; Vol. 3, pp 182–187.
27. MATLAB ,version 9.7.01190202(R2021a);The mathworks Inc: Natick, MA, USA, 2021.