[1]Akash Ghodake
[2]Udaykumar Patil

Control and Operation of Bidirectional Converter for Electric Vehicles

JES Journal of Electrical Systems

Abstract: - Bidirectional converter plays a strategic role in electric vehicle (EV) applications, specially, in vehicle-to-grid (V2G) and grid-to-vehicle (G2V) necessities. This allows the usage of vehicle battery pack as a source of distributed energy. It also supports the concept of smart grid, where EVs can serve as flexible energy storage systems contributing to grid stability, load balancing, and permitting renewable energy integration. A plentiful type of bidirectional converters can be used in electric vehicle applications, including AC-DC-AC and DC-DC converters including advanced converters. Selection and configuration of the converter depends on the requirements of the vehicle and factors such as efficiency, size, and cost. The operation and control strategy of a configurable bidirectional Buck-Boost converter is presented in this paper for three-phase induction motor applications in electric vehicles. Simulink results are discussed for motoring and regeneration mode with state-of-charge (SoC) of battery

Keywords: Bidirectional converter, 3 phase induction motor, State of charge, Self-excited induction generator, EVs

I. INTRODUCTION

With Development And Progression In Configuration And Control Strategy, DC-DC Converters Are In Use From A Long-Time. These Converters Are Accomplished To Boost As Well As Reduce The Input Voltage To Required Level By Controlling The Duty-Ratio Effortlessly Like Transformers In Ac Systems. This Facilitated The Converters To Control The Power-Flow In Both Directions Making Them As Bi-Directional Converters. Bi-Directional Converters Are Used In Many Applications Like Renewable Energy Conversion, Electrical Drives And Now A Days In Evs. Bidirectional DC To DC Converter (BDC) Is Built Normally By Combining Buck Converter And Boost Converter [1]. The Elementary Purpose Of A BDC Is To Achieve DC Bus Voltage Regulation With Ability To Control Power Flow In Both Directions. The Bdcs Are Categorized Into Isolated Type And No Isolated Type Converters [2].

The BDC Configurations And Working Is Presented In [1-3]. The Isolated Converter Configuration Is Preferred For Grid Connected EV Charging Systems Whereas, For Integrating The Regenerative Braking, Non-Isolated Converter Configurations Are Preferred [4]. An Overview Of Different Topologies And Control Schemes Used In Bidirectional DC-DC Power Converters Is Presented In [5]. The Bdcs Are Built In Topologies Of Buck – Boost, Half Bridge, Full Bridge, CUK And Other Types As Per The Application Demands. These Converters Are Used In Applications Such As Electric Vehicles, Renewable Energy Systems, And Energy Storage Systems. The Energy Transfer Process And The Control Requirements For Achieving Bidirectional Power Flow Mainly Involves The Duty Cycle Control Of Appropriate Switching Devices For Controlling The Power Flow And Voltage [6]. The Modified Converter Of [7] Uses A Dual-Mode Controller, Which Allows It To Operate In Either Buck Or Boost Mode. Also, The Converter Includes A Feedback Loop That Is Designed To Maintain The Minimum Phase Behavior. The Non-Isolated BDC Presented In [9] Uses A Simplified Control Technique With Single Controlling Switch. The Simplified Converter Is A Promising New Technology For Energy Storage Systems Of Electric Vehicles. It Offers Several Advantages Over Traditional Bdcs, Including Improved Dynamic Performance, Smaller Size, And Lower Cost [10, 11]. The Bidirectional Converters Are Adopted In EV Chargers [12] Which Allows V2G And G2V Power Flow [13, 14].

In The Control Of Bidirectional Converters, The Voltage Regulation Is A Prime Focus. A PI Controller Is Primarily Deployed For Duty Cycle Control Of Power Electronic Switching Devices In The Converter [15]. These Controlled Converters Are Configured For Regenerative Braking Of Electric Bikes As Well As Electric Cars [16]. To Support The Regenerative Braking, The Motor Shall Act As A Generator. Particularly For Induction Motor, It Is Required To Be Configured As Self-Excited Induction Generator By Providing Capacitor Bank For Excitation [17]. For Providing The Reactive Power Through Capacitor Bank The Sizing Of Capacitors Is Done According

[1] *Corresponding author: Research Scholar, Shivaji University Kolhapur & ADCET Ashta, Maharashtra, India 416301
[2] Department of Electrical Engineering, Government college of Engineering, Ratnagiri, Maharashtra, India 415612

To The Ratings Of Induction Motor [18]. The Controlled Operation Of Induction Generator Is Also Desired To Keep The System Within The Voltage Limits. The Self-Excited Induction Generator Exhibits A Nonlinear Operation. It May Require Over Excitation To Support Generation At Lower Speeds And Hence An Intelligent Controller Is Required For Induction Generator [19, 20]. A PWM Controlled Converter In Terms Of Dummy Load Controller Is Proposed In [21] For Voltage Regulation.

For Electric Vehicle Application, The Motoring Operation Can Be Accomplished Through Open Loop To Advanced Field-Oriented Control [22] Or Direct Torque Control Methods [23]. The Regeneration Is Used For Not Only Battery Charging But Also For Super Capacitors And Ultra-Capacitors [24] In Hybrid Electric Vehicles. As Compared To Other Motor Drives [25], The Regenerative Braking Of Induction Motors Is Challenging Due To Its Nonlinear Voltage-Speed Characteristics

II. PROPOSED SYSTEM

In This Paper, A Configurable Bidirectional DC – DC Converter Is Proposed And Presented With 3-Ph Induction Motor In Electric Vehicle Applications. The Configurable Bidirectional DC – DC Converter Is Composed Of An Inductor And Four Power Electronic Switches (Mosfets) As Shown In Figure 1.

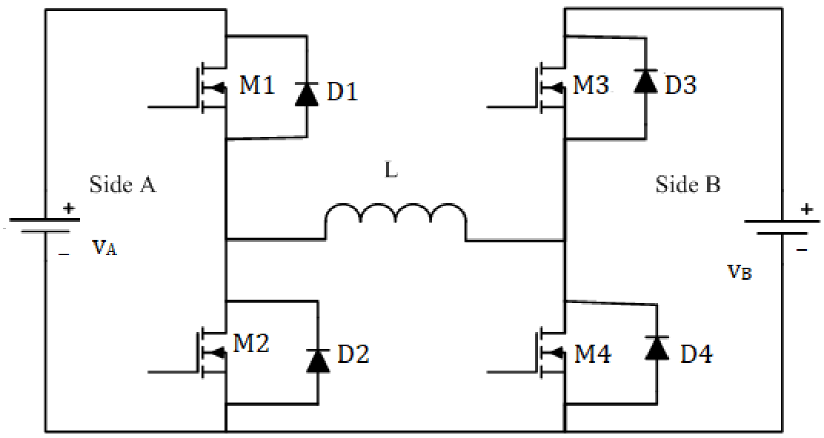

Figure 1: Configurable Bidirectional DC To DC Converter

By Comparing The Voltages On Side-A And Side-B The Direction Of Power Flow Can Be Decided. The Power Transfer Can Be Controlled By Controlling The Duty-Ratio Of The Switching MOSFET. The Corresponding Operations Of The Switches Is Mentioned In Table 1 Where, D Is The Duty Ratio.

Table 1: Switching Actions For Circuit Operation

Power Flow	**Mode**	**M1**	**M2**	**M3**	**M4**
A To B	Buck	D	OFF	OFF	OFF
A To B	Boost	ON	OFF	OFF	D
B To A	Buck	OFF	OFF	D	OFF
B To A	Boost	OFF	D	ON	OFF

For Side-A To Side-B Buck Conversion, MOSFET M1 Is Provided With PWM Signal, And All Other Devices Are OFF. Whereas For Boost Conversion In Same Directions, M1 Is Always ON And PWM Control Is Applied To MOSFET M4, Here Remaining Devices Are In OFF State.

For Side-B To Side-A Buck Conversion, MOSFET M3 Is Provided With PWM Signal, And All Other Devices Are OFF. Whereas For Boost Conversion In Same Directions, M3 Is Always ON And PWM Control Is Applied To MOSFET M2, Here Remaining Devices Are In OFF State. To Enable A Closed Loop Control In The

Hardware, A Controller With Two ADC Channels And Four PWM Outputs Would Be Sufficient For Implementation. To Support The Motor Load Operation The System Is Equipped With A Bidirectional AC – DC Converter As Shown In Figure 2. The Induction Motor Is Chosen For Electric Vehicle On Account Of Its Simple Construction, Robustness, Almost Maintenance Free Operation, High Torque, Simplicity Of Control, Availability And Regenerative Braking Capability By Operating It As A Self-Excited Induction Generator.

The Voltage Output Equation For Buck Converter Is,

$$V_0 = D.V_{in} \quad \ldots (1)$$

The Voltage Output Equation For Boost Converter Is,

$$V_0 = \frac{1}{1-D}.V_{in} \quad \ldots (2)$$

Equation (1) And (2) Shows That The Output Voltage Of Both Types Of Converters Is A Function Of Duty Cycle. Hence For Voltage Regulation, PWM Control Strategy Is Adopted.

The Value Of Required Inductor For Boost Conversion Is Calculated As,

$$L = \frac{V_{in}}{f_{sw}\Delta I_L} D \quad \ldots (3)$$

Where,

L = Inductance In Mh

V_{in} = Input Voltage (400V)

F_{sw} = Switching Frequency (10khz)

D = Duty Cycle (33% For Boost Converter)

ΔI_L = Inductor Ripple Current Considered As 40% Of Inductor Current

∴ L = 6mh

The Bidirectional Inverter Rectifier For Induction Motor Control Is Shown In Figure 2. It Consists Of A Three-Phase Inverter Wherein Each Power Electronic Switching Device Is Shunted With Diode. This Configuration Acts As Inverter As Well As Rectifier.

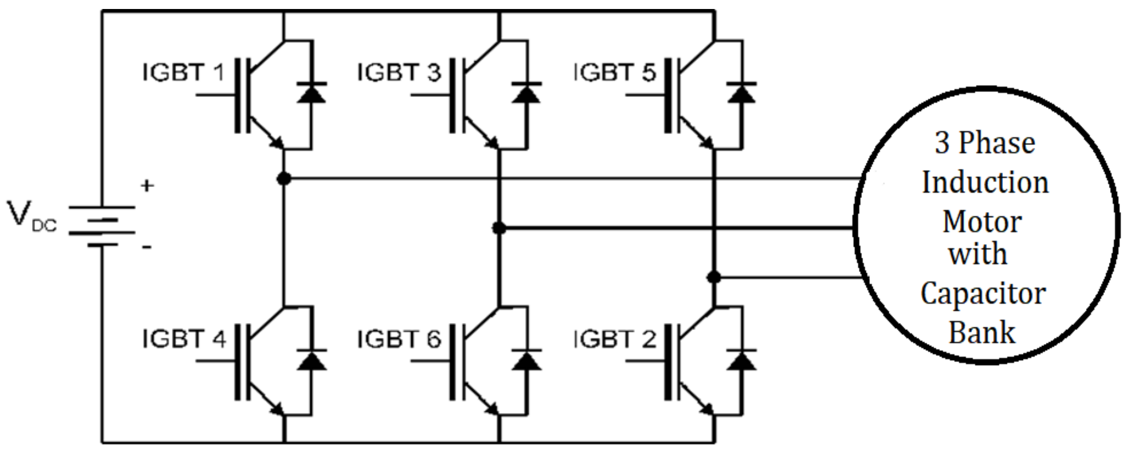

Figure 2: Three Phase Induction Motor Drive With Self-Excitation Capacitors

The Specifications Of The Proposed Converter Are Mentioned In Table 2.

Table 2: Specification Table

Particulars	**Value**
DC – DC Converter	
V_A	400 V
V_B	600 V
Switching Frequency	10 Khz
Inductor	6 Mh
Load (3 Phase Inverter Driven Induction Motor)	
Voltage (Vrms)	415 V
Power	2.2 Kw
Current	4.6 A
Frequency	50Hz
Self-Excitation Capacitors	8 µf, 16 µf, 32 µf

III. CONTROL STRATEGY AND SIMULATION RESULTS

Figure 3 Represents The Block Diagram Of The Proposed System For EV Applications Using 3-Phase Induction Motor. Usually, Brushless Dc Motors (BLDC) Are Preferred In Evs By Most Of The Manufacturers. Being Numerous Advantages Of Induction Motor With Availability Of Energy Efficient Motors In Commercial Market, 3-Phase Induction Motor With Self-Excitation Capacitors Is Proposed For The Application. Figure 4 Represents The Control Strategy For The Presented Scheme With Bidirectional Converter.

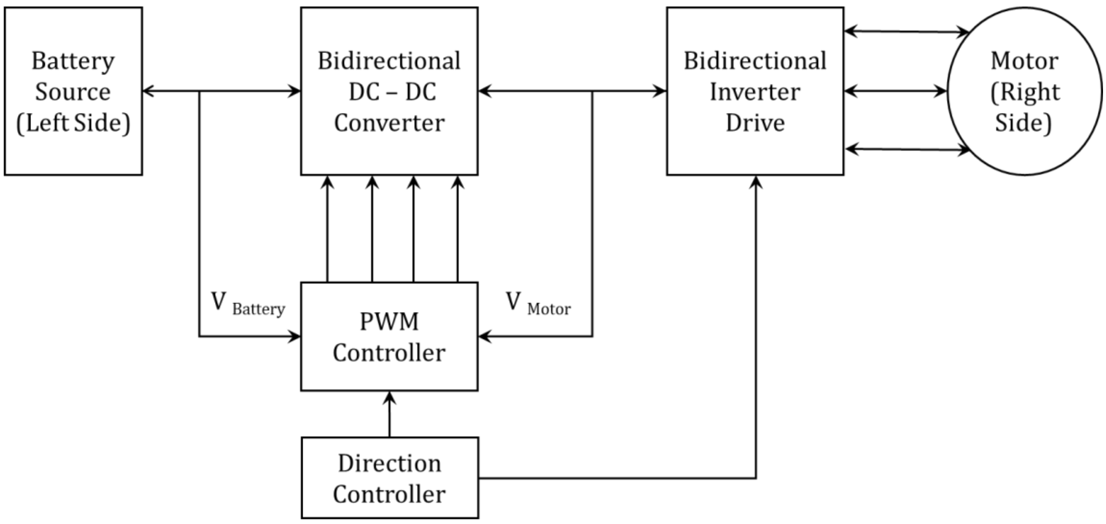

Figure 3: Block Schematic Of Proposed Control System

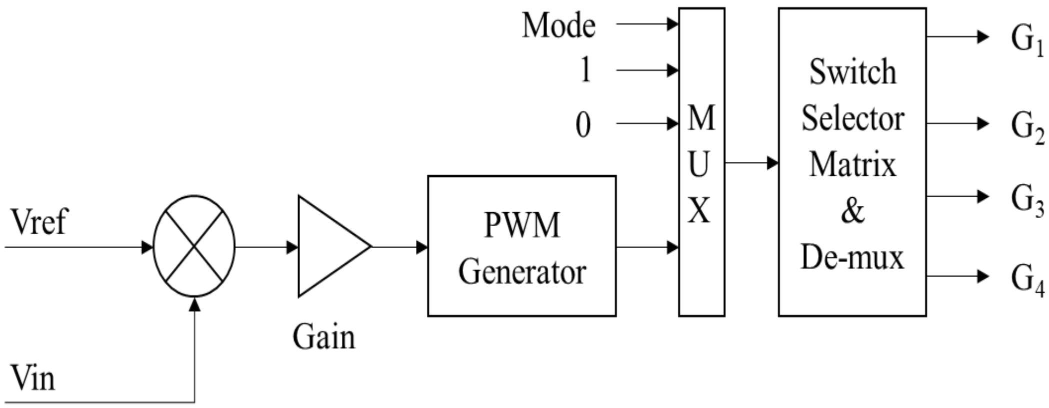

Figure 4: Control Strategy For Bidirectional Converter

The Block Diagram Of BDC With Proposed Control Technique Is Shown In Figure 3. The System Consists Of A BDC Which Is Responsible For Maintaining A Constant DC Link Voltage For Induction Motor Drive And For Battery Charging In Case Of The MATLAB Simulink Model, The System Is Executed For A Time Period Of 1 Second. The Motoring Mode I.E. Power Flow From Battery To Motor, Is Executed For The Time Interval 0 – 0.7 Second And The Regeneration Mode I.E. Power Flow From Motor To Battery Is Executed For The Time Interval 0.7 – 1.5 Second. The MATLAB Simulink Model Is Shown In Figure 5. And The Control Scheme Is Shown In Figure 6. The Controller Continuously Monitors The Voltages On Battery Side And DC Link Side Of The Motor Along With The Status Of The Brakes. Here, The Status Of The Brakes Is Considered As Operating Mode, I.E., Motoring Mode Or Regenerative Braking Mode. In Motoring Mode Operation, The Controller Generates A Proportional PWM Signal To Boost The Battery Voltage And Maintain Constant DC Link Voltage Of 600V. This DC Link Voltage Is Used By The Induction Motor Drive And Further Induction Motor Operation Is Regulated. In Regenerative Braking Mode, The Induction Motor Acts As Self-Excited Induction Generator. The Voltage Generated By Inductor Motor Is Converted Into DC By The Induction Motor Drive. This DC Voltage Is Input To The BDC And The Controller Takes Appropriate Action To Regulate The Voltage To Battery Charging Level.

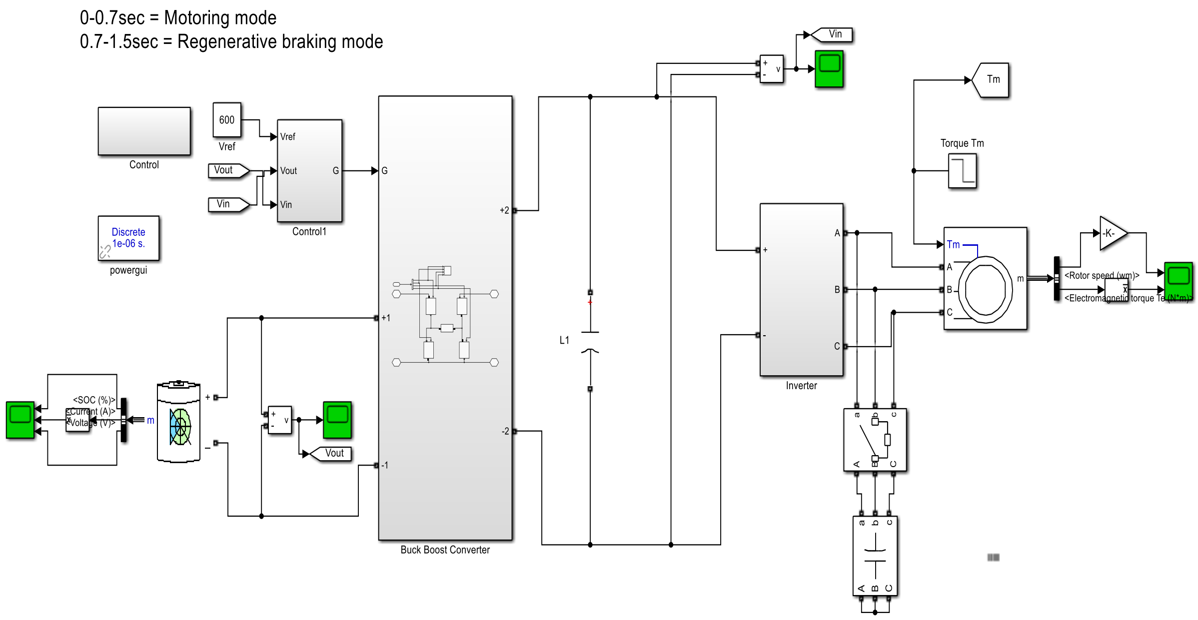

Figure 5: MATLAB Simulink Model

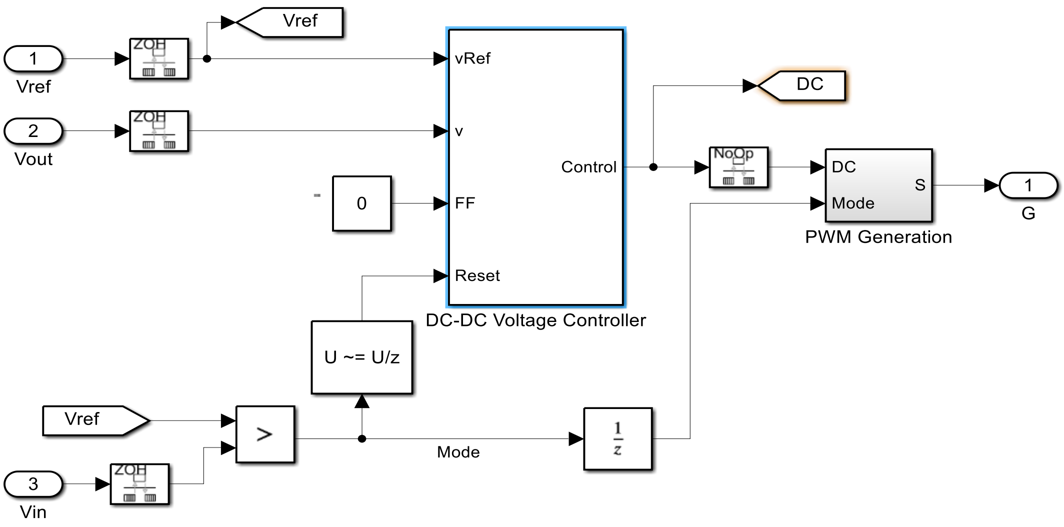

Figure 6: Pulse Generation For Bidirectional Converter

At Time Instance T = 0, The Motoring Mode Operation Is Initiated By Setting The Converter To Operate From Battery To Motor Up To Time T = 0.7S. The Power Flow Can Be Seen From State Of The Charge Of Battery. As The Power Is Given Out From Battery, The State Of Charge (Soc) Of Battery Decreased And The Direction Of The Battery Current Is Positive I.E. From Battery To Load. At Time Instance T = 0.7S, The Operating Mode Is Change For The Power Flow From Motor To The Battery I.E. Regeneration Mode. Here, An Increase In State Of Charge Of The Battery Is Observed And Direction Of Current Is Seen To Be Negative, Indicating That The Battery Getting Charged. The Battery Soc, Voltage And Current Are Indicated In Figure 7.

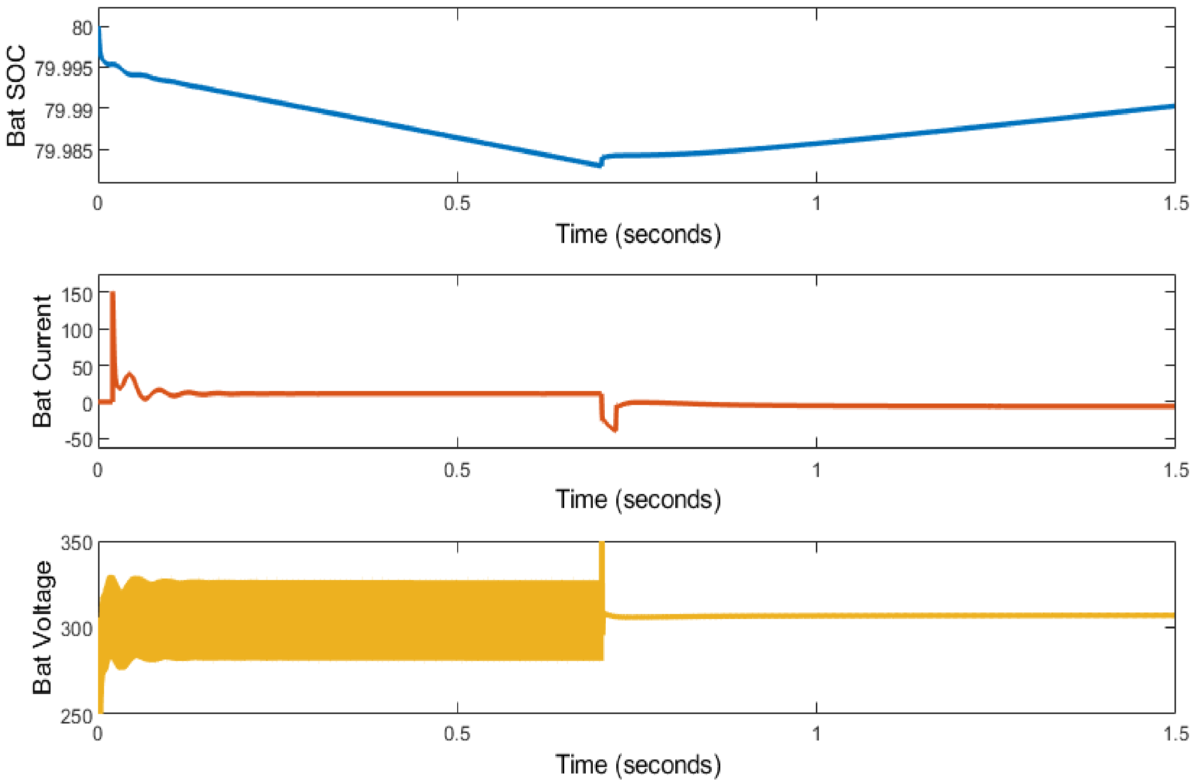

Figure 7: Battery Soc, Current And Voltage During Motoring And Regeneration Mode

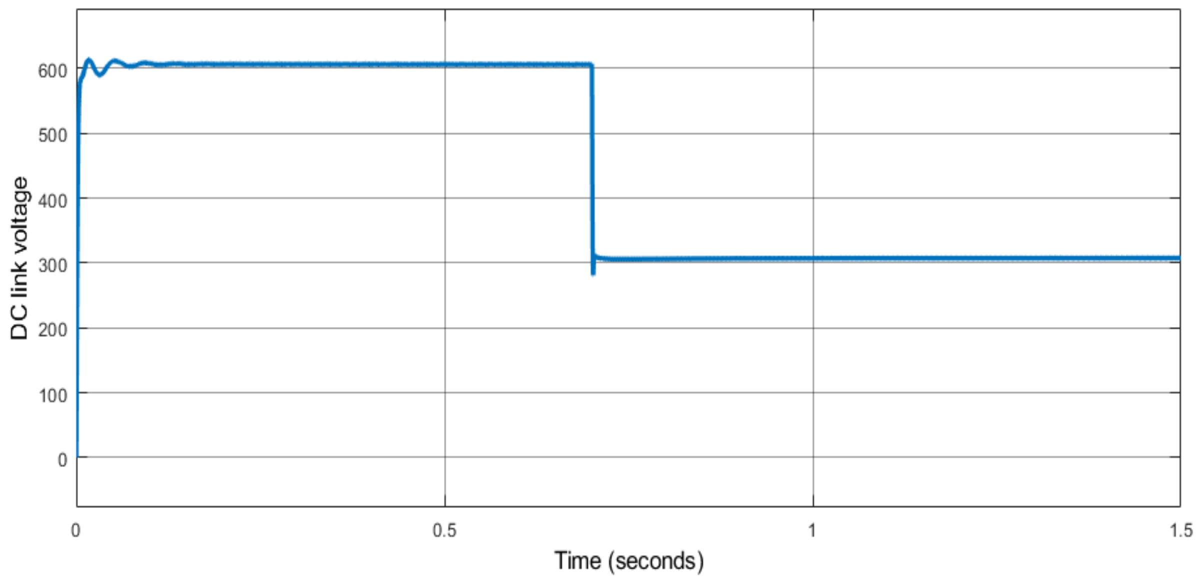

Figure 8: DC Link Voltage

The DC Link Voltage At The Right Side Of The Bidirectional DC – DC Converter Is Shown In Figure 8. During Motoring Mode Operation, A Constant DC Link Voltage Of 600V Is Provided By The Converter. In Case Of The Regeneration Mode, The Value Of DC Link Voltage Is Dependent Of Motor Voltage Output. The Graph Of Motor Torque And Speed Is Shown In Figure 9. The Negative Torque Indicates That The Induction Motor Is Operating As A Self-Excited Induction Generator.

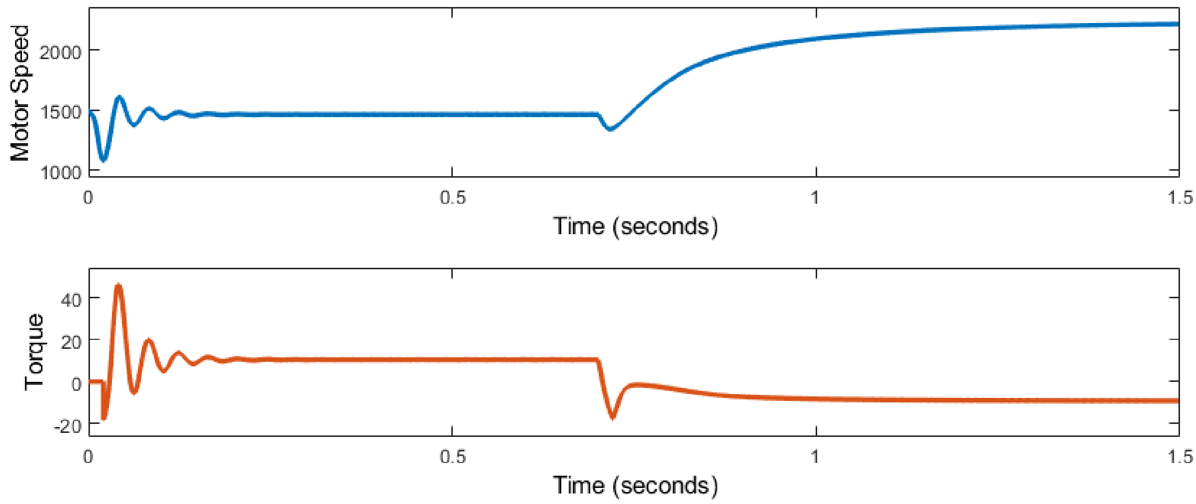

Figure 9: Motor Torque and Speed

IV. CONCLUSION

In This Paper, Operation And Control Of A Bidirectional Power Converter For Electric Vehicle Application Is Discussed With MATLAB Simulations. The Bidirectional Converter Allows Power Flow For Motoring As Well As Regenerative Braking. The Regenerative Braking Is Essential Component Of EV Controller As Is Allows To Increase The Battery Life And Travel Range Of The Vehicle Thus Extending The Possibility Of Optimization. The Selected Bidirectional Converter Configuration Is Capable Of Operating In Buck As Well As Boost Mode In Both Directions. The DC Link Voltage In Motoring Mode Is Regulated To 600V Through PWM Control Of Bidirectional Converter. In Regeneration Mode, The Voltage Is Generated By Induction Motor Acting As Self-Excited Induction Generator. The Capacitor Bank Excited Induction Generator Produces 300V At The DC Link. This Value If Often Dependent On Speed Of The Motor As Well. The Bidirectional Converter Regulated This DC Link Voltage For Battery Charging. This Configuration Permits The Voltage Rating Of The Load To Be Different Than The Source.

The Control Technique Developed Is Effective In Regulating The Voltage In Motoring Mode And Well As In Regenerative Braking Mode.

References

[1] Tytelmaier, Kostiantyn & Husev, Oleksandr & Veligorskyi, Oleksandr & Yershov, Roman. “A Review Of Non-Isolated Bidirectional Dc-Dc Converters For Energy Storage Systems”, IEEE International Young Scientists Forum On Applied Physics And Engineering, Pp.22-28, 2016

[2] Jiulong Wang, Bingquan Wang, Lei Zhang, Jianjun Wang, N.I. Shchurov, B.V. Malozyomov, “Review Of Bidirectional DC–DC Converter Topologies For Hybrid Energy Storage System Of New Energy Vehicles”, Green Energy And Intelligent Transportation, Volume 1, Issue 2, September 2022

[3] Ingilala Jagadeesh And V. Indragandhi, “Review And Comparative Analysis On Dc-Dc Converters Used In Electric Vehicle Applications”, IOP Conference Series: Materials Science And Engineering, 2019

[4] Ranjan Pramanik, B.B. Pati, “Modelling And Control Of A Non-Isolated Half-Bridge Bidirectional DC-DC Converter With An Energy Management Topology Applicable With EV/HEV”, Journal Of King Saud University – Engineering Sciences, Volume 35, Issue 2, Pp. 116-122, 2021

[5] S. A. Gorji, H. G. Sahebi, M. Ektesabi And A. B. Rad, "Topologies And Control Schemes Of Bidirectional DC–DC Power Converters: An Overview," In IEEE Access, Vol. 7, Pp. 117997-118019, 2019

[6] B. Y. Li, C. Xua, C. Li, Z. Guan, “Working Principle Analysis And Control Algorithm For Bidirectional DC/DC Converter”, Journal Of Power Technologies, Vol. 97 (4) (2017) , Pp.327–335

[7] B. V. Kumar, R. K. Singh And R. Mahanty, "A Modified Non-Isolated Bidirectional DC-DC Converter For EV/HEV's Traction Drive Systems," 2016 IEEE International Conference On Power Electronics, Drives And Energy Systems (PEDES), Trivandrum, India, 2016, Pp. 1-6, Doi: 10.1109/PEDES.2016.7914345.

[8] Kou-Bin Liu, Chen-Yao Liu, Yi-Hua Liu, Yuan-Chen Chien, Bao-Sheng Wang And Yong-Seng Wong, “Analysis And Controller Design Of A Universal Bidirectional DC-DC Converter”, MDPI Journal Of Energies, 2016

[9] Gaurav, N. Jayaram, S. Halder, K. P. Panda And P. S. V. Kishore, "Design And Analysis Of A Simplified Non-Isolated Bidirectional DC-DC Converter For Energy Storage Systems," 2022 International Conference On Intelligent Controller And Computing For Smart Power (ICICCSP), Hyderabad, India, 2022, Pp. 1-6, Doi: 10.1109/ICICCSP53532.2022.9862364.

[10] B. Y. Li, C. Xua, C. Li, Z. Guan, “Working Principle Analysis And Control Algorithm For Bidirectional DC/DC Converter”, Journal Of Power Technologies, Vol. 97, No. 4, Pp.327–335, 2017

[11] S. A. Gorji, H. G. Sahebi, M. Ektesabi And A. B. Rad, "Topologies And Control Schemes Of Bidirectional DC–DC Power Converters: An Overview," In IEEE Access, Vol. 7, Pp. 117997-118019, 2019

[12] Kou-Bin Liu, Chen-Yao Liu, Yi-Hua Liu, Yuan-Chen Chien, Bao-Sheng Wang And Yong-Seng Wong, “Analysis And Controller Design Of A Universal Bidirectional DC-DC Converter”, MDPI Journal Of Energies, 2016

[13] C. K. Gowda, V. G. Khedekar, N. Anandh, L. R. S. Paragond And P. Kulkarni, "Bidirectional On-Board EV Battery Charger With V2H Application," 2019 Innovations In Power And Advanced Computing Technologies (I-PACT), Vellore, India, 2019, Pp. 1-5, Doi: 10.1109/I-PACT44901.2019.8960126.

[14] M. K. Chaitanya, A. S. Vinayak, B. J. G. Pavan, N. N. Lakshmi And K. Sandeep, "A Review Of Bidirectional DC-DC,DC-AC Converters For V2G And G2V Applications," 2023 International Conference On Power, Instrumentation, Energy And Control (PIECON), Aligarh, India, 2023, Pp. 1-6, Doi: 10.1109/PIECON56912.2023.10085877.

[15] R. Kannan, P. K, K. C, N. M. Nor And S. Gandhi A, "Design And Simulation Of A Bidirectional DC-DC Converter With PI Controller For Regenerative Braking In Electric Vehicles," 2023 IEEE Conference On Energy Conversion (CENCON), Kuching, Malaysia, 2023, Pp. 64-69, Doi: 10.1109/CENCON58932.2023.10369135.

[16] A. Sharma, R. Mishra, A. K. Yadav And A. Phukan, "Bidirectional DC-DC Converter For Incorporating Regenerative Braking In E-Bikes," 2018 International Conference On Electrical, Electronics, Communication, Computer, And Optimization Techniques (ICEECCOT), Msyuru, India, 2018, Pp. 1019-1024, Doi: 10.1109/ICEECCOT43722.2018.9001557.

[17] J. -N. Bae, Y. -E. Kim, Y. -W. Son, H. -S. Moon, C. -H. Yoo And J. Lee, "Self-Excited Induction Generator As An Auxiliary Brake For Heavy Vehicles And Its Analog Controller," In IEEE Transactions On Industrial Electronics, Vol. 62, No. 5, Pp. 3091-3100, May 2015, Doi: 10.1109/TIE.2014.2379218.

[18] E. O. Silva, W. E. Vanço And G. C. Guimarães, "Capacitor Bank Sizing For Squirrel Cage Induction Generators Operating In Distributed Systems," In IEEE Access, Vol. 8, Pp. 27507-27515, 2020

[19] S. Cholula, A. Claudio And J. Ruiz, "Intelligent Control Of The Regenerative Braking In An Induction Motor Drive," 2005 2nd International Conference On Electrical And Electronics Engineering, Mexico City, Mexico, 2005, Pp. 302-308, Doi: 10.1109/ICEEE.2005.1529631.

[20] C. P. Ragasudha And S. Hemamalini, "Performance Analysis Of A High Gain Bidirectional DC-DC Converter Fed Drive For An Electric Vehicle With Battery Charging Capability During Braking," In IEEE Access, Vol. 12, Pp. 14499-14511, 2024, Doi: 10.1109/ACCESS.2024.3357726.

[21] T. Ahmed, K. Nishida And M. Nakaoka, "Advanced Control Of PWM Converter With Variable-Speed Induction Generator," In IEEE Transactions On Industry Applications, Vol. 42, No. 4, Pp. 934-945, July-Aug. 2006, Doi: 10.1109/TIA.2006.876068.

[22] I. Azizi And H. Radjeai, "Motor And Regenerative Braking Operations For An Electric Vehicle Using Field Oriented Control," 2022 19th International Multi-Conference On Systems, Signals & Devices (SSD), Sétif, Algeria, 2022, Pp. 2145-2150, Doi: 10.1109/SSD54932.2022.9955671.

[23] P. D. Patel And S. N. Pandya, "Energy Regeneration During Deceleration Of Direct Torque Control Of Induction Motor Drive For Electric Vehicles," 2019 IEEE International Conference On Electrical, Computer And Communication Technologies (ICECCT), Coimbatore, India, 2019, Pp. 1-4, Doi: 10.1109/ICECCT.2019.8869494.

[24] A. A. Ahmed, M. G. Mousa And Y. I. Lee, "Regenerative Braking Control Of IM With Battery/Ultracapacitor Hybrid ESS In Electric Vehicles," 2017 Nineteenth International Middle East Power Systems Conference (MEPCON), Cairo, 2017, Pp. 320-325, Doi: 10.1109/MEPCON.2017.8301200.

[25] M. E. Elsayed, O. M. Hebala, H. A. Ashour And M. S. Hamad, "A Comparative Study Of Different Electric Vehicle Motor Drive Systems Under Regenerative Breaking Operations," 2021 31st International Conference On Computer Theory And Applications (ICCTA), Alexandria, Egypt, 2021, Pp. 104-111, Doi: 10.1109/ICCTA54562.2021.9916634.

[26] U. R. Muduli, A. R. Beig, R. K. Behera, K. A. Jaafari And J. Y. Alsawalhi, "Predictive Control With Battery Power Sharing Scheme For Dual Open-End-Winding Induction Motor Based Four-Wheel Drive Electric Vehicle," In IEEE Transactions On Industrial Electronics, Vol. 69, No. 6, Pp. 5557-5568, June 2022, Doi: 10.1109/TIE.2021.3091919.