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SST Based Medium Voltage Extreme Fast Charger for Electric Vehicles Using Fuzzy-PI and ANN Controllers

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Abstract

The development of power electronics devices and the integration of intelligent non-linear loads into the existing grid with the combination of various renewable sources along with batteries are increasing. For achieving the fast response in charging stations for electric vehicles, an efficient control strategy should be introduced when the renewable source like PV is integrated with the grid along with battery. This paper proposes the utilization of Solid-State Transformers replacing the conventional transformers for achieving the bidirectional power flow in addition to attain the better controlling over the system. To achieve the fast response in the charging station to the Electric vehicles traditional PI controller is replaced with the Fuzzy-PI and Artificial Neural Networks controllers and comparative analysis of these two are also done.

The framework of the charging station is done by considering three different levels of voltages in view of achieving practical layout for the project. To demonstrate the proposed methods simulations are done using MATLAB/Simulink tool,

1. Introduction

The ever increase in demand made the existing system more stress and is increasing gradually due to the integration of renewable energy sources along with the intelligent loads are creating more disturbances and imbalance due to system [1]. Due to the invariable nature of the Solar panel, the integrating of PV sources into the system made more control over the system [2][4]. Due to the capability of bidirectional power flow of the electric vehicles, the system should be more capable to with stand the disturbances and allowing the bidirectional flow for the operation of the system [5][7][9].

Due to the inherent nature of the PV and charging and discharging of the electric vehicles tends to develop the harmonics and imbalances into the systems which results in the system imbalances [1]. In order to achieve the balancing of the system, a balancing controller should be introduced for efficient operation. The Solid-State Transformer is developed with the combination of Front end CHB and a Dual-active bridge for achieving the controlling of the system [8], [12].

The system will always be in synchronization to the utility grid, but due to the bidirectional flow of the EV's and the incapability nature of continues supply of PV tends to imbalances in system which cannot be achieved by using the existing type of traditional transformers [15] [19] [25]. Bidirectional power flow can be achieved by using the SST in the utility grid side. The development of three various voltages levels for the EV's tends to voltages imbalances as three phases are no equal at the instant of integration, which tends to system collapse, proper balancing controller is required for the operation. Here synchronization balancing controller is used for the balancing the system when it is connected grid [20], [24].

The integrating of various levels of PV's and batteries into the existing grid along with the various voltage's classes of EV's makes more complexity in the controlling [1]. So, research concentrated on the development of better controlling techniques for the better operation of the system along with the bidirectional power flow and to decrease the fluctuations and harmonic distortions [13][14]. several research projects have been or are dedicated to SSTs for grid applications [16] [17], i. e., the technical feasibility has been demonstrated multiple times The existing PI controller is not so much effectual for controlling and maximum peak overshoot at the instant of load connection. So, the need to advanced controllers is required for achieving the fast response of the system. So, the development of advancement controllers like fuzzy based controllers, Artificial Neural Networks, Genetic algorithms etc., commenced.

In this paper, initially the fuzzy-pi controller is developed, and further neural networks-based controller is also developed along with them comparative analysis between PI, Fuzzy-PI and ANN controllers are also done.

2. Solid State Transformer

The evolution and utility of power electronic devices and integration of various renewable sources into the grid has increased very rapidly. The development of EV's made the necessity of change in existing grid to smart grid to withstand the various forms of disturbances [1]. Solid state transformers are modern power electronics devices which replace the long-established distribution transformers with the combination of power converters and DC links. SSTs had various more functionalities, which allows the bi-directional power flow by using the High-Frequency transformer and also allows power flow control.

In this paper, we developed a fast-charging station of DC which has capability of 3 different levels of charging independently associated with the three different levels of voltages and power ratings.

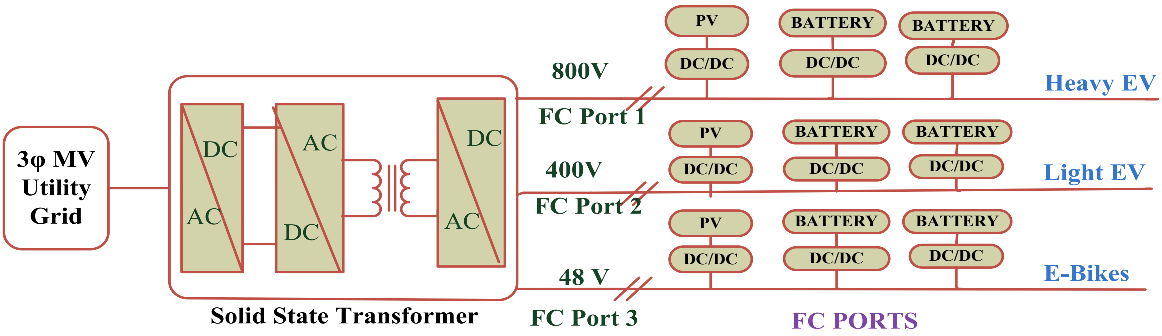


Fig. 1 *Representation of fast charging station structure with 3 levels of EV's along with SST*

The Solid-state transformer with AC-DC then DC-DC is developed as the galvanic isolation in between the DC-DC conversion with the medium frequency transformer to differentiate the three ports of the charging station and the complete system is connected to the 3-ϕ MV system for maintaining the balance in the system. DER source like PV is used along with batteries to decrease the pressure on the grid.

The system is designed by the combination of a CHB [23] converter and DAB converter, a synchronization control is used at the connecting point of the grid along with the balancing control to maintain the phase balance after the controller turned ON as both of these are part of the CHB in the process of achieving transformer less connection with the grid, while the DAB is used as the isolated bidirectional DC-DC converter which is attached to every individual submodules in the initial phase [21]. The cell here represents the combination of submodule, CHB and DAB. Three charging ports are developed from the outputs obtained from the individual phases and cells which are connected parallel individually to the ports.

Every cell of each phase is individually connected to each one of the ports which are connected parallel. The combination of all these is represented as clusters and each one is connected to each port in the system to maintain power flow and also to maintain the system stability batteries are connected parallel to the ports.

3. Controlling Structure of SST

The controlling over the solid-state transformers can be obtained and determined as the combination of the CHB and DAB.

3.1 Front end CHB controlling structure

The CHB type of converter is used in the construction of SST [25] due to tremendous benefits, which is developed as the combination of submodules with each phase; the clusters are combined in delta formation which is 3 in number for every CHB in the system.

3.1.1 Synchronization Controller

The synchronization controller plays the key role in controlling the entire system; it reduces the phase imbalances and system instability at the instant of connectivity to the grid and maintains proper stability. This mainly controls the cluster currents, and the grid voltages and current controlling component is also developed. The direct-quadrature (d-q) axis can be represented based on the synchronous rotating frame and the equation as [1]

$$3V_{c_{avg}}\begin{pmatrix}D_d\\D_q\end{pmatrix}+R_f\begin{pmatrix}i_{s,d}\\i_{s,q}\end{pmatrix}+L_f\frac{d}{dt}\begin{pmatrix}i_{s,d}\\i_{s,q}\end{pmatrix}-L_f\omega_g\begin{pmatrix}i_{s,q}\\-i_{s.d}\end{pmatrix}-\begin{pmatrix}V_{s,d}\\V_{s,q}\end{pmatrix}=0 \tag{1}$$

3.1.2 Balancing Controller

After the synchronization control mode is completed, it is necessary to maintain the system in balanced mode. This is difficult due to the different levels of power for the three charging ports. Due to this phase imbalances occurred, and this causes circulating [26] of unnecessary currents in the system, these type of currents can be decreased by allowing zero sequence components into the system and to maintain proper operation

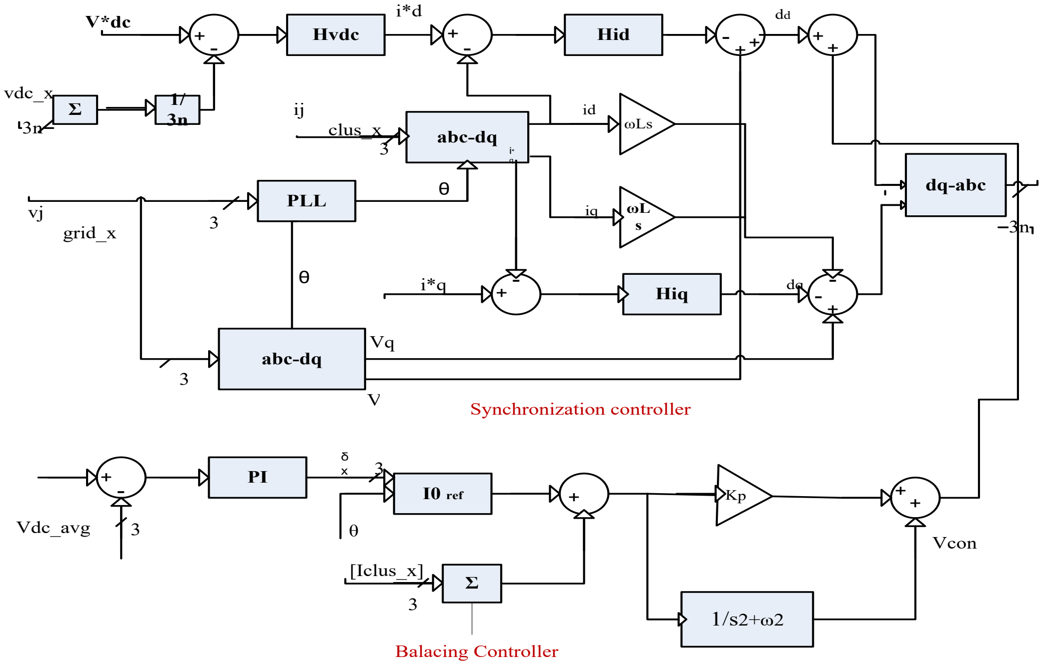


Fig. 2 *Schematic representation of CHB converter*

The MV gird line voltages and currents can be represented below as equation (2) to (11) [1]

$$v_{s,XY} = V_{s,m}\sin(\omega t+30°) \tag{2}$$

$$v_{s,YZ} = V_{s,m}\sin(\omega t+270°) \tag{3}$$

$$v_{s,ZX} = V_{s,m}\sin(\omega t+150°) \tag{4}$$

$$i_{s,X} = I_{s,m}\sin(\omega t) \tag{5}$$

$$i_{s,Y} = I_{s,m}\sin(\omega t - 120°) \tag{6}$$

$$i_{s,Z} = I_{s,m}\sin(\omega t + 120°) \tag{7}$$

When the system is unbalanced, to balance the system zero sequence currents [27] are introduced into the clusters, these currents can be represented as

$$i_0 = I_{0,m}\sin(\omega t + \emptyset°) \tag{8}$$

Therefore, the average powers in the system is

$$P_{average} = \frac{P_{XY} + P_{YB} + P_{BX}}{3} \tag{9}$$

Hence the equation for injecting currents is

$$i_0 = \frac{1}{V_{s,m}}\left\{\frac{\sqrt{3}}{2}(\delta_{XY} + \frac{\delta_{YZ}}{3} - \frac{\delta_{ZY}}{3}) \times \sin\omega t + \frac{1}{2}\left(\delta_{XY} - (\delta_{YZ} - \delta_{ZX})\right) \times \cos\omega t\right\} \tag{10}$$

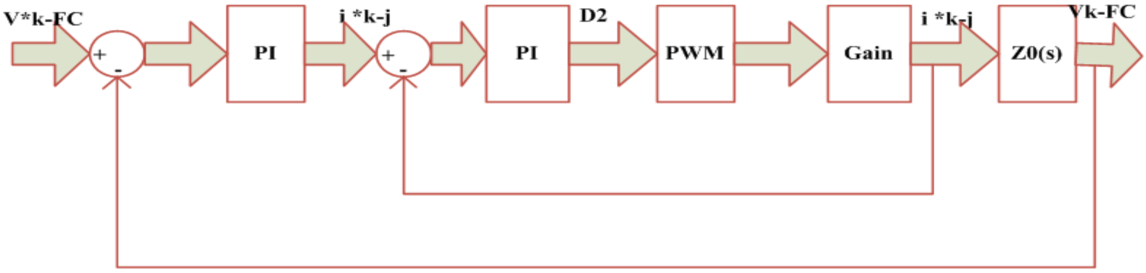


Fig. 3 *Representation of DAB converter*

The cluster currents are represented as below for one cluster.

$$I_{cluster} = \frac{I_{s,m}}{\sqrt{3}}\sin(\omega t + \frac{\pi}{6}) + I_{0.m}\sin(\omega t + \emptyset_0) \tag{11}$$

The total current magnitude in the clusters is

$$|I_{total}| = \sqrt{\frac{I_{s,m}^2}{3} + \frac{P_{avgerage}^2}{V_{s,m}^2} + \left[\delta_{XY}^2 + \frac{1}{3} * (\delta_{YZ} - \delta_{ZX})^2\right] + \frac{2}{\sqrt{3}}\frac{I_{s,m}}{V_{s,m}}\delta_{XY}} \tag{12}$$

The maximum current when the system is subjected to unbalanced is

$$I_{total}^{maximum} = \frac{2P_{average}}{V_{s,XY}} \tag{13}$$

$$I_{nominal} = \frac{\sqrt{2}P_{average}}{V_{S,XY}} \tag{14}$$

Dynamical representation of DAB is

$$\frac{di_{x-j}}{dt} = \frac{-R_x}{L_{l,x-j}} i_{x-j}(t) + \frac{V_{c,x}}{L_{i,x-j}} S_1(t) - \frac{n_x V_{c,x} - FC}{L_{i,x-j}} S_2(t) \tag{15}$$

$$\frac{d}{dt} v_{c,x} - FC^{(t)} = \frac{S_1(t)}{C_{x-j}} i_{x-j}(t) - \frac{I_{x,j}}{C_{x-j}} \tag{16}$$

$S_1(t)$ and $S_2(t)$ are the switching period of the CHB [30], which can be represented as

$$S_1(t) = \begin{cases} 0, & 0 \leq t < \frac{D_1 T_s}{2} \\ 1, & T_s \leq t < \frac{T_s}{2} \\ 0, & \frac{T_s}{2} \leq t < \frac{(2D_1 + 1)T_s}{2} \\ -1, & \frac{(2D_1 + 1)T_s}{2} \leq t < T_s \end{cases} \tag{17}$$

$$S_2(t) = \begin{cases} -1, & 0 \leq t < \frac{D_2 T_s}{2} \\ 0, & 0 \leq t < \frac{(D_1 + D_2)T_s}{2} \\ 1, & \frac{(D_1 + D_2)T_s}{2} \leq t < \frac{(1 + D_2)T_s}{2} \\ 0, & \frac{(1 + D_2)T_s}{2} \leq t < \frac{(1 + D_1 + D_2)T_s}{2} \\ -1, & \frac{(1 + D_1 + D_2)T_s}{2} \leq t \; T_s \end{cases} \tag{18}$$

These are the equations which is are to obtain the various functions of the system from the equations (12) to (18) [1] represents the total currents of the clusters and also the maximum currents which are drawn by the system whenever the system in unbalanced mode of operation. Also, represented the switching time periods of the system as the function of the time of the Cascaded H bridge converter.

3.2 Controlling of DAB Converter

The entire operation of the system at the output side is operated and controlled by the DAB converter [44], in which the controlling is done proper operating of the switches in this mode, where initially the voltage and current references are generated at the charging port side then it fed to the PWM [29] generator for the observation of variations from the initial reference values. If any deviations are observed then the zero sequences are injected into the system to correct the error, and then these final voltages at each cluster are given to the charging ports.

4. Fuzzy-PI Controller Designing

Fuzzy logic controllers are the most effective alternatives in the present scenario to the traditional type of existing Pi controllers and the combination of both Fuzzy-PI controllers gives more interoperability to the system and also withstands the sudden changes and due to various factors [8][11]. There are various drawbacks in the PI as it has slow response to the quick variations in the system and also many more. The fuzzy system allows for a wide range of options in the system [12]. In fuzzy-pi controller, whenever a sudden disturbance or error occurs in the system the parameters of PI i,e., Kp & Ki will changes and the fuzzy rules should be formed in the way to correct the error and to resilient to the disturbances occur in the system.

Initially the fuzzy inference system is developed based on the fuzzy conditions [30] and the developed outputs are fed to the system as the Kp & Ki values which is used at the CHB converter.

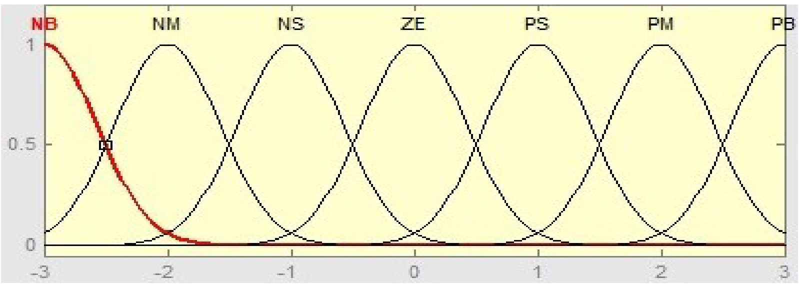


Fig. 4 *Representation of membership function of input1*

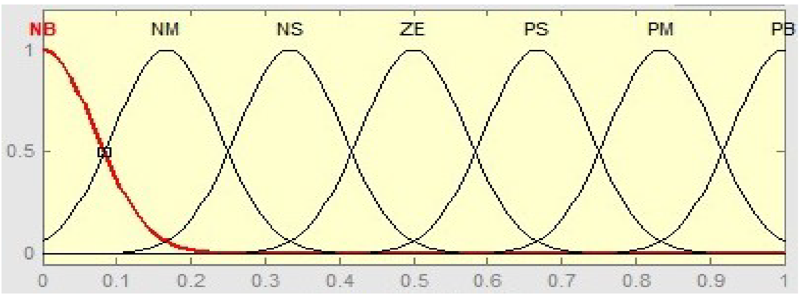


Fig. 5 *Representation of membership function of input2*

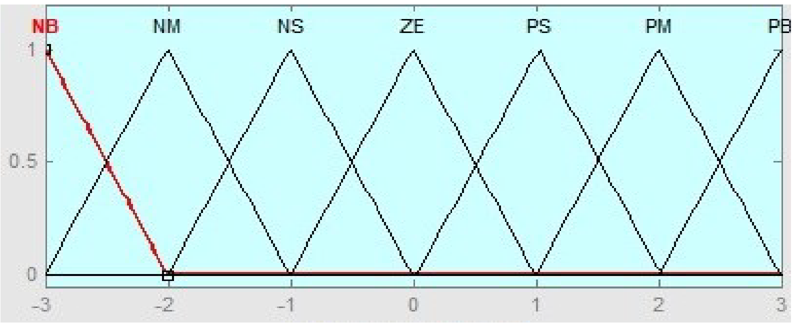


Fig. 6 *Representation of output membership functions*

The fuzzy system is developed as the combination of steps which are Fuzzification, inference system, rule base, knowledge base with last step as defuzzification. The fuzzy controller [31] is developed with the error (e) and rate of change of error (Δe) are inputs with ranges [-3 3] and [0 1] using Mamdani approach of the system for proper operation and further for tuning the Kp & Ki values. The centroid method is used for the defuzzification as two outputs of ranges [-3 3].

Table 1 *Fuzzy logic rule table for 1st output*

e\Δe	NB	NM	NS	ZE	PS	PM	PB
NB	PB	PB	PM	PM	PS	ZE	ZE
NM	PB	PB	PM	PS	PS	ZE	NS
NS	PM	PM	PM	PS	ZE	NS	NS
ZE	PM	PM	PS	ZE	NS	NM	NM
PS	PS	PS	ZE	NS	NS	NM	NM
PM	PS	ZE	NS	NS	NM	NM	NM
PB	ZE	ZE	NM	NM	NM	NB	PB

The inputs of fuzzy system are developed using Gaussian method [32] due to the non-linear nature of the system and the outputs are designed as the rectangular as linear function. The membership functions of the system are taken as the range of negative big (NB) to positive big (PB) [33] with medium, small and zero (ZE). 49 numbers of rules are formed based on the inputs of the controller and the rules are formed based on If-Then rules. The techniques used to analyze performance are stated the objective functions and rules adopted to achieve the best optimized results.

Table 2 *Fuzzy logic rule table for 2nd output*

e\Δe	NB	NM	NS	ZE	PS	PM	PB
NB	NB	NB	NM	NM	ZE	ZE	ZE
NM	NB	NB	NM	NS	NS	ZE	NS
NS	NB	NM	NS	NS	NS	PS	PS
ZE	NM	NM	NS	ZE	PS	PM	PB
PS	NM	NS	ZE	PS	PS	PM	PB
PM	ZE	ZE	PS	PS	PM	PB	PB
PB	ZE	ZE	PS	PM	PM	PB	PB

The developed fuzzy data is utilized to run in the fuzzy inference system to reduce and avoid the error to zero. This controller is used in the DAB converter to replace the existing Pi controller, which is useful for the better operation of the charging station. The operation of the Fig 7 is whenever the error is occurred it is compared to the change in error, the change is applied to the fuzzy-pi inference system [34] to modify and further it is applied to the tuning controller where the Kp &Ki values are to be modify, then change in error will be resolved and the signal will give to the PWM generator to generate the pulses.

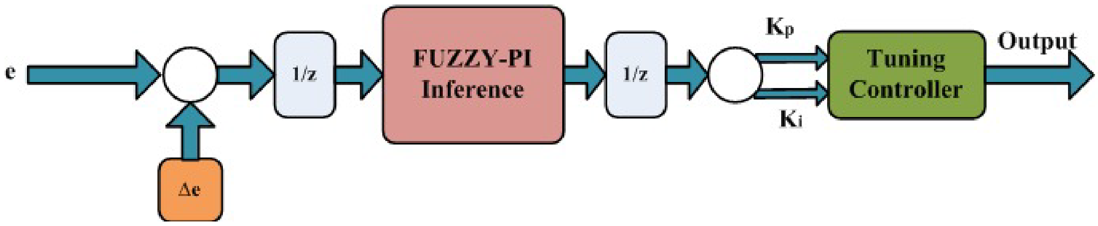


Fig. 7 *Fuzzy-PI functioning diagram*

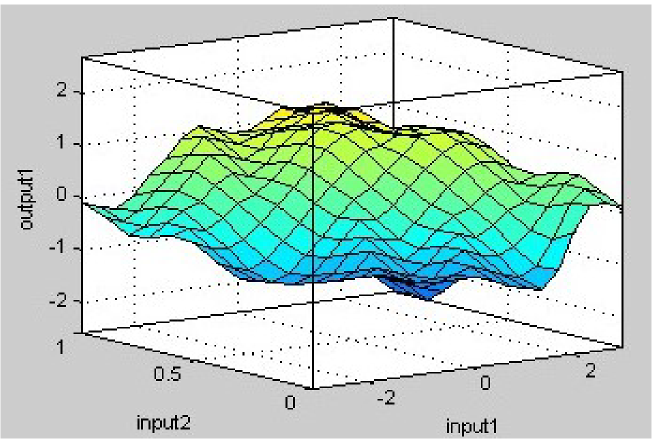


Fig. 8 *Fuzzy-PI surface viewer*

5. Artificial Neural Networks Controller Designing

Artificial neural networks are the most advanced techniques used for the controlling purpose, these are developed from the natural inspiration [35] of the systems. These networks are formed by connecting points named as nodes, which are connected to each other. In this these neural networks are trained in the feed-forward method to obtain the proper data.

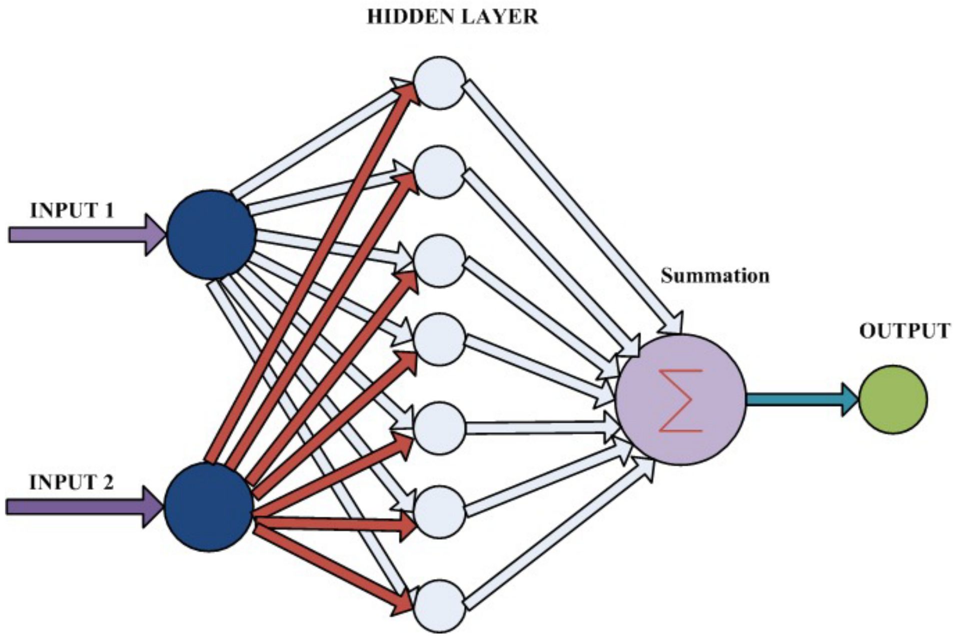


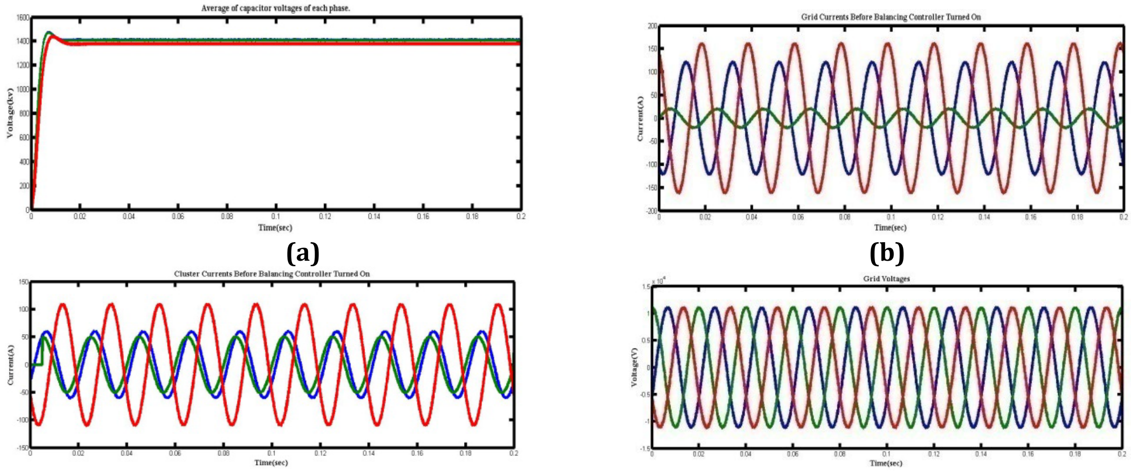
Fig. 9 *Representation of ANN*

In general, these neural networks contain very inputs and several hidden layers of data. Further these all-hidden layers are merged using summation points and then output of the system is obtained.

6. Simulation Results and Analysis

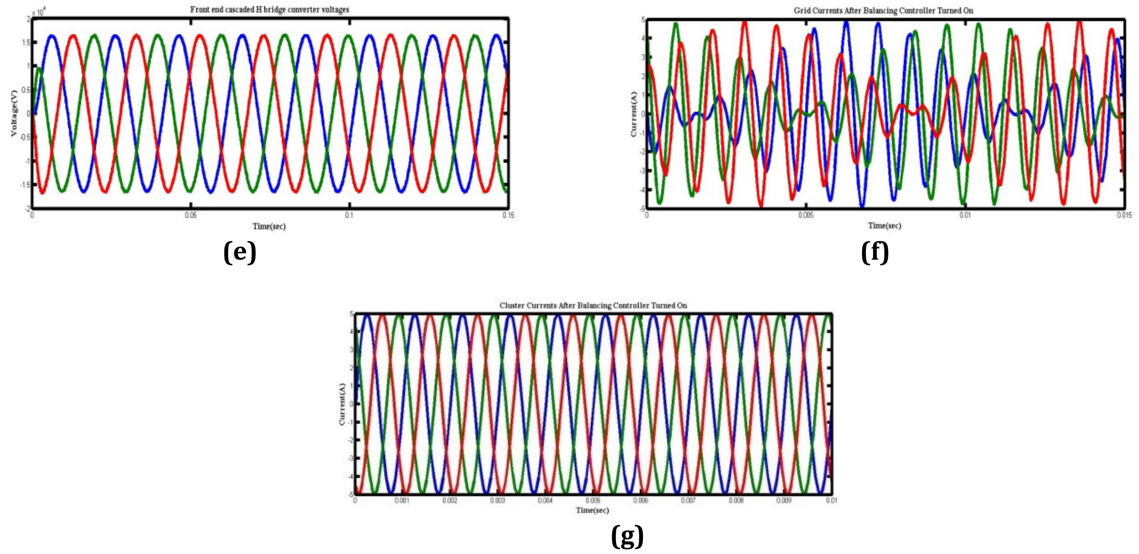
The simulation results of this paper are executed using both Fuzzy-PI and ANN as controllers as mentioned earlier, a capacity of 11kV for the medium voltage grid [43] and rating of 1.2 MVA fast charging station. Initially the system is in an unbalanced state of operation, after the balancing controller turned ON, the system will operate in balanced state. Various currents and voltages at the front-end side is simulated for the time of 2secs, at which the controller is ON. After the system operates in stable condition the operations of EV's at 3 ports are simulated and variations in SOC due to the effect charging and discharging.

The simulation is performed for the 3 charging ports of 800V, 400V and 48V charging capacity at three ports and for battery SOC is executed considering the max of battery charging is 80%.



(a) **(b)**

(c) **(d)**



(e) **(f)**

(g)

Fig. 10 *(a) Avg of capacitor voltages for every phase; (b) Grid currents; (c) Cluster currents; (d) Voltages of grid; (e) CHB voltages; (f) Grid currents; (g) Cluster currents*

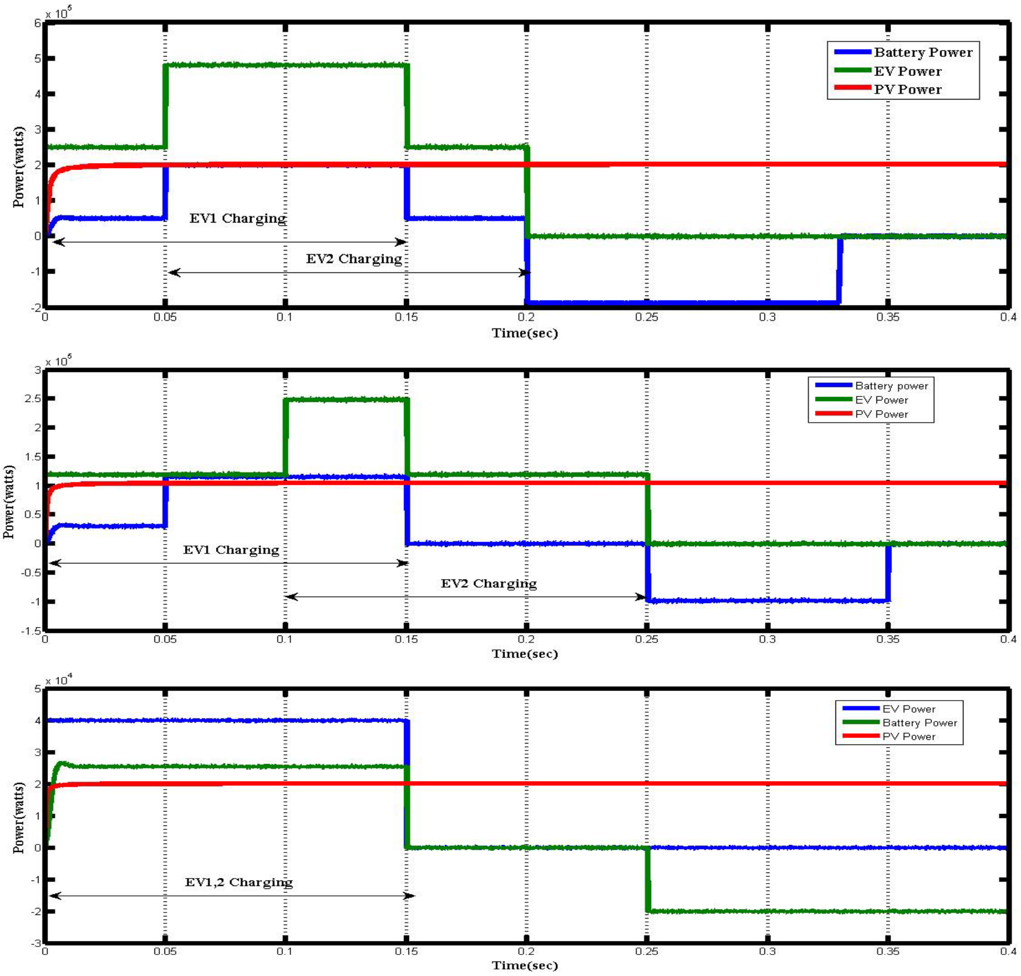


Fig. 11 *Power levels at all 3 FC ports using Fuzzy-PI controller*

The simulations are executed to compare and understand the real-life scenario practically; the results in Fig (10) are executed when the system is in unbalanced condition and also after the balancing controller turned ON.

The PV is functioning constantly at a fixed MPPT point to deliver throughout the operation, this is to understand and proper analysis of the system. Three cases are considered for the operation and understanding of the powers in the EV's and system i.e., (i) requirement of power by EV's & batteries (ii) The amount of power generated by the PV [21] at max point (iii) Battery [39] capacities at the 3 ports.

The three clusters are connected parallel to the FC of three levels of voltages [42] i.e., 800 V for heavy EV's, 400 V for medium EV's and 48 V port for the light EV's and battery capacities of 180 kW,100 kW and 40 kW respectively.

The simulation is carried out for a duration of 40 min and represents the entire operation within simulated time of 4sec, where initially the simulation is started with a EV connected at 1st& 2nd ports while 2 EV's are connected to 3rd port.

The demand of EV1 at port 1 is satisfied and after a few min another EV is connected to port1, where the demand power at port1 is not sufficiently generated by PV and battery, hence the deficit energy is shared via., circulated currents.

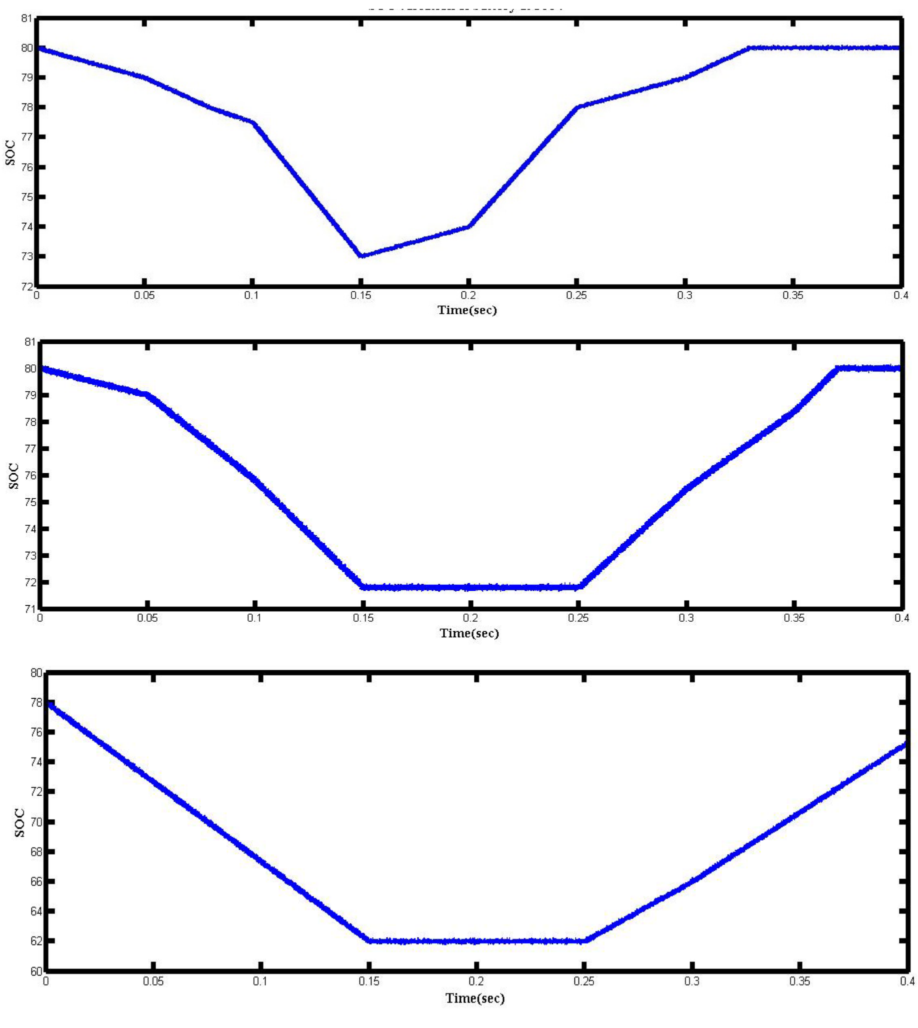


Fig. 12 *Variations in SOC at all 3 FC ports using Fuzzy-PI controller*

The energy deficit among the FC ports is managed by the utility grid and when there are no EV's connected to the port, the energy generated by the PVs of individual ports transfers the amount to the MV grid. For data validations from the reference work [21] all data are compared and verified for feasibility and implementation.

6.1 Comparison Table of PI, FUZZY-PI & ANN

The THD values of the system are observed for 50Hz frequency as the comparative analysis between the PI, Fuzzy-Pi and ANN [40] is represented below. It clearly shows that various techniques are compared and analyzed with the given conditions.

Table 3 *Comparative analysis of various controllers*

Name of the Controller	THD % (50Hz)
PI Controller	10.39%
FUZZY-PI Controller	2.7%
ANN Controller	1.37%

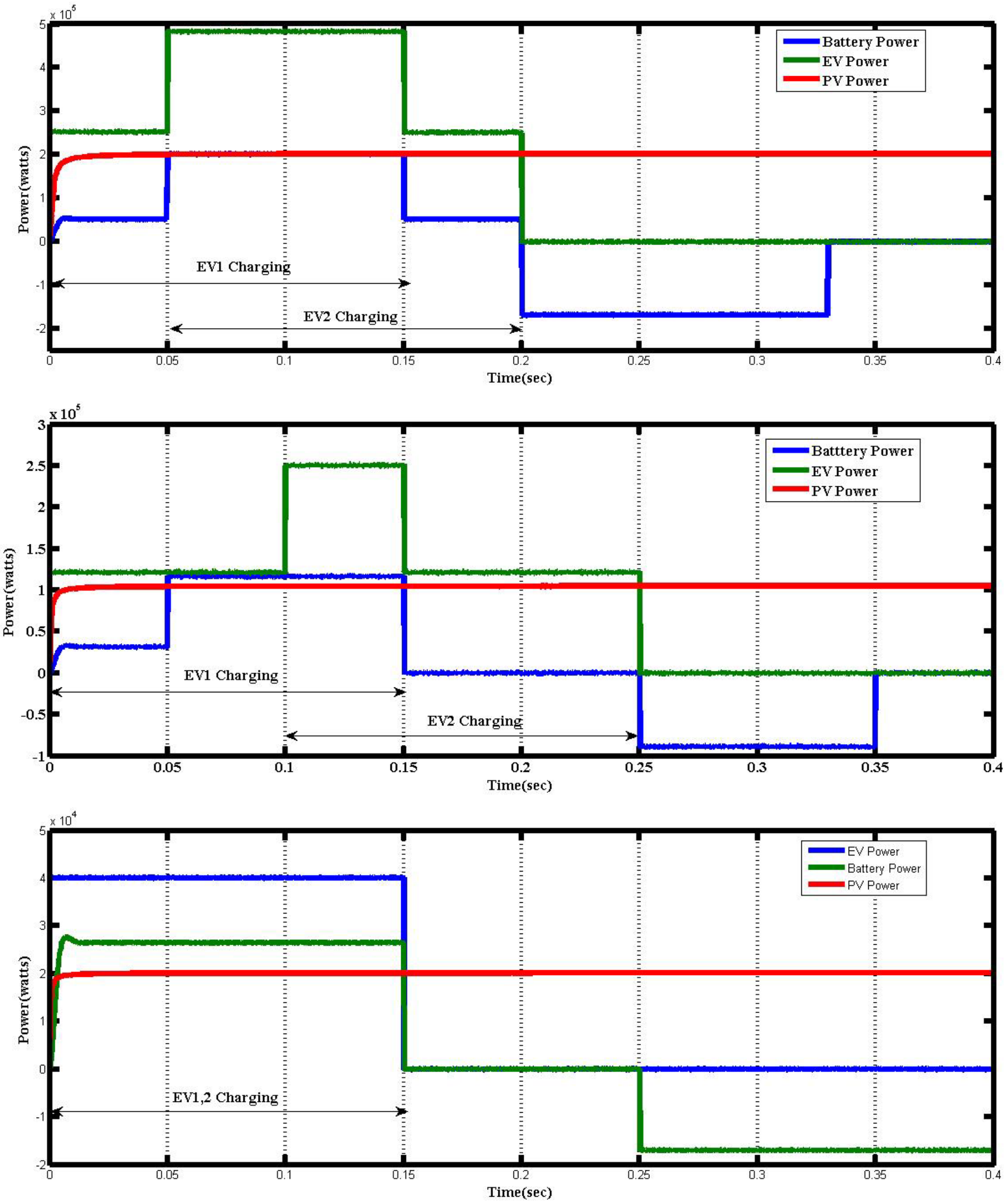


Fig. 13 *Power levels at all 3 FC ports using ANN controller*

The State of Charge (SOC) [41] variation is taken limited in between 20%-80%, due to its best operational range, whenever there is deficit in the system the battery supplies the power to balance the amount required and all the battery is charged by the amount generated by the PV's and excess supply is given to other side of the ports.

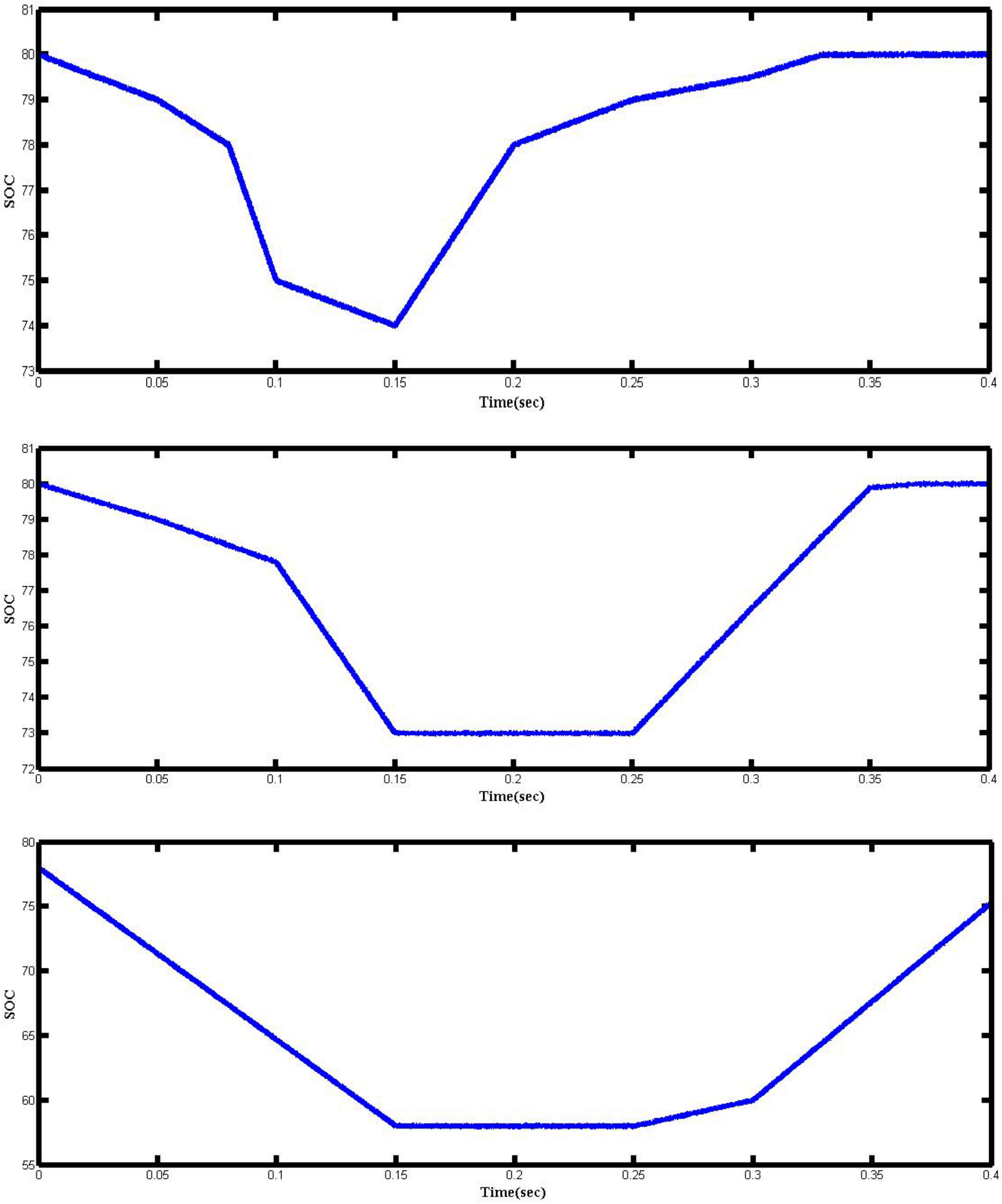


Fig. 14 *Variations at SOC at all 3 FC ports using ANN controller*

From the results it's observed that THD component reduction is 1.37% which is highly appreciable as for as the grid system integration. The convergence of required functions is faster over Fuzzy systems by ANN, since the functions minimize the mathematical calculation by rules.

7. Conclusions

The integration of PV's and batteries with the MV utility grid is developed using the solid-state transformer for constructing the fast-charging station with Fuzzy-Pi and ANN as controllers is achieved. By using advanced controlling techniques like Fuzzy-Pi and ANN fast response in the system is achieved due to its performance. The entire system is also made more resilient to withstand sudden variations while connecting and disconnecting the EV's. Using these modern techniques gives a better range of interoperability to the system and tends to reduce the THD% to permissible limits. The Fuzzy-PI & ANN controllers had better outcomes compared to the existing controller which can be clearly observed by THD% of various techniques results depicts and reduce from 10.39 to 1.37 percentage and values as stated in IEEE 519-2014 lead to acceptable level. Focusing on developing modern controlling techniques gives much smoother operation to the system, when various types of energy sources are integrated; this is the much more area to be focused on and had a wide range of scope. The future research of this paper is to implement the practical hardware by doing complete analysis of the developed model.

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Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

Author Contribution

The authors confirm contribution to the paper as follows: ***study conception and design:*** *Sai Lakshmi Arigela ;* ***data collection:*** *Sai Lakshmi Arigela ;* ***analysis and interpretation of results****: Sai Lakshmi Arigela, A. Pandian ;* ***draft manuscript preparation:*** *Sai Lakshmi Arigela A. Pandian. All authors reviewed the results and approved the final version of the manuscript.*

References

[1] A. C. Nair and B. G. Fernandes, "A Solid State Transformer based Fast Charging Station for all Categories of Electric Vehicles," *IECON 2018 - 44th Annual Conference of the IEEE Industrial Electronics Society*, Washington, DC, USA, 2018, pp. 1989-1994, doi: 10.1109/IECON.2018.8592739.

[2] I. Syed and V. Khadkikar, "Replacing the Grid Interface Transformer in Wind Energy Conversion System With Solid-State Transformer," in IEEE Transactions on Power Systems, vol. 32, no. 3, pp. 2152-2160, May 2017, doi: 10.1109/TPWRS.2016.2614692.

[3] X. Zhang, Y. Xu, Y. Long, S. Xu and A. Siddique, "Hybrid-Frequency Cascaded Full-Bridge Solid-State Transformer," in IEEE Access, vol. 7, pp. 22118-22132, 2019, doi: 10.1109/ACCESS.2019.2898985.

[4] F. Bignucolo, M. Bertoluzzo and C. Fontana, "Applications of the solid state transformer concept in the electrical power system," 2015 AEIT International Annual Conference (AEIT), Naples, Italy, 2015, pp. 1-6, doi: 10.1109/AEIT.2015.7415235.

[5] M. A. Hannan et al., "State of the Art of Solid-State Transformers: Advanced Topologies, Implementation Issues, Recent Progress and Improvements," in IEEE Access, vol. 8, pp. 19113-19132, 2020, doi: 10.1109/ACCESS.2020.2967345.

[6] H. Tu, H. Feng, S. Srdic and S. Lukic, "Extreme Fast Charging of Electric Vehicles: A Technology Overview," in IEEE Transactions on Transportation Electrification, vol. 5, no. 4, pp. 861-878, Dec. 2019, doi: 10.1109/TTE.2019.2958709.

[7] X. She, A. Q. Huang and R. Burgos, "Review of Solid-State Transformer Technologies and Their Application in Power Distribution Systems," in IEEE Journal of Emerging and Selected Topics in Power Electronics, vol. 1, no. 3, pp. 186-198, Sept. 2013, doi: 10.1109/JESTPE.2013.2277917.

[8] M. R. Nayeri, S. Khosravi and M. Aliyari Sh., "Design and implementation double input fuzzy PI and fuzzy gain scheduling PI controller on hydraulic plant," 2013 13th Iranian Conference on Fuzzy Systems (IFSC), Qazvin, Iran, 2013, pp. 1-5, doi: 10.1109/IFSC.2013.6675648.

[9] O. Veneri, L. Ferraro, C. Capasso and D. Iannuzzi, "Charging infrastructures for EV: Overview of technologies and issues," 2012 Electrical Systems for Aircraft, Railway and Ship Propulsion, Bologna, Italy, 2012, pp. 1-6, doi: 10.1109/ESARS.2012.6387434.

[10] Pipalava, Dinesh & Kotwal, Chetan. (2016). ANFIS-PI controller based coordinated control scheme of variable speed PMSG based WECS to improve LVRT capability of wind farm comprising fixed speed SCIG based WECS. Indian Journal of Science and Technology. 9. 10.17485/ijst/2016/v9i44/95253.

[11] D. Aggeler, F. Canales, H. Zelaya-De La Parra, A. Coccia, N. Butcher and O. Apeldoorn, "Ultra-fast DC-charge infrastructures for EV-mobility and future smart grids," 2010 IEEE PES Innovative Smart Grid Technologies Conference Europe (ISGT Europe), Gothenburg, Sweden, 2010, pp. 1-8, doi: 10.1109/ISGTEUROPE.2010.5638899.

[12] Q. Wu, A. H. Nielsen, J. Østergaard, S. T. Cha and Y. Ding, "Impact study of electric vehicle (EV) integration on medium voltage (MV) grids," 2011 2nd IEEE PES International Conference and Exhibition on Innovative Smart Grid Technologies, Manchester, UK, 2011, pp. 1-7, doi: 10.1109/ISGTEurope.2011.6162733.

[13] A. Q. Huang, "Medium-Voltage Solid-State Transformer: Technology for a Smarter and Resilient Grid," in IEEE Industrial Electronics Magazine, vol. 10, no. 3, pp. 29-42, Sept. 2016, doi: 10.1109/MIE.2016.2589061.

[14] S. Srdic, C. Zhang, X. Liang, W. Yu and S. Lukic, "A SiC-based power converter module for medium-voltage fast charger for plug-in electric vehicles," 2016 IEEE Applied Power Electronics Conference and Exposition (APEC), Long Beach, CA, USA, 2016, pp. 2714-2719, doi: 10.1109/APEC.2016.7468247.

[15] Yilmaz, M. & Krein, Philip. (2013). Review of Battery Charger Topologies, Charging Power Levels, and Infrastructure for Plug-In Electric and Hybrid Vehicles. Power Electronics, IEEE Transactions on. 28. 2151-2169. 10.1109/TPEL.2012.2212917.

[16] Melo, Hugo & Trovao, Joao Pedro & Pereirinha, P.G. & Jorge, Humberto & Antunes, Carlos. (2017). A Controllable Bidirectional Battery Charger for Electric Vehicles with Vehicle to Grid Capability. IEEE Transactions on Vehicular Technology. PP. 1-1. 10.1109/TVT.2017.2774189.

[17] D Lenine, Ch Sai Babu, G Shankaraiah, “Performance Evaluation of Fuzzy and PI Controller for Boost Converter with Active PFC”, International Journal of Power Electronics and Drive Systems, Vol.2, No.4, December 2012, pp. 445~453. DOI: http://dx.doi.org/10.11591/ijpeds.v2i4.522.

[18] Jonas E. Huber, and Johann W. Kolar, “Applicability of Solid-State Transformers in Today’s and Future Distribution Grids”, IEEE Transactions on Smart Grid, Vol. 10, No. 1, January, pp-2019 317-326, DOI: 10.1109/TSG.2017.2738610

[19] M. Kang, P. N. Enjeti, and I. J. Pitel, “Analysis and design of electronic transformers for electric power distribution system,” IEEE Trans. Power Electron., vol. 14, no. 6, pp. 1133–1141, Nov. 1999, DOI: 10.1109/63.803407

[20] Tian, Y., Liu, Z., Li, H., & Xu, L. (2023). "A Novel Control Strategy for Solid-State Transformer-Based DC Fast Charger with Active Power Decoupling." IEEE Transactions on Industrial Electronics, 70(5), 4730-4739.

[21] Zhang, B., Liu, Y., & Liu, H. (2022). "Control Strategy for Solid-State Transformer Integrated High-Efficiency DC Fast Charging Systems." IEEE Transactions on Power Electronics, 37(4), 3807-3818.

[22] Xu, Y., Zheng, Y., & Zong, Y. (2022). "Modeling and Control of Solid-State Transformer for EV Fast Charging Stations." IEEE Transactions on Power Delivery, 37(3), 1415-1426.

[23] Shao, J., & Yang, D. (2021). "Design and Control of Solid-State Transformer-Based EV Charger for High-Efficiency Power Conversion." IEEE Transactions on Smart Grid, 12(2), 1154-1163.

[24] Zhou, Y., & Shi, Z. (2021). "Improved Control Method for Solid-State Transformer-Based Bidirectional DC Fast Charger." IEEE Transactions on Industrial Electronics, 68(8), 7185-7193.

[25] Wu, L., et al. (2020). "Solid-State Transformer-Based Control for Real-Time DC Fast Charger Operation." IEEE Transactions on Power Electronics, 35(12), 12087-12098.

[26] Chen, X., Yu, X., & Wang, L. (2020). "Integrated Control of Solid-State Transformers for High-Power DC Fast Charging." IEEE Transactions on Power Delivery, 35(4), 2005-2014.

[27] Hassan, M., & Al-Saidi, N. (2019). "Solid-State Transformer for Fast Charging Station Applications: Design and Control Considerations." IEEE Transactions on Industrial Applications, 55(4), 4209-4219.

[28] Liu, H., & Wu, X. (2019). "A Hybrid Control Strategy for SST-Based EV Charging Systems under Dynamic Load Conditions." IEEE Transactions on Power Electronics, 34(7), 6875-6885.

[29] Zhang, Y., & Liu, Z. (2018). "High-Efficiency Bidirectional Control of Solid-State Transformer for EV Charging and Vehicle-to-Grid Integration." IEEE Transactions on Vehicular Technology, 67(11), 10760-10769.

[30] Liu, Z., Wang, Z., & Li, T. (2023). "Adaptive Control of SST-Based Fast Charging Systems for Electric Vehicles." Energy Reports, 9, 1467-1476.

[31] Wang, C., & Zhang, Y. (2022). "Control Strategies for High-Power SST-Based DC Fast Charger." Journal of Power Sources, 523, 231047.

[32] Chen, X., & Li, J. (2021). "Improved Power Flow Control for Solid-State Transformer in High-Power Fast Charging Applications." Energy Conversion and Management, 242, 114331.

[33] Zhao, Y., & Zhang, L. (2021). "Solid-State Transformer-Based Power Conversion for Fast Charger Control in Electric Vehicle Charging Stations." Electric Power Systems Research, 191, 106865.

[34] Zhang, Q., & Xu, L. (2020). "Optimal Control of Solid-State Transformers for EV Charging and Power Quality Improvement." Renewable Energy, 153, 1234-1243.

[35] Yang, Y., & Li, F. (2020). "Control Algorithms for SST-Based Fast Charging Systems for Electric Vehicles." Journal of Electrical Engineering & Technology, 15(4), 1543-1552.

[36] He, J., & Li, X. (2020). "Design and Optimization of Solid-State Transformer for EV DC Fast Charger." Energy, 202, 117718.

[37] Ma, W., & Zhang, D. (2019). "Control of Power Flow in Solid-State Transformer-Based EV Charging Stations." Journal of Energy Storage, 26, 101009.

[38] Li, Y., & Xu, J. (2019). "Solid-State Transformer Integrated with High-Power DC Fast Charger for Electric Vehicle Charging Systems." Electric Power Components and Systems, 47(10), 1077-1087.

[39] Gao, W., & Chen, Z. (2018). "High-Efficiency Bidirectional DC Fast Charger Using Solid-State Transformer." Journal of Power Electronics, 18(5), 1150-1160

[40] Li, C., & Zhang, H. (2022). "Optimization and Control of SST for Fast Charger Integration in Smart Grids." *Electric Power Systems Research*, 203, 107657.

[41] Zhao, X., & Yang, X. (2022). "Design and Control of a Power-Efficient SST for Electric Vehicle Fast Charging Applications." *Journal of Power Electronics*, 22(7), 1549-1560.

[42] Chen, D., & Gao, Y. (2021). "Unified Control of Solid-State Transformer in EV Charging Stations for Power Distribution Management." *Journal of Energy Engineering*, 147(5), 04021014.
[43] Liu, Y., & Wang, S. (2021). "Model Predictive Control for Solid-State Transformer-Based Fast Charging Systems in Electric Vehicle Stations." *International Journal of Circuit Theory and Applications*, 49(12), 3259-3270.
[44] Yu, P., & Luo, B. (2020). "Decentralized Control Strategy for Solid-State Transformer in High-Power Electric Vehicle Fast Charging Stations." *Electric Power Components and Systems*, 48(3), 248-257.