VOL. 10, NO. 4, MARCH 2015 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

PERFORMANCE OF DC TO DC DUAL ACTIVE BRIDGE CONVERTER DRIVING SINGLE PHASE INVERTER

Digvijay B. Kanase, H. T. Jadhav and R. A. Metri
Department of Electrical Engineering, Rajarambapu Institute of Technology, Rajaramnagar, Islampur. Sangli (MS), India
E-Mail: digvijaykanase91@yahoo.in

ABSTRACT

Solid state transformer is a high frequency transformer can be used as power electronic converter. The three stage SST configuration includes ac to dc rectifier, isolated dc to dc dual active bridge converter, dc to ac inverter. The switching frequency of inverter part is greater than DAB part so inverter stage is model for double line frequency i.e. at 120 Hz. The second harmonics are dominant at this frequency. For better performance of DAB converter PI control is used but at 120 Hz it has limited gain. To proposed methods are PI plus feed forward and PI plus Resonant controller.

Keywords: Solid State transformer (SST), DAB converter, pi controller, pi plus feed forward control, pi plus resonant controller.

1. INTRODUCTION

In order to reduce the dependency on non renewable energy there is increasing in demand for renewable energy sources. Connection of these renewable energy sources to grid lead to the development of power electronic converter. The dual active bridge converter is used to interface these sources to grid. Dual active bridge converter interconnects medium voltage distribution and low voltage distribution network [1]. The SST is important element for future renewable electric energy. SST manages the renewable energy transfer from grid to distribution side [3]. The distribution transformer is fundamental component and is inexpensive, highly reliable and efficient [2]. SST provides active power flow control. But due to presence of power converter there are conduction and switching losses [4]. The output of DAB converter is dc whereas the output at inverter side is ac so the power fluctuates at 120 Hz. So in order that DAB converter to drive such inverter it is necessary to select the capacitor that can absorb such 120 Hz harmonics. As the second order harmonics is less, to compensate it, capacitor bank should be connected at the output of DAB, but the system becomes ineffective also cost increase [6] [9]. So as to decrease the capacitor bank it is necessary to make DAB converters operate at 120 Hz. The PI controller is used to control DAB converter but the limitation of PI controller is that at 120 Hz frequency it has limited gain whereas for dc it has infinite gain it results in steady state error at 120 Hz [1] [5]. There is limitation associated with conventional PI controller when driving single phase inverter. Two methods are proposed first is feed forward and second one is Resonant controller that achieves high gain at 120 Hz. The PR controller is equivalent to PI in rotating frame. PR controller can also be used in three phase system to reduce steady state error and harmonics [7] [11]. Resonant controller is used to track positive and negative sequence components at given frequency [10] [12]. The paper discusses the design of dual active bridge converter at 120 Hz double line frequency and the elimination of second order harmonics. Detail study of controller design issues for DAB converter is carried out.

2. SYSTEM CONFIGURATION

Figure-1 shows SST configuration, first stage is ac to dc rectifier. Second part is isolated dc to dc dual active bridge converter, power is transferred between two dc buses using transformer in this part. The third stage is dc to dc inverter.

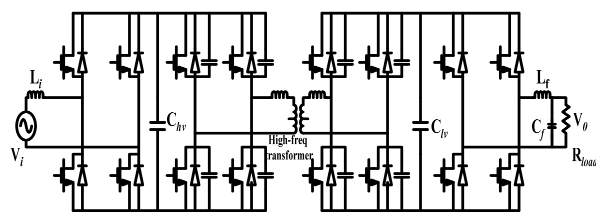

Figure-1. Multi-stage configuration of SST.

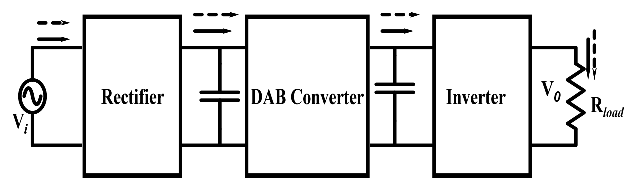

Figure-2. Power transfer using multistage SST.

Figure-2 shows the novel power flow of DAB converter. The solid line indicates the active power flow and the dashed line is double frequency line. The output power from rectifier and inverter is average power (dc) and ripple power (second order harmonics 120Hz).

$$p = \sqrt{2}V\sin(w_s t)\sqrt{2}I\sin(w_s t) = VI(1+\cos(2w_s t)) \qquad (1)$$

The main aim is design of DAB converter in SST following assumptions is made (1) rectifier stage is designed to provide stable dc input to DAB converter (2) inverter is designed such that output voltage is sinusoidal nearly equal to 120 V (3) switching frequency of inverter is more than converter. In this study the switching

VOL. 10, NO. 4, MARCH 2015 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

frequency of DAB converter is 5 KHz and that of inverter is 20 KHz. This is because the voltage at input of DAB converter is higher than the inverter at distribution level [1]. The solid state transformer acts as important solution in FREED system to have control among the power grids, loads, distributed energy sources, and energy storage devices.

By separating the load from the source, the disturbances at grid side will be absent because it is compensated by the SSTs. Thus solid state transformer help is providing the isolation between the two sides of the converter and to reduce the disturbances occurring.

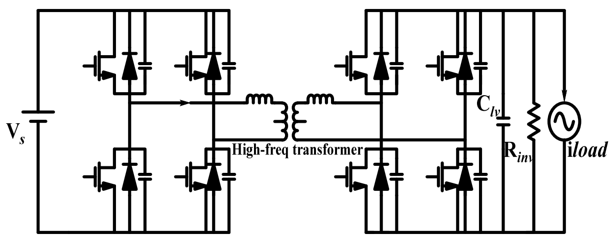

Figure-3. Simplified diagram of DAB converter.

The simplified diagram of converter is shown in figure above.

A. Model Analysis

After defining the problem it is important to model dc to dc DAB converter. For this full order discrete time model technique is used. This model provides accurate control to output transfer function [28] in matrix form written as

$$\frac{d}{dt}x = Ax + B\Delta d \tag{2}$$

$$y = Cx \tag{3}$$

Where,

$$y = [\Delta v_{o0}] \tag{4}$$

$$x = [\Delta v_{o0} \quad \Delta i_{t1R} \quad \Delta i_{t1I}]^T \tag{5}$$

$$A = \begin{bmatrix} -\frac{1}{RC_o} & -\frac{4\sin(D\pi)}{\pi C_o} & -\frac{4\cos(D\pi)}{\pi C_o} \\ \frac{2\sin(D\pi)}{\pi L_t} & -\frac{Rt}{L_t} & w_s \\ \frac{2\cos(D\pi)}{\pi L_t} & -ws & -\frac{Rt}{L_t} \end{bmatrix} \tag{6}$$

$$B = \begin{bmatrix} \frac{4}{C_o}\left(I_{oI}\sin(D\pi) - I_{oR}\cos(D\pi)\right) \\ \frac{2V_{o0}}{L_t}\cos(D\pi) \\ -\frac{2V_{o0}}{L_t}\sin(D\pi) \end{bmatrix} \tag{7}$$

$$C = [1 \quad 0 \quad 0]^T \tag{8}$$

Where v_{o0} output voltage of DAB converter, L_t is leakage inductance of transformer of DAB converter, R_t is lumped equivalent resistance of transformer winding. $w_s = 2\pi fs$, $fs = 5000$ Hz[2]-[8]. The Transfer Function of converter is given as

$$G_{vd}(s) = C(sI - A)^{-1}B \tag{9}$$

The power transferred by DAB converter is

$$P = \frac{v_s v_o}{2 f_s L_t} d(1-d) \tag{10}$$

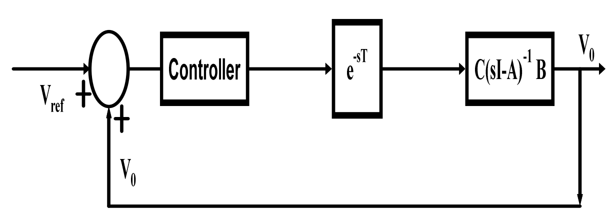

Figure-4. Schematic diagram of closed loop DAB converter.

Figure shows output transfer function of closed loop DAB converter.

VOL. 10, NO. 4, MARCH 2015 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

B. Controller design issues for DAB converter Model

Various methods for controlling the output voltage of DAB converter is discussed in the paper in detail viz, conventional PI controller, PI plus feed forward, PI plus Resonant controller

I] Conventional PI controller:

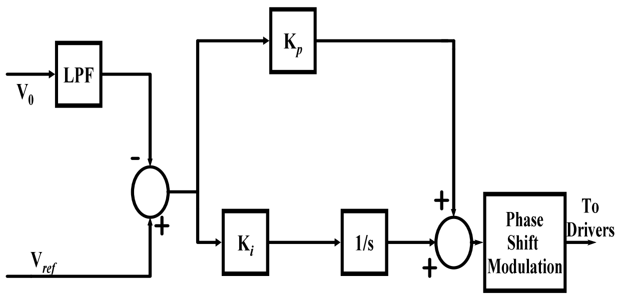

Figure-5. PI control only.

Figure-4 shows closed loop schematic of DAB converter and PI controller (Figure-5).

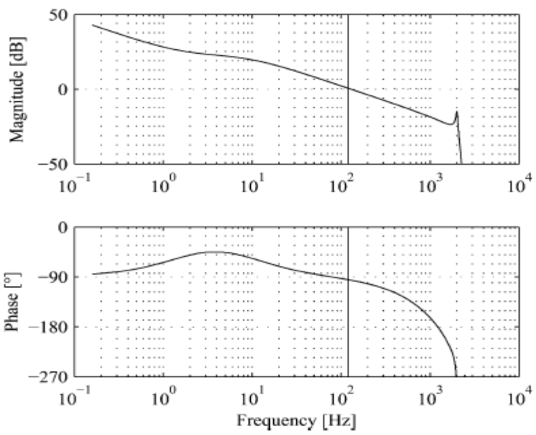

Figure-6. Phase and Magnitude using PI controller only.

Figure-6 shows the gain of PI control at 120 Hz (vertical line is at 120 Hz). The gain is low and it is difficult to identify and compensate the 120 Hz harmonic current at inverter side. So it is necessary to increase the gain of K_p.

There are two improvements provided for PI controllers namely PI plus feed forward and PI plus Resonant controller. The main target control of DAB converter is (1) to regulate output voltage and control average output power, (2) to suppress the harmonics at 120 Hz from inverter and to track 120 Hz ripples.

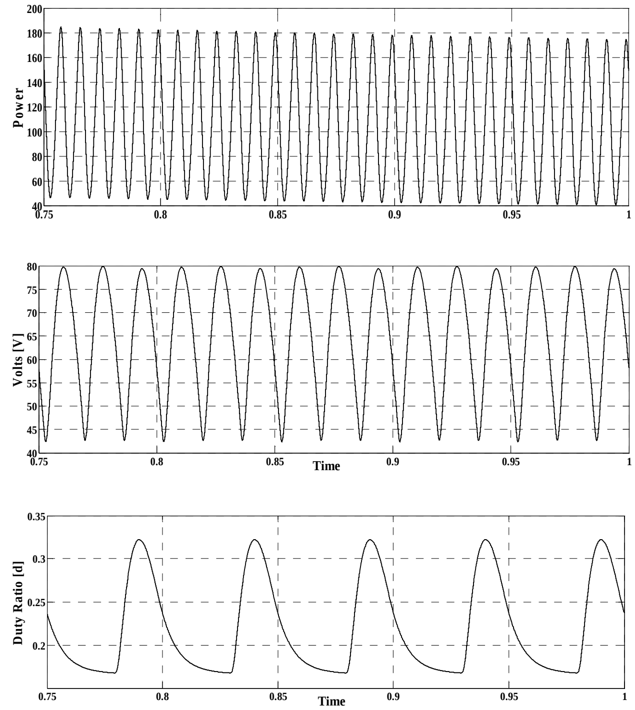

Figure-7. Simulation results of PI control. Output power (P_{inv}), Output voltage, Duty ratio for pure resistive load 30 Ω.

II] PI plus feed forward:

PI controller only regulates output dc voltage and control output average power, while feed forward portion takes care of disturbances at 120 Hz from inverter side and tracks 120 Hz ripples. After voltage of DAB converter is sampled low pass filter whose pass band is below 120 Hz.

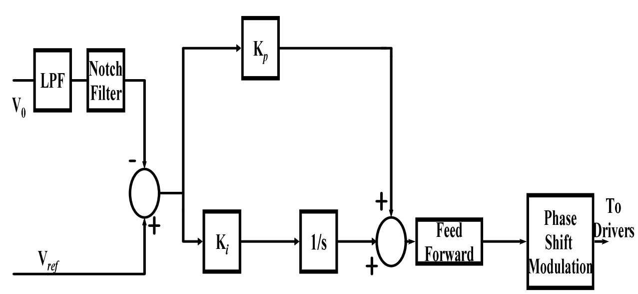

Figure-8. Schematic diagram of PI plus feed forward.

The cut-off frequency of Low pass filter is less and PI controller only regulates dc voltage, so band width of PI controller is not necessary to be large. The phase angle of inverter output is controlled by the controller used at inverter. According to equation (1) the power angle is given by

$$\theta_p = 2\theta_v - \frac{\pi}{2} \tag{11}$$

VOL. 10, NO. 4, MARCH 2015 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

Feed forward portion provides excellent ripple rejection for unity power factor loads. But the performance of converter is affected for unity power factor load. So to improve its performance PI controller is combined with resonant controller.

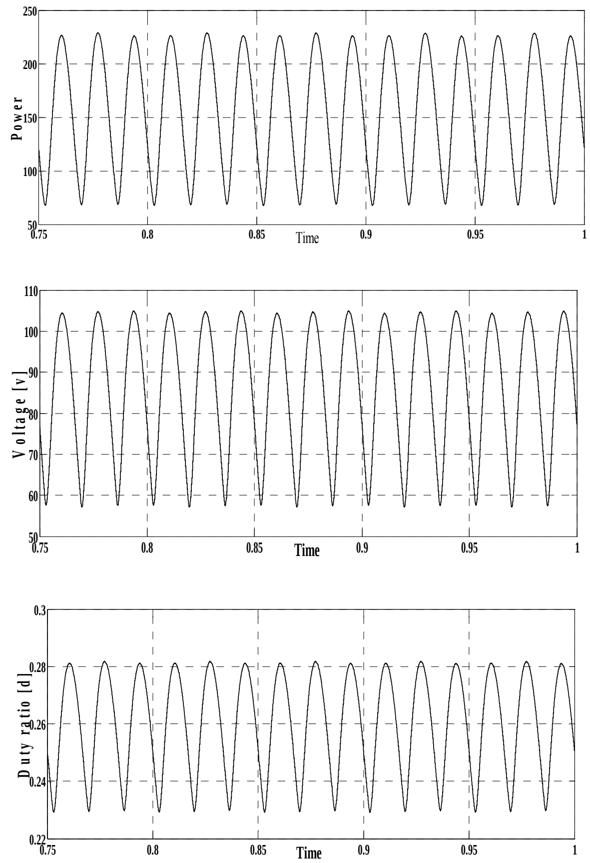

Figure-9. Simulation results of Feed Forward control. Output power (P_{inv}), Output voltage, Duty ratio for pure resistive load 30 Ω.

C] PI plus Resonant controller:

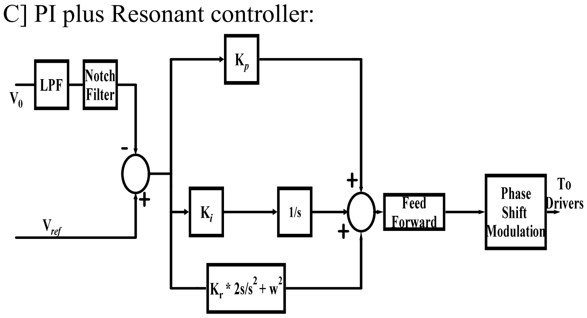

Figure-10. PI plus Resonant controller.

In order to compensate fluctuation at 120 Hz, the feedback compensator is necessary to have high gain at given frequency. So gain of PI controller must be increased, this reduces the phase margin. To overcome this, another controller i.e. resonant controller is combined with PI controller [13]. PI controller controls dc voltage while resonant controller tackles the disturbances at 120 Hz and reduces the ripples from inverter. The transfer function of R-controller is given by

$$Gpr(s) = Kr \frac{2s}{(s)^2 + (w_2)^2} \tag{12}$$

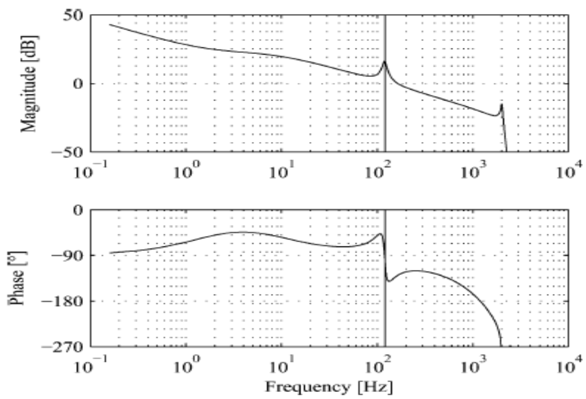

Figure-11. Bode plot of R-control.

By using R-controller only the loops gain is changed, as shown in Figure-6. The advantage of this system is that the voltage regulation is good as compared to PI controller at 120 Hz. The output impedance of the converter is low. That is lower ripple at 120 Hz will be caused.

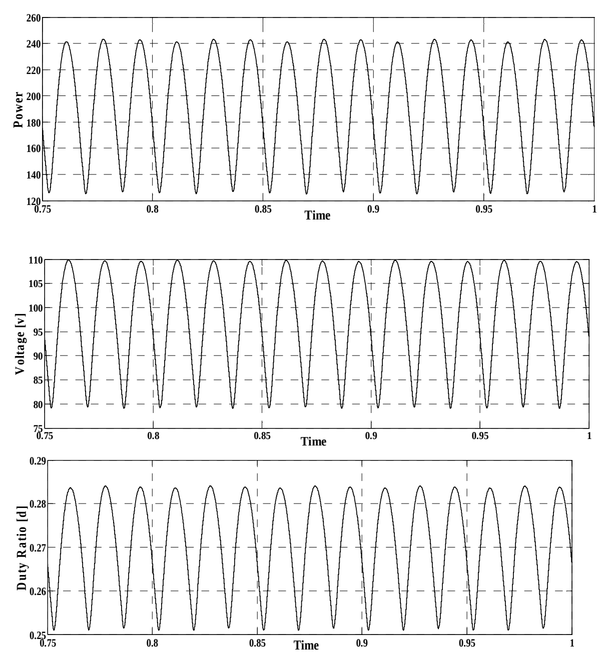

Figure-12. Simulation results of resonant control. Output power (P_{inv}), Output voltage, Duty ratio for pure resistive load 30 Ω.

ARPN Journal of Engineering and Applied Sciences

Simulation Parameters

A. Converter Design

Switching device	**MOSFET**
Inductance, at input side	500µH
Inductance, at low voltage side	500µH
Switching Frequency (Rectifier)	5KHz
Capacitor, at output side	2.7 nF
ZVS Capacitor	200µF
Switching Frequency (Inverter)	20KHz
Load Resistance	30Ω

B. Filter Design

Inductance	300µH
Capacitance	30 µF

RESULTS AND DISCUSSIONS

Figure-7, 9 and 12 shows simulation results of PI, Feed Forward and Resonant controller to regulate the output voltage. The voltage ripple using conventional PI controller is high, as compared with Feed forward and resonant controller. The ripple voltage is approximately 20 V (Duty Ratio waveform). By increasing the bus capacitance the ripple voltage can be reduce. To reduce the ripple voltage both Feed Forward and Resonant controller are used. Both Feed Forward and Resonant controller achieve the similar results, but they differ in transient performance and also in handling no unity power factor loads.

CONCLUSIONS

In multi stage configuration of SST, single phase inverter has dominant second order harmonics at its input side. Conventional PI controller has limited gain at 120 Hz. Two methods are proposed to overcome the limitations of PI controller. First one is PI plus feed forward control and second PI plus Resonant controller to control the dc output voltage of DAB converter and to track the disturbances at 120 Hz from inverter. Feed Forward Resonant controller gives better transient response and achieves the ripple reduction at the output of inverter. The dynamic and transient response of DAB converter can be improved further by using Sliding mode control (SMC) technique.

ACKNOWLEDGEMENTS

Author express his profound gratitude and deep regards to his guide Prof. H. T. Jadhav for their exemplary guidance, monitoring and constant encouragement throughout.

Author also expresses a deep sense of gratitude to his fellow companion Prof. R A Metri, Prof. Pradip Bamane, Mr. Sagar Sonavane and Mr. Sagar Desai for their cordial support, valuable information which helped Author in completing this task through various stages.

Lastly author thanks almighty, his parents, brother, sister and friends for their constant encouragement without which this assignment would not be.

REFERENCES

[1] Huang M., Crow G., Heydt J., Zheng. and S. Dale. The future renewable electric energy delivery and management (freedm) system: “The energy internet. Proc. IEEE. Vol. 99, no. 1, pp. 133–148, Jan. 2011.

[2] R. Ronan., S. D. Sendoff., S. F. Glover. and D. L. Galloway. A power electronic-based distribution transformer. IEEE Power Eng. Rev., vol. 22, no. 3, pp. 61–61, Mar. 2002. I S Jacobs and C.P. Bean, “Fine particles, thin films and exchange anisotropy” in Magnetism vol. III G.T. Rado and H Suhl Eds New York: Academic. 1963, pp. 271-350.

[3] Bhattacharya, T. Zhao, G.Wang, S. Dutta, S. Baek,Y.Du, B. Parkhideh, X. Zhou, and A. Q. Huang, “Design and development of generation-I silicon based solid state transformer,” in Proc. IEEE Appl. Power Electron. Conf. Expo., Feb. 2010, pp. 1666–1673.

[4] Qin. and J. Kimball “A comparative efficiency study of silicon-based solid state transformers” in Proc. IEEE Energy. Convers. Congr. Expo. Sep. 2010, pp. 1458–1463.

[5] Holmes T. Lipo., B. McGrath., and W. Kong. Optimized design of Stationary frame three phase ac current regulators. IEEE Trans. Power Electro. Vol. 24, no. 11, pp. 2417–2426, Nov. 2009.

[6] Hwang, P. Lehn. and M. Winkelnkemper. A generalized class of stationary frame-current controllers for grid-connected AC–DC converters” IEEE Trans. Power Del. Vol. 25, no. 4, pp. 2742–2751, Oct. 2010.

[7] Dong T. Thacker., R. Burgos., D. Boroyevich. and F. Wang. On zero steady-state error voltage control of single-phase PWM inverters with different load-types,” IEEE Trans. Power Electron., vol. 26, no. 11, pp. 3285–3297. Nov. 2011.

ARPN Journal of Engineering and Applied Sciences

[8] Zhao D. D.-C. Lu. and V. G. Agelidis. Current control of grid connected boost inverter with zero steady-state error," IEEE Trans. Power Electron. Vol. 26, no. 10, pp. 2825–2834, Oct. 2011.

[9] T Phan. and H.-H.Lee. Control strategy for harmonic elimination in Stand-alone DFIG applications with nonlinear loads. IEEE Trans. Power Electron. Vol. 26, no. 9, pp. 2662–2675, Sep. 2011.

[10] Loh Y. Tang., F. Blaabjerg. and P. Wang. Mixed-frame and stationary frame repetitive control schemes for compensating typical load and grid harmonics. IET Power Electron. Vol. 4, no. 2, pp. 218–226, Feb. 2011.

[11] Nian. and R. Zeng. Improved control strategy for stand-alone distributed generation system under unbalanced and non-linear loads. IET Renewable Power Generat. Vol. 5, no. 5, pp. 323–331, Sep. 2011.

[12] Hu. and Y.He. Modeling and control of grid-connected voltage-sourced converters under generalized unbalanced operation conditions. IEEE Trans. Energy Convers. Vol. 23, no. 3, pp. 903–913, Sep. 2008.

[13] Amin Hasanzadeh., Omer C. Onar., Graduate Student Member, IEEE, Hossein Mokhtari, Member, IEEE, and Alireza Khaligh, Senior Member, IEEE "A Proportional-Resonant Controller-Based Wireless Control Strategy with a Reduced Number of Sensors for Parallel Operated UPSs" IEEE transactions on power delivery. Vol. 25, no. 1, January 2010.

[14] D. Watson., J. W.Kimball. and S. Atcitty. Linear single phase inverter model for battery energy storage system evaluation and controller design. in Proc. IEEE Appl. Power Electron. Conf, Feb. 2012, pp. 1861–1867.

[15] Qin. and J. W. Kimball. Generalized average modeling of dual active bridge DC–DC converter," IEEE Trans. Power Electron. Vol. 27, no. 4, pp. 2078–2084, Apr. 2011.