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A Bidirectional DC Converters: operation, Control development, and Applications

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Abstract– **In recent day modern power, system and industrial application witnessed great interest by engineering and scientist. Converters used with these applications also developed leading to improve efficiency, power management, cost, reliability and others. Bidirectional dc-dc converters are the base for all electric systems, which depends on dc power flow through networks or grids. In this work different kind of bidirectional converter are introduce, As well as the operation principle with limitation will propose. This review includes several parts covering converter topologies and related control strategies, as well as their operation in various applications.**

Keywords - ***dc-dc converter; bidirectional converter; renewable energy; PV array; electric vehicle***

I. INTRODUCTION

Due to recent developments in electrical and industrial power systems, power converters have emerged as a branch of power electronics, where it treated as linked between the components of power system. Modern electric system including renewable energy system, hybrid electric vehicle, smart grid etc... have been developed due to raising the demand, so the need to manage the power transfer and optimizing it become necessary. Bidirectional dc-dc converter played great scenario in different industrial fields, their function deals with transfer power between loads source and storage units. They enhance energy flow at the state of light demand from source to battery and vice versa. By different form of bidirectional converter, they offered many of advantages such as, small and compressed size, dynamically response against the changing in load and power generated, their ability to change the level of voltage as buck or boost converter and their higher efficiency.

This review search targeted to present complete description for bidirectional converter covering, operation, topology, control, application and suggested strategy aimed to enhance their performance

II. PREVIOUS WORKS

H. Tao, A. Kotsopoulos, J.L. Duarte and M.A.M. Hendrix derived different kind of multi-port bidirectional dc-dc converter. They depend on the conventional type as a base circuit combining of dc link and inductors magnetically coupling where conventional type showed in Figure 1.

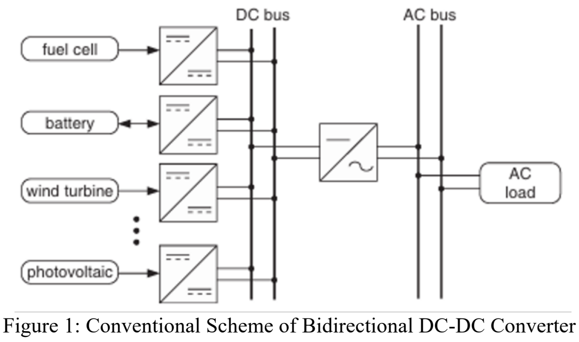

Figure 1: Conventional Scheme of Bidirectional DC-DC Converter

The suggested construction permits to add multi source as well as single source to circuit without use extra switches. In case of using single source researcher called the suggested converter multi-port instead of multi-input then it connected to battery as storage unit to achieve power flow between source and battery (charge and discharge) operation. In this work Dc link used a method to create state of multiport of dc source instead of using multi dc source however, in special states, it cannot use dc bus only to overcome load variety therefore the need to use different types of sources has become necessary. Interconnected magnetic coupling inductor played a great role to connect between sources like transformer. Figure 2 display different kind of converters

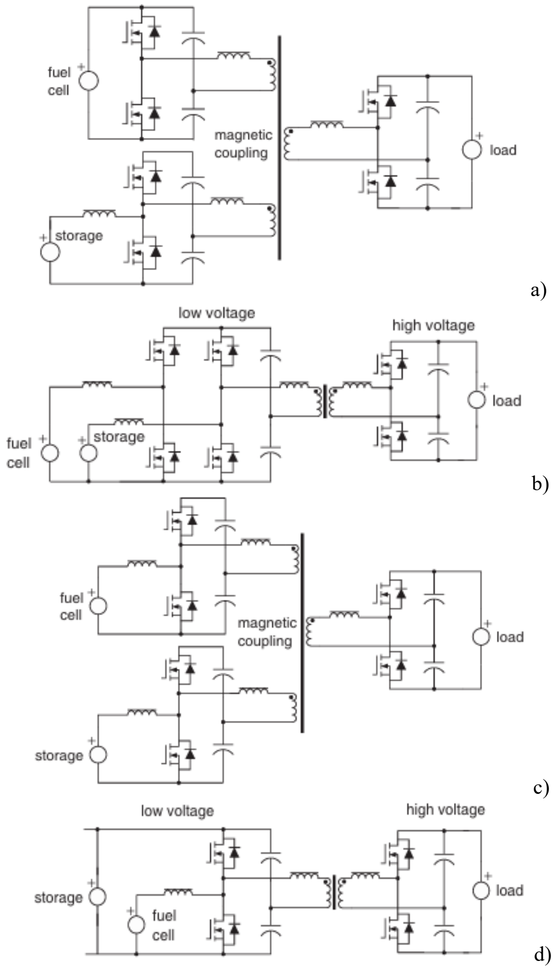

Figure 2: Different kind of multiport bidirectional converter. (a) Magnetically coupled three-port converter, (b) Three-port converter combining DC-link and magnetic coupling, (c) Magnetically coupled three-port converter with one current fed port, (d) Magnetic

For the mentioned kinds of converters any control strategy implemented must depends on the idea of power flow between converter sides which executed du regulating the duty cycle of power switches, or using appropriate phase shift, taking account the losses for equation of balancing power. At the end of paper researcher conclude that this kind of converter has flexibility and diversity. Using PID controller with digital control succeeded to give fully power management in system. converter system constructed with multiport without increase power switches, this lead to reduce switching and conduction losses and raising efficiency [1].

Deepak Ravi, Bandi Mallikarjuna Reddy, Shimi S.L., Paulson Samuel presented different types of converters. Due to variation of load and environmental operation, voltage and power oscillate then the conventional converter may could not face the mentioned problem. The operation principle, mode of switching, capability of power management and converter construction led researchers to suggest converters classify to many families such as: Classify according to construction which can subdivide to: **Non-Isolated Bidirectional DC to DC Converter (NIBDC)** and **Isolated Bidirectional DC to DC Converter (IBDC)**.

The first part (NIBDC) considered more effective in medium and low frequency applications due to eliminate high frequency transformer. Hence, it is also divided to:

a) **Bidirectional Buck-Boost Converter**
b) **Cascaded Bidirectional Buck-boost Converter** which it consists of cascaded buck and boost converter, it operates in four quadrant which mean that buck and boost converter operate together in both directions.
c) **3-Bidirectional CUK Converter**, it combined from conventional CUK converter replacing MOSFET instead of diode.
d) **4-Bidirectional SEPIC-ZETA DC to DC** Converter which it similar to conventional CUK converter with same output polarity.
e) **5-Switched Capacitor Bidirectional DC to DC Converter**, this type suffers from high ripple current because it has magnetic component.
f) **6-Interleaved Non-isolated Bidirectional DC to DC Converter**. This kind of converter combined from many converters with phase shift between then equal to 360/n.

All the mentioned kinds will illustrate in Figure 3.

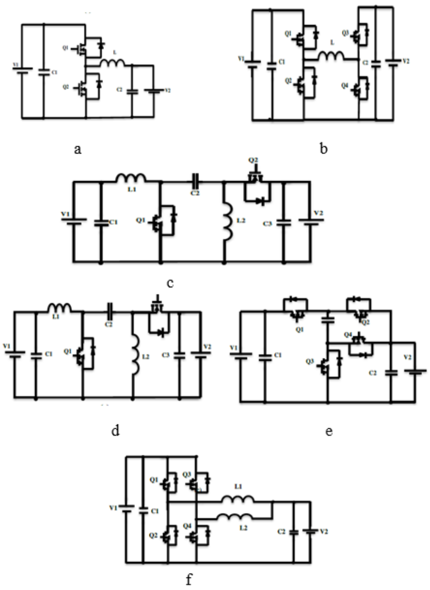

Figure 3: (a) Bidirectional dc to dc Buck-Boost Converter, (b) Cascaded Bidirectional Buck-boost Converter, (c) Bidirectional CUK Converter (d Bidirectional SEPIC-ZETA dc-dc Converter, (e) Switched Capacitor Bidirectional dc to dc Converter, (f) 2-phase interleaved

The second part of converters (IBDC) use high frequency transformer for insulation which offer safety operation conditions. The operation principle of this type goes through two stages, the first is convert dc to ac form while the second is convert dc to ac form. the sub divided of converter can classify into:

a) Dual Half Bridge (DHB)-Isolated Bidirectional DC
b) Dual Active Full Bridge (DAFB)-Isolated Bidirectional DC to DC Converter which

characterized by its high efficiency reached to 95% in high power application.

Figure 4 shows the two mentioned types.

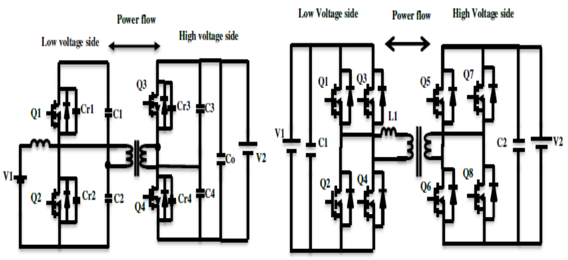

Figure 4: a) Dual Half Bridge (DHB) Isolated Bidirectional DC-DC (IBDC), b) DAFB-IBDC

Researchers also illustrate the methods used to adjust isolated converter operation, where hard switching is implemented as well as soft switching methods to eliminate the switching and conduction losses, they recognized at using the last method system become more complex and larger .at the end of work investigators conclude many problems faced isolation converter such as volume, weight and limited application. On the other hand, the non-isolated converters are more suitable for many applications especially hybrid electric vehicle and renewable energy systems [2].

Salah Alatai, Mohamed Salem, Dahaman Ishak, Himadry Shekhar Das Mohammad Alhuyi Nazari, Ali Bughneda and Mohamad Kamarol reviewed different kind of multilevel bidirectional dc-dc converters. They depend on converter's structure, applications, capability, advantages and disadvantages as well as their weight size and efficiency. Investigators exposed the many applications used bidirectional dc converter in simple scheme as shown in Figure 5.

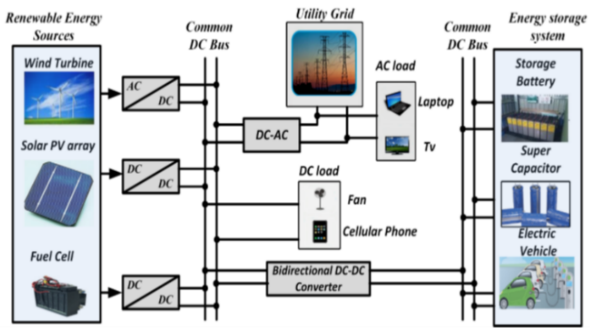

Figure 5: Bidirectional Dc-Dc Converter Application in Power Electronics System

As well as they classified converter cording to their switching method, linearity, isolation and construction in Figure 6.

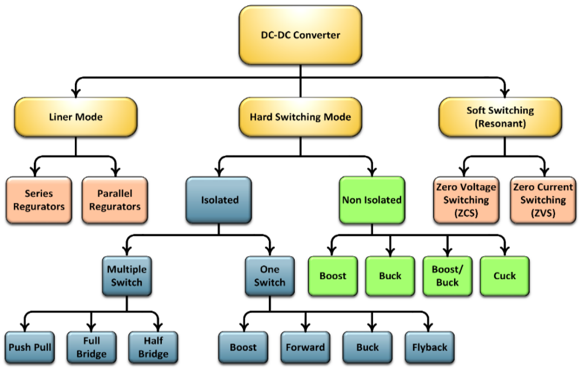

Figure 6: Bidirectional DC-DC Converters Family

After reviewed the kind of bidirectional converter (isolated and non-isolated) researchers illustrate the advantages and dis-advantages of these converter in TABLE I and TABLE II displayed below

TABLE I. THE ADVANTAGES AND DISADVANTAGES OF NON-ISOLATED CONVERTER

Advantages	Disadvantages
it has wide wide range of voltage operation	it is operated in one side for buck or boos converter
it is safe in short circuit case	it is unpractical for application need high voltage ratio
it has low ripple	it has low isolation between two sides
It is characterized by simplicity of construction	

TABLE II. THE ADVANTAGES AND DISADVANTAGES OF ISOLATED CONVERTER

Advantages	Disadvantages
it is use soft switching method	it has high ripple current
It is characterized by simplicity of construction	it has complex control circuit
has fast dynamic response	it is use large number of components

Researchers also reviewed many kinds of resonance converter a classified them into groups according to their construction, number of used components and control method as Figure 7 shown below.

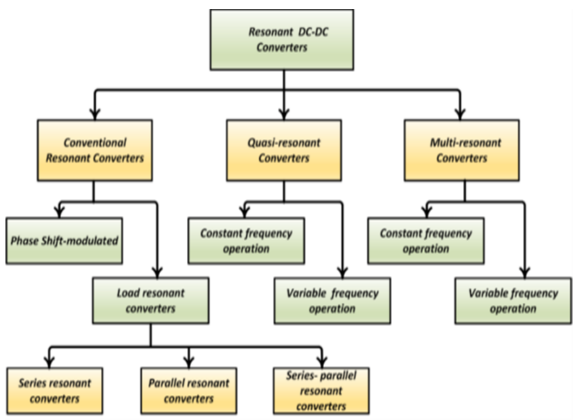

Figure 7: Sorting of Resonant Converter

At the end of work researchers conclude the using resonant multilevel converters is more suitable for many applications such as electric vehicle, renewable energy system and others, using these kinds of converters characterized by their low cost, low harmonics and their capability to operate at high frequency switching [3].

Mohammad Reza Mohammadi and Hosein Farzanehfard displayed a zero-voltage transition of bidirectional converter. They used soft switching method to trigger all power electronic switches so it reduced the stress on them. the suggested type of converter is a combination of auxiliary and main circuit where the first consist of coupled inductors connecting with the main inductor magnetically as shown in Figure 8.

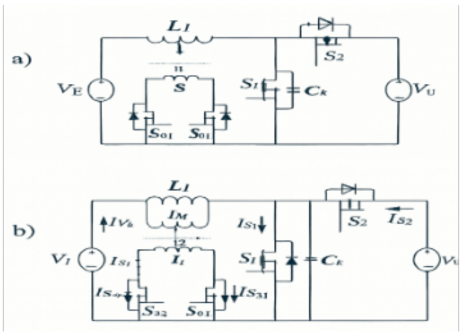

Figure 8: Suggested Bidirectional: a) Suggested Converter; b) Equivalent Circuit

The scheme shown in Figure 9 remove all conduction losses. Researchers clarify the modes of converter operation where it runs at two modes buck and boost. For analyzing circuit behavior, the following facts were advocated:

1. The circuit is ideal
2. Condition of operation implement at steady state
3. Magnetizing inductor is very large
4. Both input and output voltage are constant

After implementing the mentioned suppositions, researchers separated the period of operation into four sectors each one describes the behavior of converter depending on duty cycle and conduction time (to- t4), each sector expressed by equation describe the state of mode operation as shown in Figure 9 below.

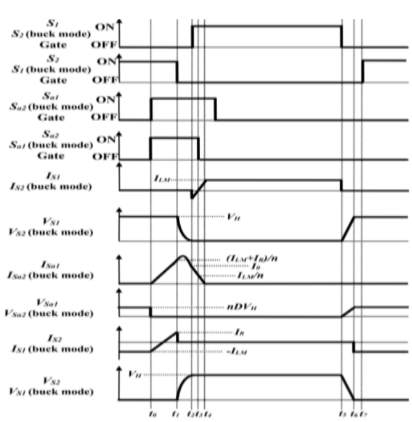

Figure 9: Bidirectional Converter Operation Modes Illustrate in Sectors

An investigator validates the theoretical and simulation results by implementing a practical circuit which exposed a match between them as well as it showed the efficiency of the implemented circuit as shown in Figure 10.

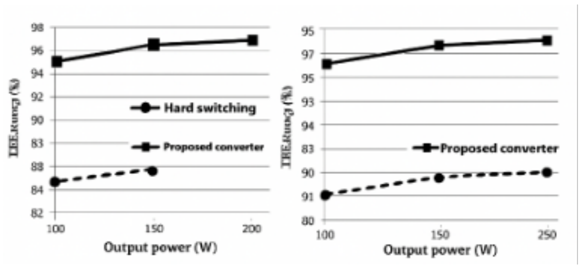

Figure 10: Efficiency Versus Output Power For VL=80V And VH=200V At Hard Switching (a) Boost (b) Buck Modes

The conclusion achieves at the end of work that the suggestion converter with soft switching has high efficiency with wide range of operation as well as using auxiliary circuit reduced the stress on power electronic switch [4].

Tole Sutikno, Rizky Ajie Aprilianto, and Hendril Satrian Purnama, proposed twenty-nine model of none isolated bidirectional converter. Where all presented model is derived from classical kind then modified. The modification includes control circuit and strategy, number of components, application and their rated. The researcher reviewed the conventional type of buck and boost converter and their operation principle with their equivalent circuit. With describing equation of converter related to its voltage, current versus time researchers derived the converter efficiency. In the other part of paper group of converters are displayed according to their topology like: DAB topology, Cascaded topology, interleaved topology, Resonant circuit, Multiport/multi-input topology and Auxiliary clamp circuit. In the end of search conclusion displayed the characteristics the converters mentioned were investigators organized a table containing the feature of them [5].

Moanis Khedr, Xianwu Zeng and Xiaoze Pei. designed an active dual bridge converter (DAB) linked with superconducting magnetic energy storage (SMES). For this design they achieved a full analysis and optimized for system to use with electric vehicle. Also, they reviewed a previous work related to mentioned subject to determine the specifications of similar kind of converter connected to SMES, the studied features are summarized in TABLE III listed below.

TABLE III. DAB AND SEMS SPECIFICATIONS

DAB features		SMES features	
switching frequency	100 kHz	Inductor	8.62E-01
Bus voltage	270	power	100.8Kw
SMES voltage	270	time of charging	1.2s
transformer ratio	1	load	50Kw
rated power	105Kw	time of discharge	0.9s

capacitor	500 e-6	Remaining energy	45.2Kj
inductor	8.70E-07		

For completely understanding the suggested, Figure 11 illustrates the design of converter where it operates in two mode charging/discharging.

The investigator describes the operation modes of the mentioned system using equations.

In this work the conclusion proved that using a combination of dual active filter with chopper is the best choice for feeding power to aircraft system. By designing suggested system soft switching reduced the conduction losses and ripple and peak current [6].

Srinivas Punna, Udaya BhaskerManthati, Arunkumar Chirayarukil Raveendran, designed an innovative control strategy for bidirectional dc converter. The proposed system used with hybrid energy storage system (HESS); this term refers to super capacitor linked with batteries. Srinivas and others suggest a dc micro grid as an application used bidirectional DC converter. connection HESS with conventional converter not easy so it needs to modified the circuit topology of converter to be has more input to accommodate many storages source system as well as controller, the new modified called (multi-input bidirectional dc-dc power converter), MIPC. Researchers The researchers reviewed many previous works related to the same topic. The proposed system consists of dc micro grid, HESS, photo voltaic, bidirectional converter addition to controller as display in Figure 12 below.

The operation principle of suggested system and its mode were analyzed using mathematical equation. It is describing the power flow from source to energy storage through converter and between both of storage units. For adjusting the operation process a PI controller was designed to regulate the state of charging/discharging modes and kept voltage of system under acceptance ratio as shown in Figure 13.

By the same method in mathematical analysis researchers designed a sub controller for each part of system, it means controller for battery and super capacitor (SC), to adjust both current and voltage at open and closed loop system. the simulation results gained through three interval operations:

1. Increase in PV generation
2. Decrease in PV generation
3. Increase in load demand

By means of practical experiment on prototype system all results gained through mathematical and simulation are validated. At the end of search the conclusion are summarized by, the battery response is low due to error in control system, but it has ling life time the voltage regulation in micro grid is fast [7].

S M Alagab, S B Tennakoon, C A Gould. Built a bidirectional dc-dc converter with rated reached to Kilo Volt, they suggested a new method depends on Marx principle to raise the rated to megawatt at both sides of converter. The suggested circuit eliminate the needs to high frequency transformer; decrease the size of converter addition to decreasing the conduction losses. Using MATLAB Simulink converter was investigated while it connected to wind turbine at 30 kv and 50 mw rated, researchers present the mathematical analysis describe the principal operation in four sectors. The written equation in this work determined the component of the studied system like capacitors and inductors at both sides high and low voltage. then the results gained at the states of foreword and reverse condition (charging and discharging) describes the overall converter behavior as well as its components such as shown in Figure 14 (a) (b).

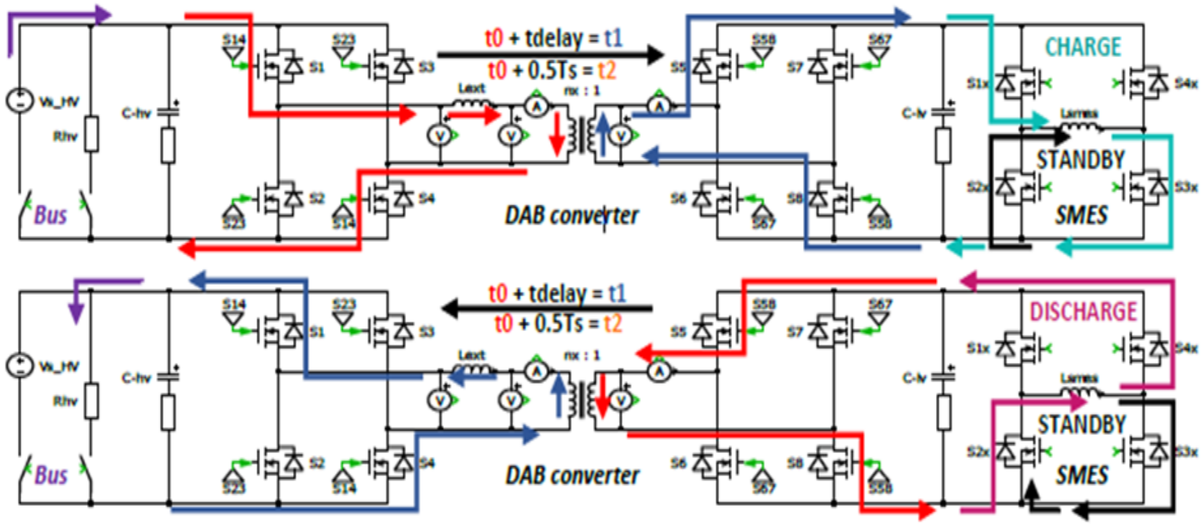

Figure 11: Modes of System at Harging/Discharging States

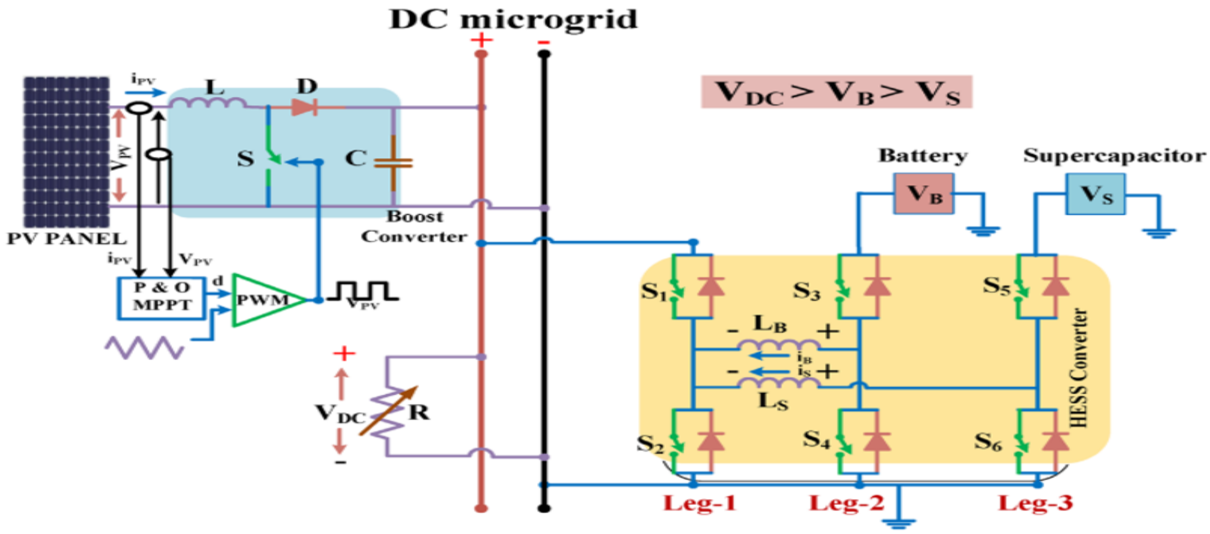

Figure 12: Proposed HESS and MIPC System

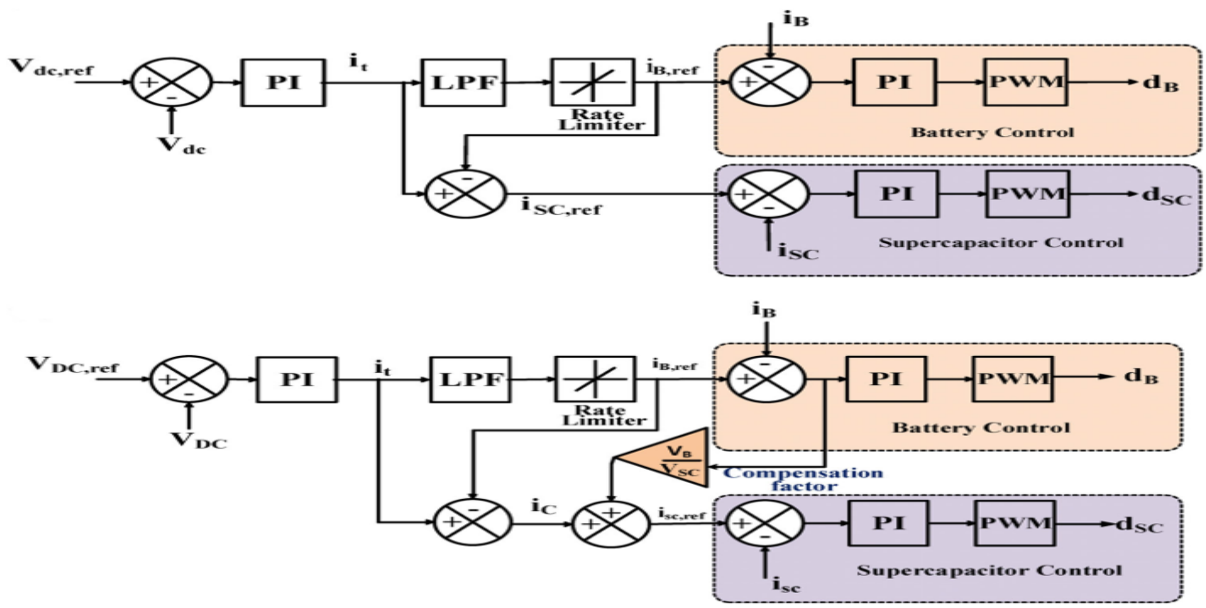

Figure 13: Whole Control System

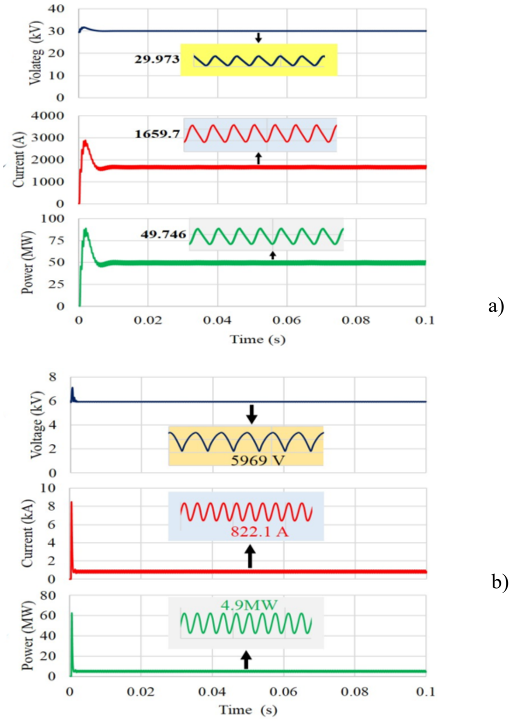

Figure 14: Waveforms at Forward Mode Operation: (A) Charging, (B) Discharging States

The conclusion stated by researchers refers to the ability of the system to rise or decline its rate by changing the number of modules make up the system while the capacitors and conductors determine the value of the switching enabling it to be soft [8].

M. Jim´enez Carrizosa, A. Benchaib, P. Alou, G. Damm. Offered DC transformer addition to design and control of bidirectional DC-DC converter has multi levels form. the model is attached with wind turbine at medium power rated. The present different kind of inverter used to convert multi-level wave form like dual active bridge (DAB), series resonance (SR), dual half bridge (DHB) and multi-level converter. by discussion of their operation topology researchers selected the last-mentioned kind to be case suggested circuit, as shown in Figure 15.

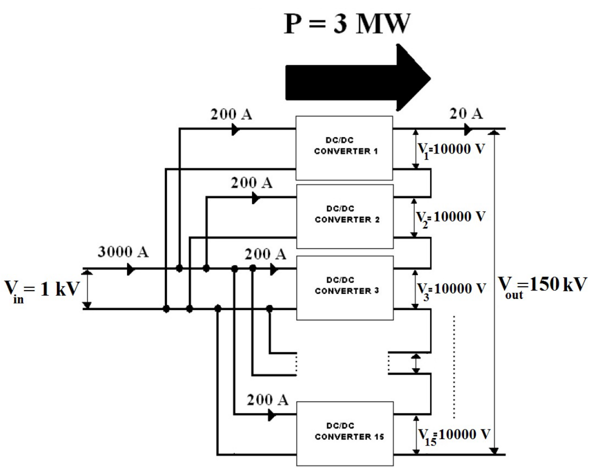

Figure 15: Suggested Multilevel Converter With 3MW Rated Power

Investigators built system consist of the suggested converter connected to renewable sources containing photovoltaic and win turbine presented in Figure 16.

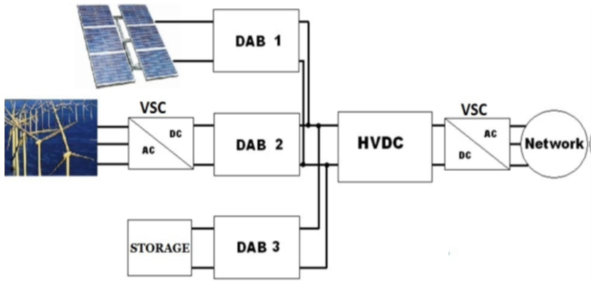

Figure 16: Multi-Level Converter with HVDC System

By studying the operation of proposed scheme to select the optimal control method. Investigators proposed a nonlinear controller circuit based on (Lyapunov) theory. The conclusion of this work denotes to using DAB scheme is the best choice to build a multi-lever converter especially in wind turbine system. This module can operate as plug and play device, which permit to the users to adapt the voltage level until reached to wanted value by insert or remove DAB. The last characterized by it low cost and simplicity Which also makes the total cost low, addition to improve the dynamic response of system and raising its efficiency [9].

Sayed M. D. Dehnavi, Gokhan Sen, Ole C. Thomsen, Michael A. E. Andersen, and Lars Møller. assembled a new construction of isolated bidirectional dc-dc converter, the new model includes super capacitors, where they assembled in parallel with converter at high voltage –low current side, and series with converter at low voltage-high current side.as shown in Figure 17.

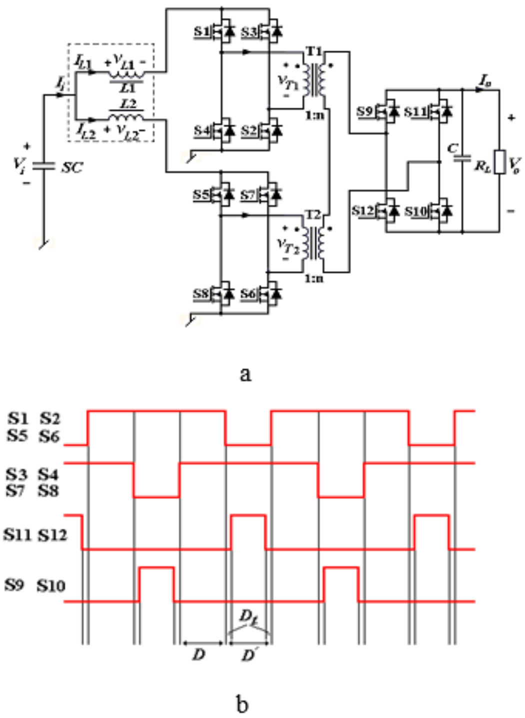

Figure 17: (a) The Suggested Circuit of An Isolated Bidirectional DC-DC Converter, (b) Converter Switching Signals

The operation principle of circuit depends on current sharing that achieved using two topologies, the first related to" current balancing transformer "(CBT), and other is "two separate inductor "(TSI). In this work, the academics divide the circuit's operation into a set of periods that relate to states of charge and discharge, each period describe by its equation in certain time. For regulating system operation researchers recommended a controller structure comprise of two parts of controller, the first is central control system while the second consist of many local control sub systems. In all parts, a PI controller was used to reduce steady state current to zero value. Figure 18 show the controller circuit.

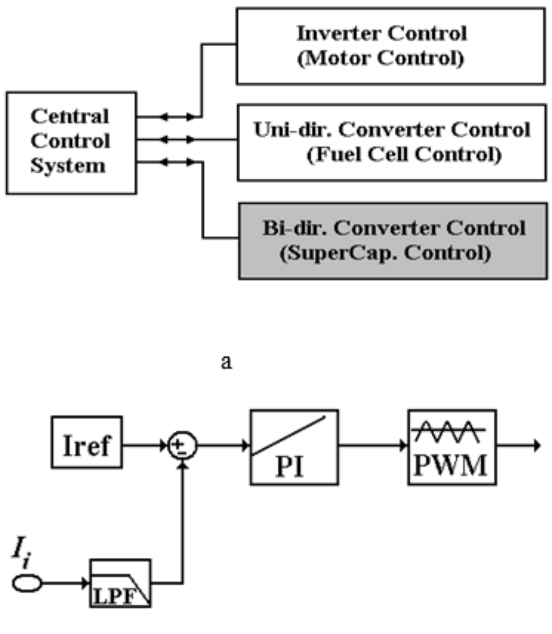

Figure 18: (a) The Suggested Controller Circuit, (b) PI Circuit

By validating the simulation results using practical experiment, the conclusion in this work of in this paper proved that developed method of using super capacitor in parallel structure make the system to be operate in bidirectional as well as it was used in unidirectional. the power flow between transformer sides an achieved using the technique of current balancing addition to separate inductors which considered easier than the first [10].

Premananda Pany, R.K. Singh, R.K. Tripathi. designed a closed loop controller regulate bidirectional dc-dc converter fed electric vehicle. The designed circuit consist of battery feeding electric vehicle (BFEVs), shown in Figure 19.

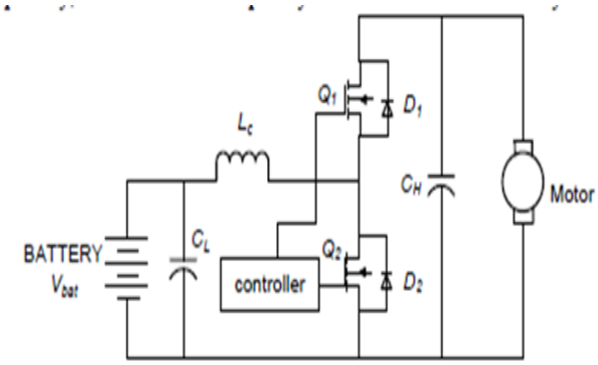

Figure 19: Designed Circuit (BFEVs)

The operation principle of the proposed described through four intervals (to –t4), each one having its own equations, as written in the following:

1. First period (t0-t1): At time t0, Q2 is ON and Q1 is OFF:

$$V_2 = L_C \times \frac{di_1}{dt} \tag{1}$$

2. Second period (t1-t2): Q1 and Q2 OFF. Diode D1 conducting:

$$\frac{dV_1}{dt} = \frac{i_a}{C_H} \tag{2}$$

$$\frac{dv_2}{dt} = \frac{V_b}{R_b \times C_1} - \frac{V_2}{R_b \times C_1} - \frac{i_L}{C_H} \tag{3}$$

3. Third period (t2-t3): At t3, Q1 is ON and Q2 is OFF:

$$\frac{di_L}{dt} = -\frac{V_1}{L_C} + \frac{V_2}{L_C} \tag{4}$$

$$\frac{dV_2}{dt} = \frac{V_b}{R_b \times C_1} - \frac{V_2}{R_b \times C_1} - \frac{i_L}{C_1} \tag{5}$$

4. Fourth period (t3-t4): Q1 and Q2 is turned OFF.

$$\frac{dV_1}{dt} = \frac{i_L}{C_H} - \frac{i_a}{C_H} \tag{6}$$

$$\frac{di_a}{dt} = \frac{V_1}{L_a} - \frac{E_b}{L_a} - \frac{i_a r_a}{L_a} \tag{7}$$

For regulating the motor speed of electric vehicle (wm) in this work PI controller achieved to adjust the output voltage of converter using PWM technique foe switching the device, where (wm) compare with (wref) to make the error between them zero as shown in Figure 20.

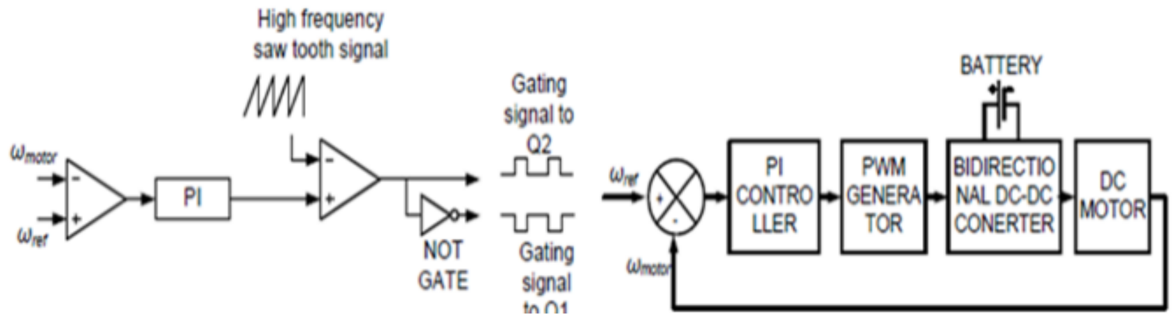

Figure 20: Complete Control Circuit

The result obtained from operating the circuit include two stages of operation, transient state and steady state condition. Where it comprises the system performance at the following statuses. (1) Changing speed, (2) regenerative braking state, while the output covered (the speed, current and torque response, power flow between battery and load and battery characteristics. At the end of search there are many facts conclude such as, using the proposed circuit make the total cost and number of switches are lower comparing to other schemes [11].

Viren Chawda, Mohammad Abuzar, Kaustubh Bhende, Mohammad Shoeb Sheikh, Anushka Dadwe, Praful V. Nandankar, designed a bidirectional dc-dc converter described by low cost due to decrease of power switches, low electromagnetic emission besides low harmonics orders. the recommended circuit is zeta converter as shown in Figure 21.

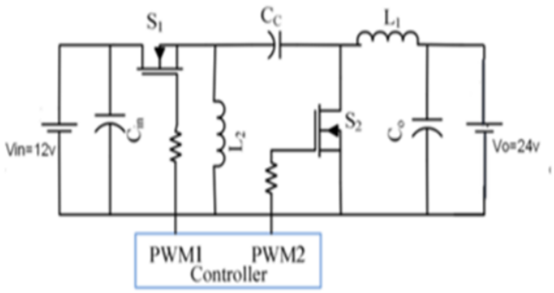

Figure 21: Suggested Zeta Converter

The above figure in implemented using MATLAB software depending on mathematical equation describe its values component and their operation. Investigators introduced the topology of switching power electronics device then they present their responses in voltage and current for each state as displayed in Figure (22) and (23).

The results displayed above are examined and validate using practical prototype build by researcher that conclude that following points, zeta converter is the better device for different kind of energy storage units than conventional type. the operation of zeta is the same as buck-boost type, it has flexibility reliability operation [12].

Mylavarapu Kyathika Rani, Valluri Lavanya Lakshmi, Peddireddy Visala Durga Pravallika. designed and simulate a bi directional dc-dc converter feeding electric vehicle, the aim of this design to improve the vehicle performance as well as reduction the carbonic emission generated by the vehicle operate by fuel as shown in Figure 24.

The results of this work are regulated using fuzzy logic controller, which responsible for determine the switching time of power device to get the appropriate voltage feeding motor armature. At the end of work the academic present, some of conclusion such as, using controller strategy reduced the state of charge (SOC) from 88% to 87.3% at constant motor voltage, while motor operate at generator mode the converter operates as buck converter. At the state when applying – torque the (SOC) increased from %87.337 to %87.445 [13].

BOYINA GURU SESHU, SK. MEERA SHAREE, K. SRINIVASULU presented a control strategy for controlling power flow in grid and electric vehicle. the studied case consists of hybrid electrical system including photo voltaic (pv) wind turbine connected to grid with bidirectional dc-dc converter feeding loads and electric vehicle, the aim in this case is to regulate power flow through this scheme.as shown in block diagram Figure 25.

The system in details contain dual half bridge connected to transformer besides single phase full bridge inverter and buck –boost dc-dc converter. this construction compacts the total stage of power stages to the fewer components. useful feature of this construction that is permit to integrated additional converter to dc link which may feed from photo voltaic arrays and batteries. This makes power flow easier between parts of circuit. Researchers at the end of work present the following proofs. using this construction developed the photo voltaic and wind turbine utilization as a results of power flow flexibility. Addition to the practical experiment show the system capability to integrate and participate by feeding continuous power to grid [14].

Andriazis Dahono and Pekik Argo Dahono made a new kind of bidirectional dc-dc converter derived from CUK converter ,the researchers also completed a comparison between the new kind of converters and conventional boosts dc-dc bidirectional converters They present firstly conventional kind circuit and how it is operates supporting by suitable equations.an other parts of search researchers showed the modified kind of buck-boost and cuk converters supporting by their equation describe their operation.as shown in Figure 26.

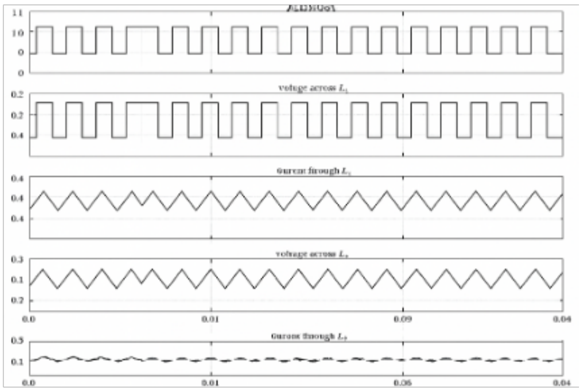

Figure 22: Switching of S1, drop voltage on L1 and L2, current passes through L1 and L2 at (charging method)

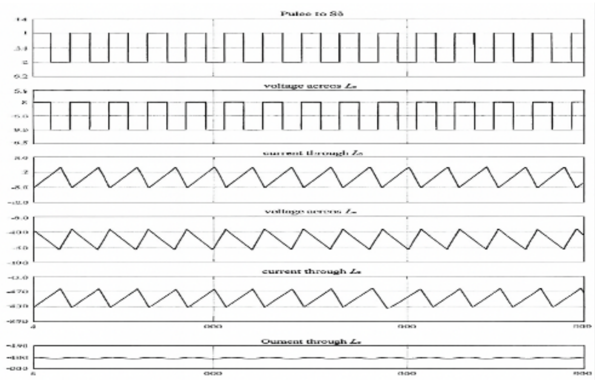

Figure 23: Switching of S1, drop voltage on L1 and L2, current passes through L1 and L2 at (discharging method)

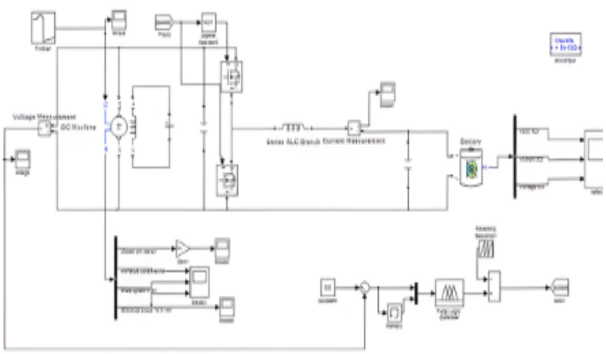

Figure 24: The suggested system consists of battery, bidirectional converter in addition to motor

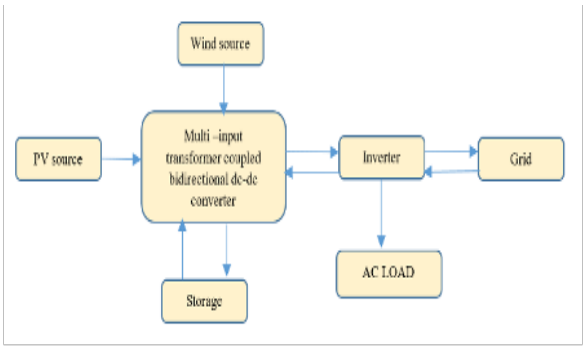

Figure 25: Block Diagram of The Suggested System

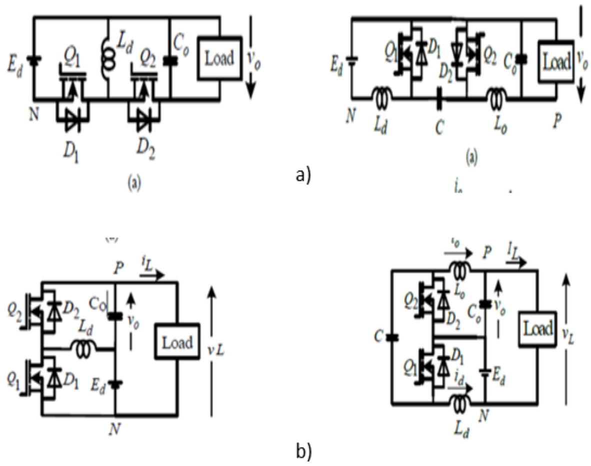

Figure 26: (a) Conventional buck-boost and modified buck-boost., (b) Conventional cuk and modified cuk

After validating the theoretical results by practical experiment researcher compare between the mentioned three types according to their performance and construction then they listed it in the TABLE IV.

The conclusions obtained after conducting the practical experiment and the comparisons recorded in the table above are summarized as follow: Chk converter has the efficiency greater than the other kind, while its modified type characterized by its continuity supplying of current with low value of ripples [15].

Srinivas Punna, Udaya Bhasker Manthati, Arunkumar Chirayarukil Raveendran, introduced a new controller circuit for multi-input power converter. They designed bidirectional DC-DC converter linked with hybrid energy storage system (HESS). The last term noticed to batteries and super capacitors (SC). Where battery cannot; keep up charge and discharge operation SC can achieve it, besides Sc cannot withstand sudden change in voltage due to load variation battery can do it. So, a combination this kind of storage energy units in (HESS) will improve system operation and raising its reliability in different states of operation. Figure 27 shown the proposed structure of bidirectional dc-dc converter. where converter connected to photo voltaic arrays controlled by maximum power point tracking (MPPT) as dc source and converter connected to micro grid. The suggested controller controlled the switching sequence of power electronic device, which it distributes into three intervals including the power flow between circuit parts at charging and discharging status such as, Power flow from DC grid to HESS, Power flow from battery to SC (Energy exchange mode). Researchers introduce a mathematical analysis as well as practical experiment for prototype circuit to build the converter controller shown in Figure 28.

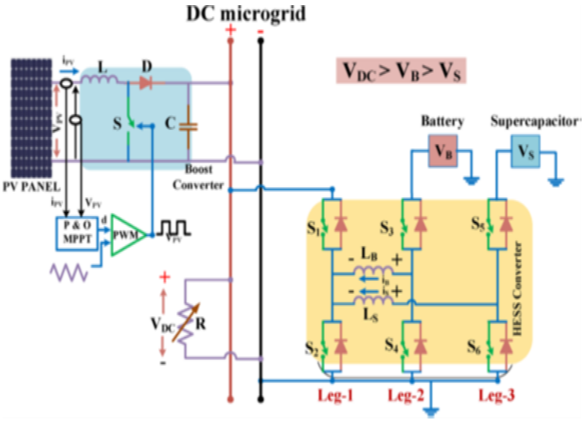

Figure 27: Suggested bidirectional DC-DC converter with its controller

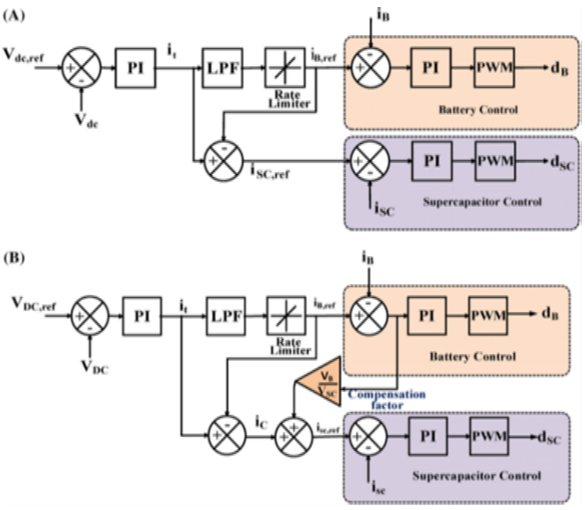

Figure 28: Total control system for current bifurcation. a) conventional control pattern and b) suggested control Pattern

The designed controller circuit include PI controller with low pass filter (LPF) accomplished with SC current control loop, battery current control loop, overall outer voltage control loop and SC charging states. Where the studied cases applied at various conditions like raising generation of photo voltaic, reducing generation of photo voltaic, raising load request, and reduce in load request for all states the comparative achieved between them the conclusion exhibited by investigator refer to exist an error of battery current tracking when using conventional controller , by using the suggested controller the dynamic response of grid was enhanced , as well as the stress on battery was reduce , and finally the new controller considered best choice for electric vehicle [16].

Kishan Jayasawal a, Yuba Raj Purja b, Kanchan Laxmi Rai c, Khagendra Thapa presented a new topology for isolated bidirectional converter. Using matlab Simulink they designed circuit consist of isolated transformer, full bridge, dc-dc converter and battery as shown in Figure 29.

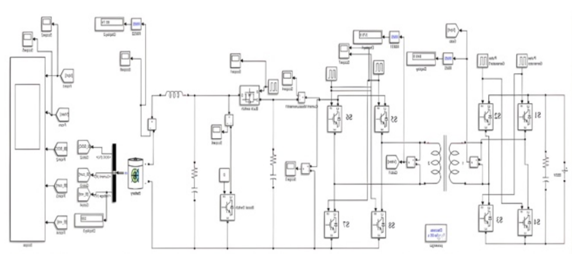

Figure 29: Proposed isolated bidirectional DC-DC converter

TABLE IV. COMPARISON BETWEEN THE PROPOSED MODIFIED AND CONVENTIONAL DC-DC BIDIRECTIONAL CONVERTER

	modified CUK	conventional boost	modified buck-boost
passive componenet	2 inductor 2 capacitor	1 inductor -1 capacitor	1 inductor -1 capacitor
average output voltage	$v1 = \frac{Ed - \alpha va - va(1-\alpha)}{1-\alpha} - \frac{(Rd - (1 - 2\alpha + 2\alpha^2) + \alpha Ra + Ra(1-\alpha))}{(1-\alpha)^2}$	$v1 = \frac{Ed - \alpha va - va(1-\alpha)}{1-\alpha} - \frac{Rd - \alpha Ra + Rr(1-\alpha) + I_l}{(1-\alpha)^2}$	$v1 = \frac{Ed - \alpha va - va(1-\alpha)}{1-\alpha} - \frac{Rd - \alpha Ra + Rr(1-\alpha) + I_l}{(1-\alpha)^2}$
source current ripple	$I_d = \frac{1}{2\sqrt{3L}} \times \frac{\alpha E_d}{fc}$	$I_d = \frac{1}{2\sqrt{3L}} \times \frac{\alpha E_d}{fc}$	$I_d = I_l \times \left(\frac{\alpha}{1-\alpha}\right)^2$
output capacitor current ripple	$I_c = \frac{1}{2\sqrt{3L}} \times \frac{\alpha E_d}{fc}$	$I_c = I_l \times \left(\frac{\alpha}{1-\alpha}\right)^2$	$I_c = I_l \times \left(\frac{\alpha}{1-\alpha}\right)^2$
transfer capacitor ripple current	$I_c = I_l \times \left(\frac{\alpha}{1-\alpha}\right)^2$	not applicable	not applicable

The isolated transformer characterized by its low weight, low cost, low noise addition to high reliability. It works step down transformer at charging state and step up at discharge state. At transformer primary side, dc source linked with full bridge inverter at charge modes or rectifier, discharging mode. While at secondary, it is also connected to full bridgework as inverter at charge or rectifier at discharge. Bidirectional (buck-boost) converter also connected to secondary of transformer, it operates depending on state of switching related to mode of charge or discharge. The results displayed for the mentioned different describing the performances of the circuit component and circuit output voltage as revealed in the following figures (Figure 30 a) – f)).

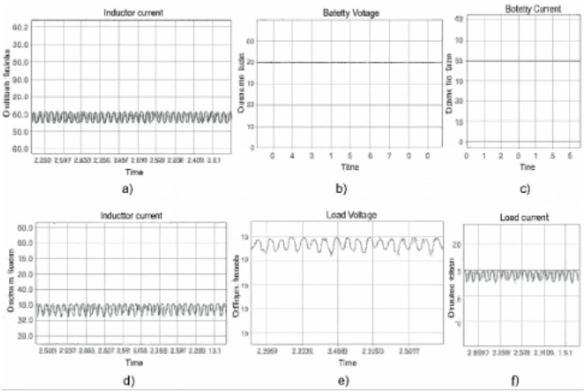

Figure 30: Performances of suggested system: a) Buck Switch Gate Pulse, b) Battery voltage, c) Battery current, d) Inductor Current, e) Load voltage; input 330 volts, f) Load current; input 330 volts

At the end of search researchers proved that the proposed system has the flexibility and reliability due to saving the energy supplied by battery and regulating power flow due to varying duty cycle [17].

Alexander Wallberg designed a bidirectional dc-dc converter. They presented firstly the theoretical and Mathematical analysis of components that constructed converter. They also present kind of dc-dc converter such as buck, boost and buck-boost which operates in four quadrants with its switching sequence as shown in Figure 31.

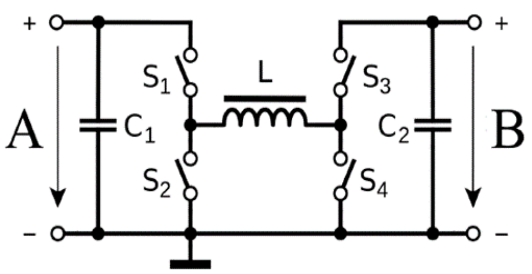

Figure 31: Proposed buck-boost converter

For switching power device researchers listed the sequence of switching that control the operation of converter in different quadrant, TABLE V shown the switching sequence of power device.

TABLE V. SWITCHING SEQUENCE OF CONVERTER

Direction	mode	S1	S2	S3	S4
A-B	Buck	switching	off	off	off
A-B	Boost	on	off	off	switching
B-A	Buck	off	off	switching	off
B-A	Boost	off	switching	on	off

Investigator recommended a PI controller scheme for achieving the last table to ensure easier power flow between circuit components and regulate the output voltage as shown in Figure 32 represent block diagram of system.

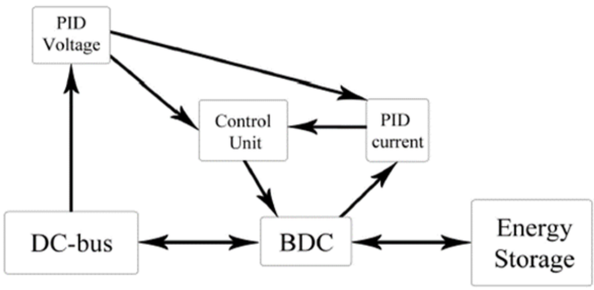

Figure 32: Block Diagram of System Controller

With practical experiment of prototype system Alexander validate the simulation results gained by simulation of circuit [18].

F. Pellitteri, V. Castiglia, P. Livreri and R. Miceli designed a buck-boost dc-dc converter feeding electric vehicle. They used a battery and ultra-capacitor as storage units to gain better performance by raising power density, ultra-capacitors (UCs) satisfying the power management at both charge and discharge status. Figure 33 displayed the suggested converter system.

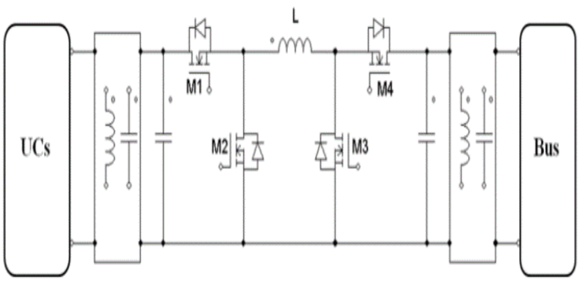

Figure 33: Suggested Bidirectional DC-DC Converter with Ultra-Capacitors (UCs)

In designing the converter, the researchers took into account the dependence on controlling the charging and discharging processes of the ultra-capacitors then regulate the flow of energy which depends on the deference between voltages as written in equation (8).

$$\Delta E = \frac{CVmax2}{2} - \frac{CVmin2}{2} \tag{8}$$

Researchers also derived the essential equation which describing converter act, where P_{loss} it's the power losses and I is the current flow in series connection state.

$$Ploss = I2\ ESR \quad = \frac{(c\Delta v)2}{\Delta t}\ ESR \qquad (9)$$

In last section of paper researchers designed controller pattern to adjust the current supplied to the bus depending on power demand, the controller aims the ultra-capacitors that connected in series and or parallel with battery as hybrid storage system. Capacitors may be interleaved as banks to reduce the total filters size. The results gained due to control circuit displayed in Figure 34.

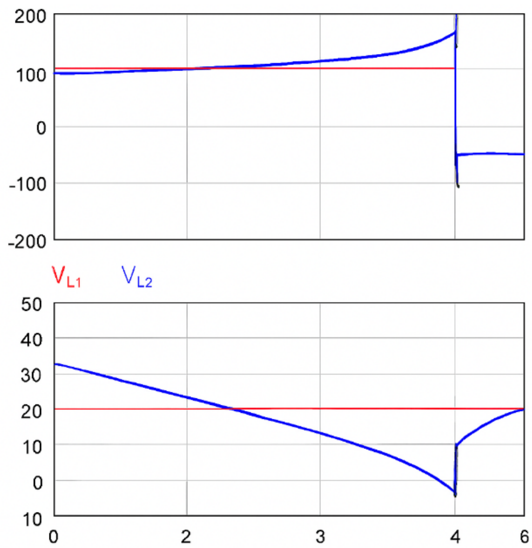

Figure 34: Time Response of Signal, First Figure Refers to Bus and Capacitor Current, While the Second Refers to Voltage for Bus and Capacitor

The conclusion of the research exposed the use hybrid storage energy system raised the efficiency of converter system to 96% [19].

Kailash Krishna Prasad.B, Suresh.J, Khaleelullah syed.I, used matlab Simulink to model bidirectional dc-dc converter connected to photovoltaic (pv) array as shown in Figure 35.

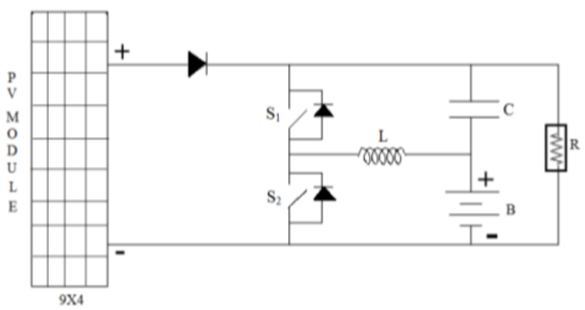

Figure 35: Simulation of Bidirectional Circuit Connected to PV Array [20]

Researchers divided paper into many sections, started with the necessary fact about converters linked with its storage units (battery). They also present the equivalent circuit of PV and its control circuit as well as model of battery. Researchers analyzed their operation principles using simulation technique and results gained from it as displayed in Figure 36.

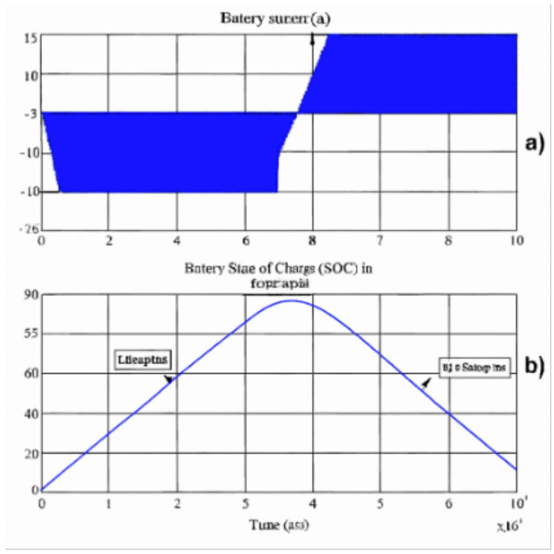

Figure 36: System Behavior. (a) Battery Voltage (In V), (b) Charge Status of Battery (%) [20]

Yoichi Ishizuka, Shun Nagata, Mika Takasaki, Toshiro Hirose suggested a new technique for regulating the operation of dual active bridge bidirectional dc-dc converter, the new control designed scheme achieved to overcome many problems faced system under operation like efficiency reduction and surge phenomena, Figure 37 shows the conventional DAB converter as case study.

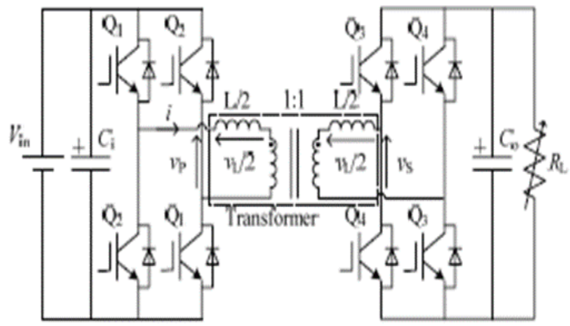

Figure 37: Conventional DAB Converter as Case Study

Analyzing technique used in this study divided the operation modes of circuit in to two main modes according to its loading status, at light load converter operates at buck at spot time =A and boost mode at spot time at B, where A and B shown in Figure 38 and equal to:

$$A = \frac{V_{in} - V_{out}}{(V_{in} + V_{out})(0.5Ts - \vartheta)} \qquad (10)$$

$$B = \frac{2V_{out}}{(V_{out} - V_{in})\vartheta} \qquad (11)$$

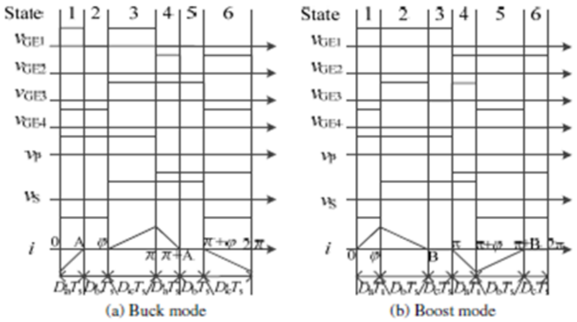

Figure 38: Modes Operation on DAB Converter

The results of suggested model and its controller was validated using practical experiment. The results related to power switches were compared between two modes buck and boost for conventional and proposed circuit. using the practical experiment, it can notice that there is improvement in switching technique were the overshoot for both current and voltage signal of switches were eliminated in proposed circuit for buck and boost modes as shown in Figures 39 and 40.

At the end of search researchers, conclude from using the new control strategy with DAB that the root mean square of error of power losses was reduced by 4% in both modes as well as efficiency at maximum power was developed by 16% [21].

Ranjan Pramanik presented an investigation of non-isolated half bridge DC-DC converter. The study investigates the converter which feeding hybrid electric vehicle where it is operate in two modes buck at charging state of battery and boost at discharging state of battery. The investigator presents the model using state space technique, with appropriate linearized equation researcher modeled the proposed system. By investigating the step-down operation status of model, he characterized it performance, describing the voltage at both high and low side of transformer addition to current versus duty cycle using bode plot strategy as shown in Figure 41.

In the end of research, the conclusion can be summarized by the following fact: The studied model represents the proper circuit for hybrid and renewable energy system, the study of circuit showing the system performance for converter in both states buck and boost modes which maintain the voltage at required level [22].

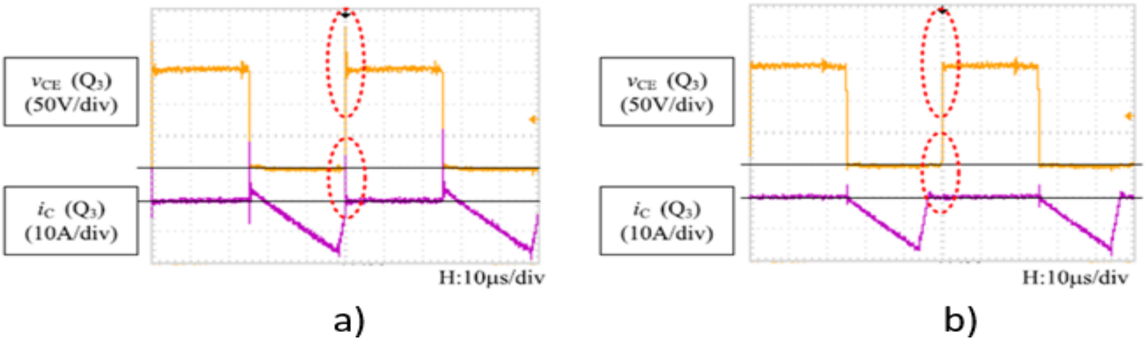

Figure 39: Buck Mode. (a) Conventional Circuit, (b) Proposed Circuit

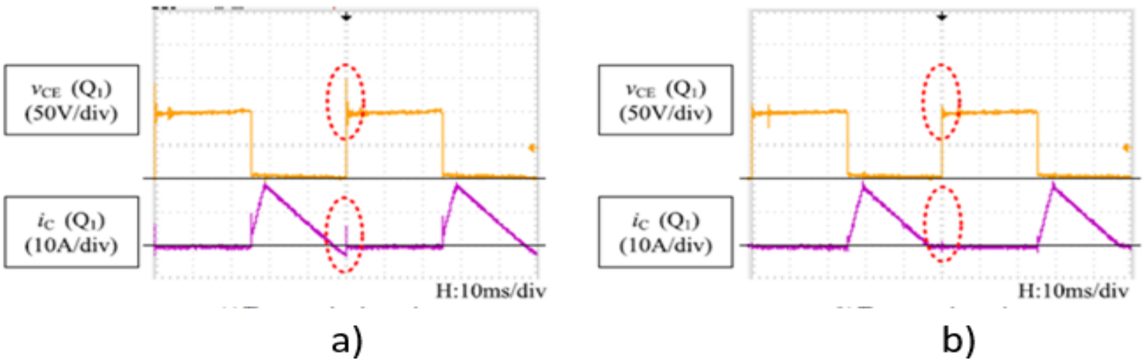

Figure 40: Boost Mode. (a) Conventional Circuit, (b) Proposed Circuit

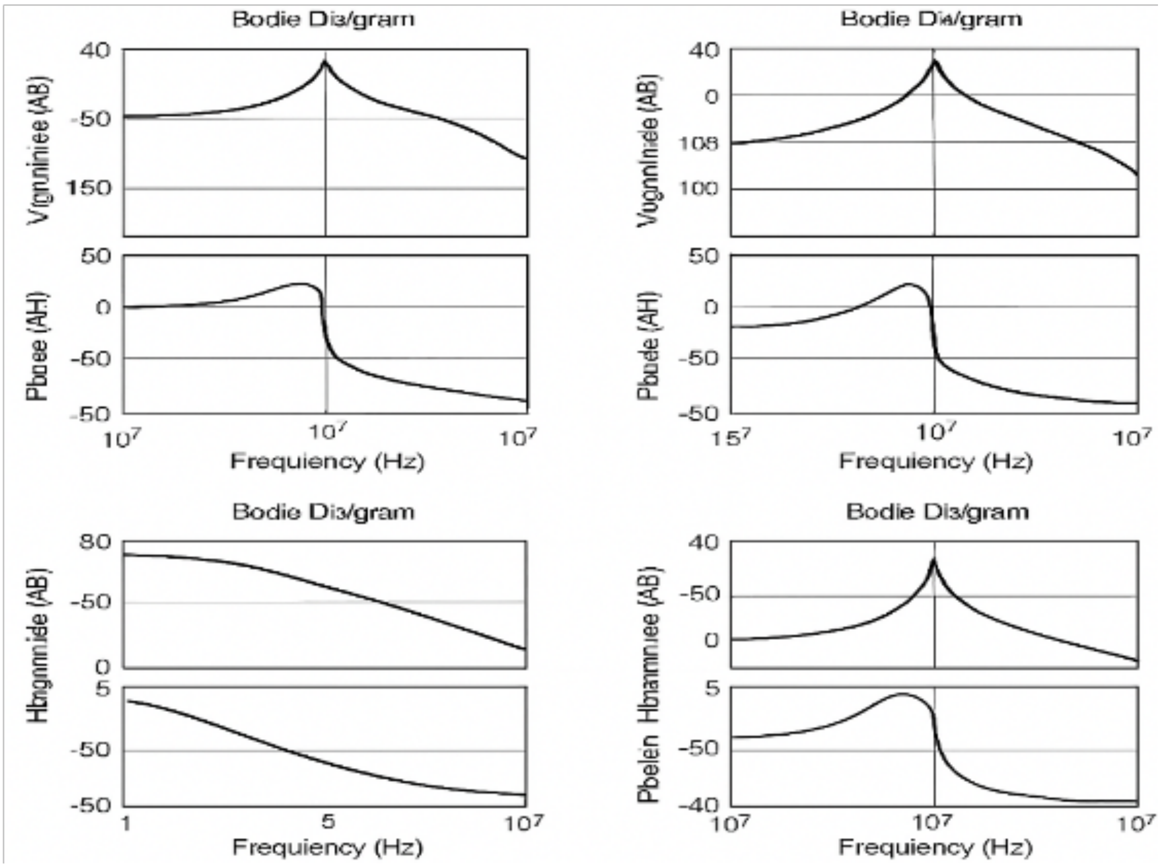

Figure 41: (a) Control to High-Side Voltage, (b) Control to Low-Side Voltage, (c) Duty Cycle-To-Inductor Current, (d) Duty Cycle-To-Inductor Current

Liqin Ni, J. Patterson, Jerry L. Hudgins designed a new structure of multiphase bidirectional DC-DC converter. the new model consists of sixteen interleaved converters with smallest filter in both sides. This construction enhanced the response and reduce the number of power switches as well as stress applied on them. Where converter connected to ultra-capacitor (UC) and battery offer continuous power supply to converter. Figure 42 show the proposed circuit by researchers.

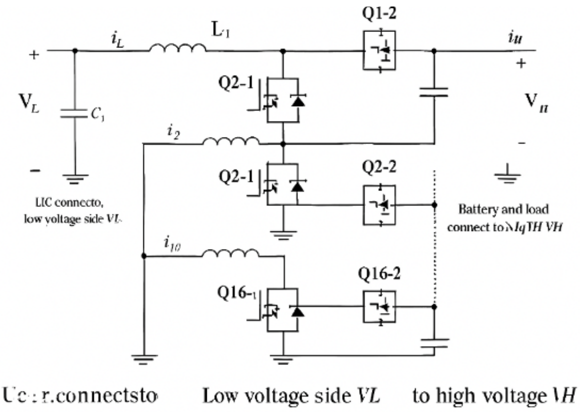

Figure 42: Proposed Sixteen Interleaved Bidirectional Converter

New interleaved model operates at discontinuous conduction mode (DCM). Researchers designed a control scheme to regulate the converter operation where it drives it using zero voltage crossing (ZVC) making switching losses conduction as less as possible for all conditions. Where the designed duty cycle for converter is achieved for both buck and boost modes to switch the power device getting the results shown in Figure 43.

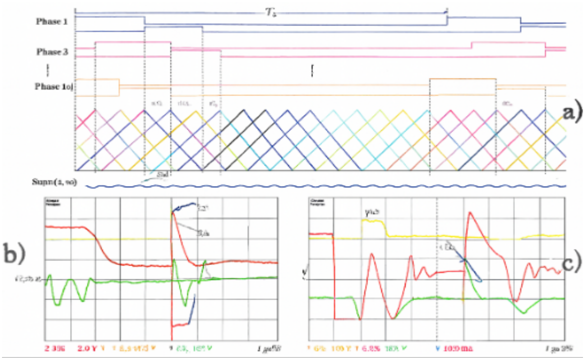

Figure 43: (a) Signal Applied on Gateand Inductor Currents, (b) Duty Cycle at Boost Mode, (c) Duty Cycle at Buck Mode

The important step implemented by researchers was designed the controller that consist of two phases the first regulate the converter operation while the second adjust the power flow and manage it between battery and UC. The new controller increased the life time of battery as well as eliminate the limitation of overheating at high load. Other steps done by investigator represent by designing the component of circuit such as inductor count to make an analyze for circuit performance taking account power losses. the results gained are validated by practical experiment archived by building a prototype model. At end of research the conclusion summarized as the following: using two stages of current controller reduced the need to use control circuit for each phase and making the current ripple as less as possible. using interleaved strategy reduced the filter sized used for smoothing signal, finally using ZVC reduced the power switch losses and voltage over shoot [23].

Sihun Yang, Kenta Goto, Yasutaka Imamura and Masahito Shoyama analyzed the bidirectional dc-dc converter performance. They studied the dynamic characteristic response and stability of converter at the state of charging and discharging. The proposed system consists of bidirectional dc-dc converter feeding from photo voltaic as a renewable source and connected to battery as storage unit.as displayed in Figure 44.

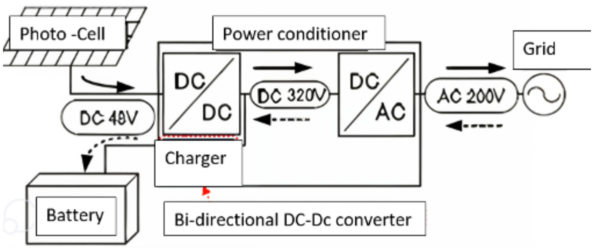

Figure 44: Proposed System

Researchers modelled the system using proper state space equation describing its behavior and performance, they used frequency analysis (bode plot) to define the topology of circuit. by executing change of power flow, they examined the transient response of converter of voltage in both side high and low. In addition, they examined the system at steady state condition for the same variables. A practical experiment was applied to confirm the analytical results in both direction modes forward and reverse will show in Figure 45.

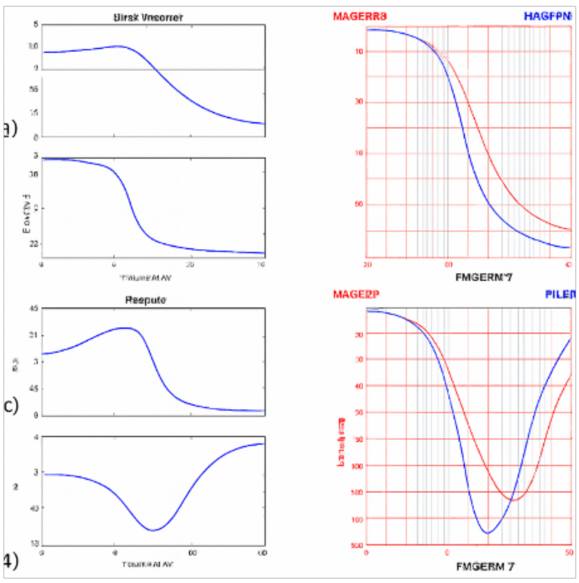

Figure 45: Forward State. (a) Analytical Results, (b) Practical Results. Reverse State. (c) Analytical Results, (d) Practical Results

From the results researchers conclude that the frequency characteristics is a function of power flow direction. signal on phases is not affected by current at high side of converter in case of low frequency which mean that current is the main affect at high frequency [24].

Zhe Zhang, Ole C. Thomsen1, Michael A. E. Andersen1, Jacob D. Schmidt and Henning R. Nielsen. studied a scheme include of fuel cell linked with super capacitor (SC) as continues power supply connected to bidirectional DC-DC converter shown in Figure 46.

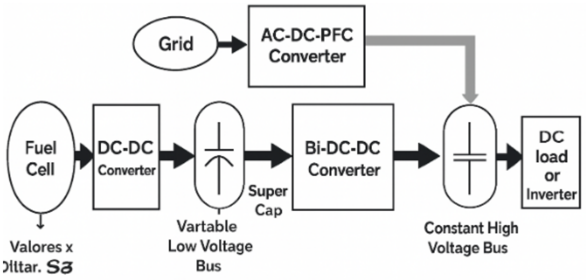

Figure 46: Proposed System with Fuel Cell and Super Capacitor

In the fourth part, researchers validated the practical simulation gained by building a practical experiment. At the end of paper, the conclusion proved that using duty control lessen the inrush current, designing parameters led to improve the overall system performance [25].

Dayu Qu studied the electromagnetic emission characteristics and proper method to improve the bidirectional DC-DC converter. He built a converter system type (L) and full bridge feeding from dc power supply across high voltage super capacitor.

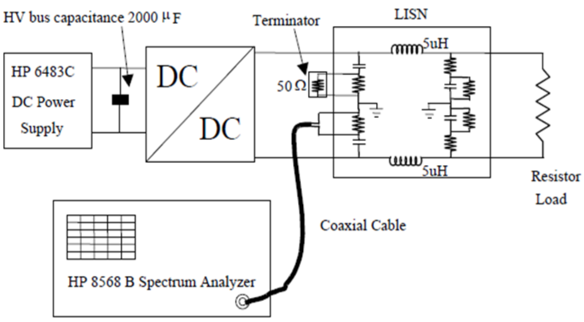

Figure 47: Total System with Filters

Based on theory and simulation of filters with converter researcher conclude that noise in common mode has the largest value of the whole noise in system. The noise sources are generated by using auxiliary start up winding in the suggested L type. Investigator present different methods to eliminate electromagnetic emission such as use synchronous rectifiers, adding filters on both sides of transformer. Using soft switching is the best method for triggering converter switch to reduce EMI, when using hard switching it is preferred to operate active clamp switch [26].

S. Waffler and J.W. Kolar present several ideas for enhancing bidirectional performance and efficiency. the case study consists of hybrid electrical vehicle linked to bidirectional dc-dc converter. For raising efficiency, they aimed to reduce the electrical losses. researcher used the soft switching technology for firing power device, as well as they optimized the time switching for the same purpose, then finally they presented a new method for zero voltage for switching device. All the used method were achieved on multi-phase converter making its output as interleaved phases. All the mentioned method were displayed in sectors in this search, each one present the mathematical analysis of the method as well as the results gained by using it as displayed in Figures 48-50.

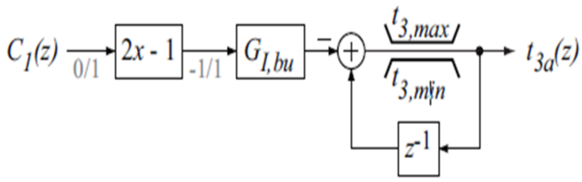

Figure 48: Control Scheme for Output Current with Time Sampling Tp

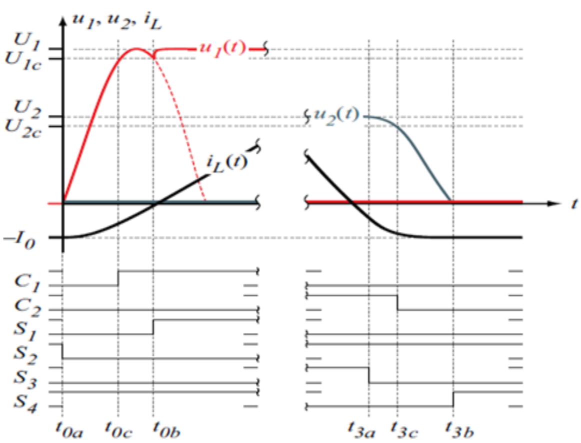

Figure 49: Timing Scheme for Switch (S1-S4) Addition to Comparator Signal (C1 And C2) Used in Buck Operation Mode, Where T=To And T=T3

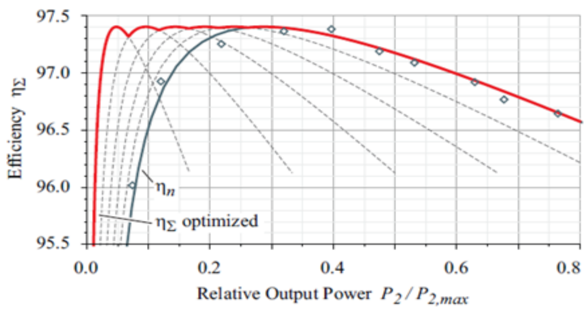

Figure 50: Efficiency and Curve Fitting, When Low Output Power with Partial Phase Operation That Increase Efficiency

Researchers validate the result gained by analytical analysis and simulation for suggested method using a practical experiment linked with digital control (DSP and FPGA) structure as shown in Figure 51.

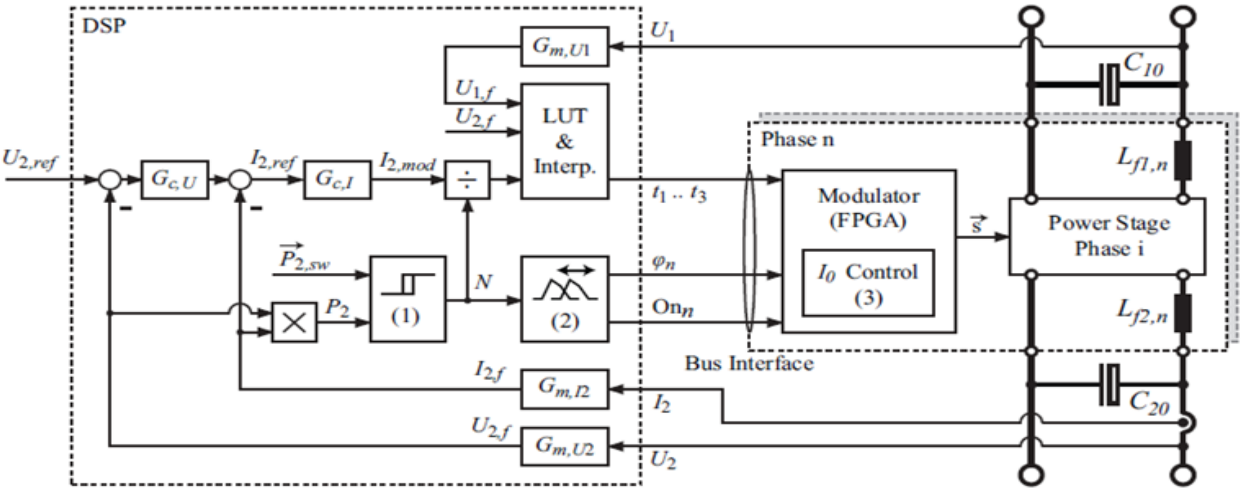

Figure 51: Diagram of Summation of Phases with Filters Interaction Controlled by DSP And FPGA

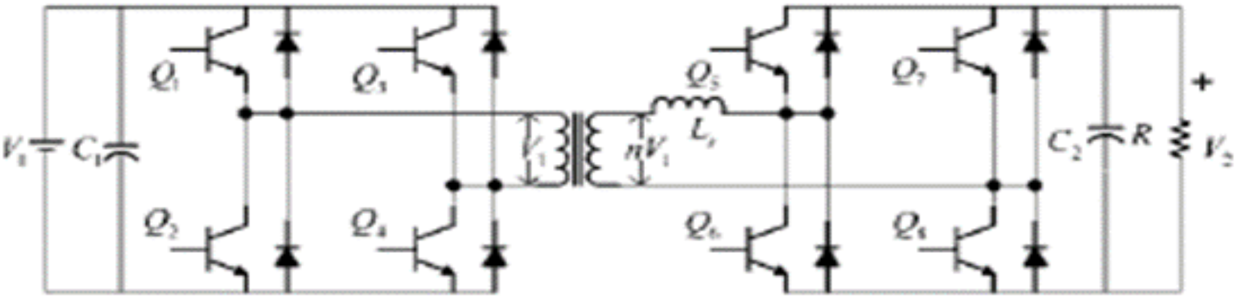

Figure 52: Isolated Buck-Boost Bidirectional DC-DC Converter

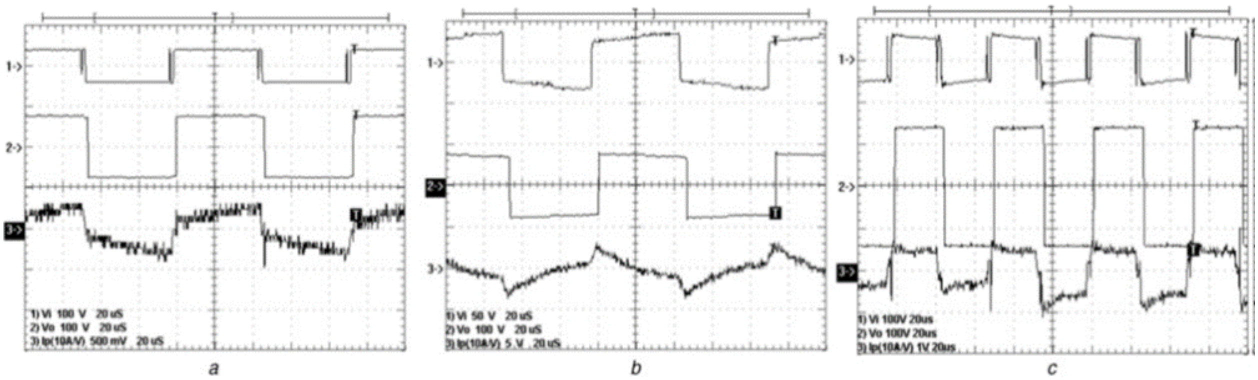

Figure 53: Dissimilar Modes at Steady-State Operation

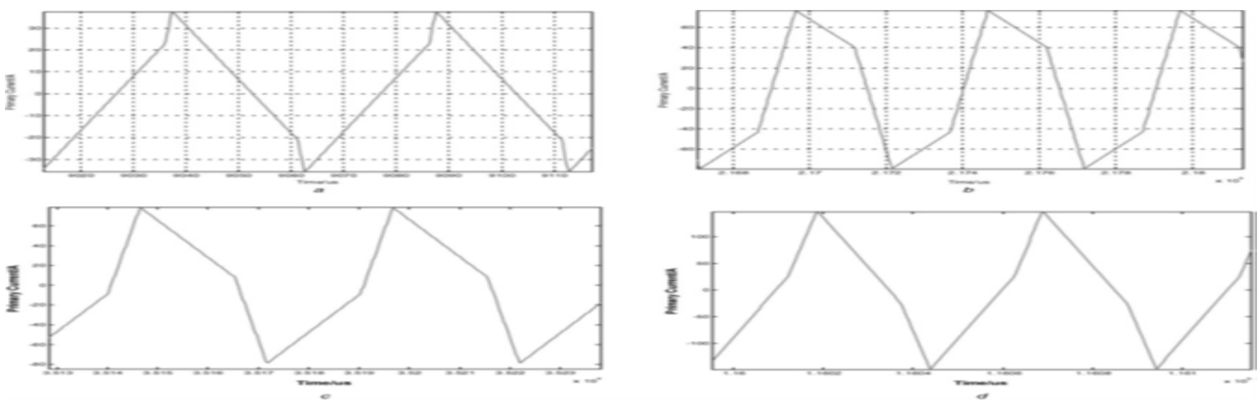

Figure 54: Analytical Result of Power, Current and Phase-Shift Angle

Depending on the practical and theoretical results it is concluded that all methods used to enhance the efficieny aimed to reduce the losses, the novel method of ZVS that reduced the rms current of inductor is suitable for high-speed dc current sensor. Using partial phase operation for multiphase converter increased efficiency by 2.8 % at maximum power reached to 5%. The system output is stable at operation mode when switching phase counted [27].

C. Mi, H. Bai, C. Wang. and S. Gargies presented a study of hybrid electric vehicle. the investigation includes making a design an isolated bidirectional dc-dc converter. They present in first section of search a complete discussion for converter circuit related to its operation for identical converter which display in Figure 52.

In the other section of search a design for controller circuit of converter was introduced to adjust the power flow through system. Different status of load conditions was assumed at light and heavy load conditions besides phase shift angel were applied on converter, so that the results obtained target absolute and relative voltage ripple, as display in Figures 53 and 54.

A prototype system is designed and implemented to validate the simulation results. The conclusion of this search is presented by the fact that converter suffering from overshot in bridge due to commutation states, so researchers advocated implanting a dead band through linked power switches, this treatment increase the reliability of system and enhance its performance [28].

Xiaoyan Yu and Paul Yeaman present a solution for voltage spike phenomena in converter. They designed a novel circuit of bidirectional dc-dc converter, where this kind of converter can operate as storage units as well as dc link bus. as shown in Figure 55.

Where the Figure above presents three blocks, block one and block three are responsible for regulation of the output signal while block two is deliver isolation with constant step up and step-down ratio in the system. Block 1 and 3 represent the input and output of converter having opposite voltage. With zero voltage switching (ZVS) of power device the operation principle explained besides, the controller strategy also clarified, Figure 56 showing the results gained due to operation of al mentioned block in system.

A prototype circuit were implemented with 48-volt bus voltage and 12 voltage battery with ration 4:1 then loaded. The result gained at showed different state of efficiency increased according to increase the amount of load, the conclusion faceted by researchers refers to ability of converter to operate in both direction as well as it supports the system by increasing the time interval of operation [29].

Partha Sarathi Subudhi, Pawan S Khante designed a new controller circuit for battery operation charging and dis charging mode. the aim of this design is to achieve continuous providing of power in micro grid system. Figure 57 show the complete system of micro grid with converter and storage units.

The operation of the proposed system can be summarized by, while some measuring device connected to mesh it will need to be operate at continues status, this system offered this facility while at the state of grid failure or critical loads battery operate as a backup power supply. Researcher reviewed the operations modes of battery charging and discharging. After presenting the converter applications, they modeled it using the following equations, where x_1 represents the inductor current and x_2 is the capacitor voltage.

$$x_1(t) = \frac{1}{L(uVin + (1-u)x2)} \tag{12}$$

$$x_2(t) = \frac{(1-u)x_1}{C} - \frac{i0}{C} \tag{13}$$

For designing control circuit of converter, the following state space equation, where $u(x_1, x_2)$ is the duty cycle function in control formula.

$$\dot{x} = Ax + Bu + Ed \tag{14}$$

$$y = Cx \tag{15}$$

$$X = [x_1, x_2];\ T_u \epsilon \{0,1\} \tag{16}$$

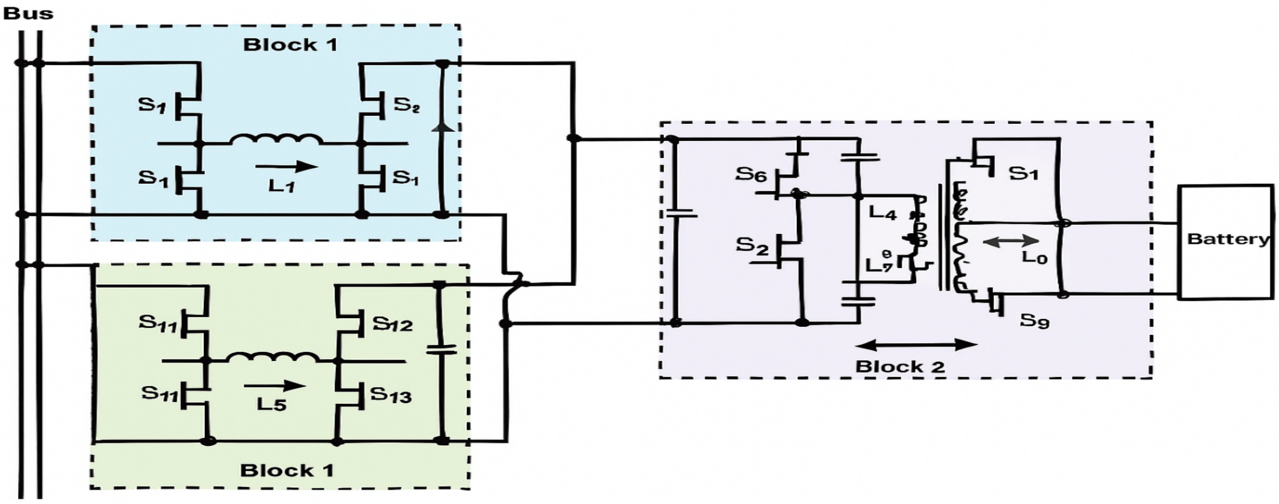

Figure 55: Novel Scheme of Bidirectional DC –DC Converter

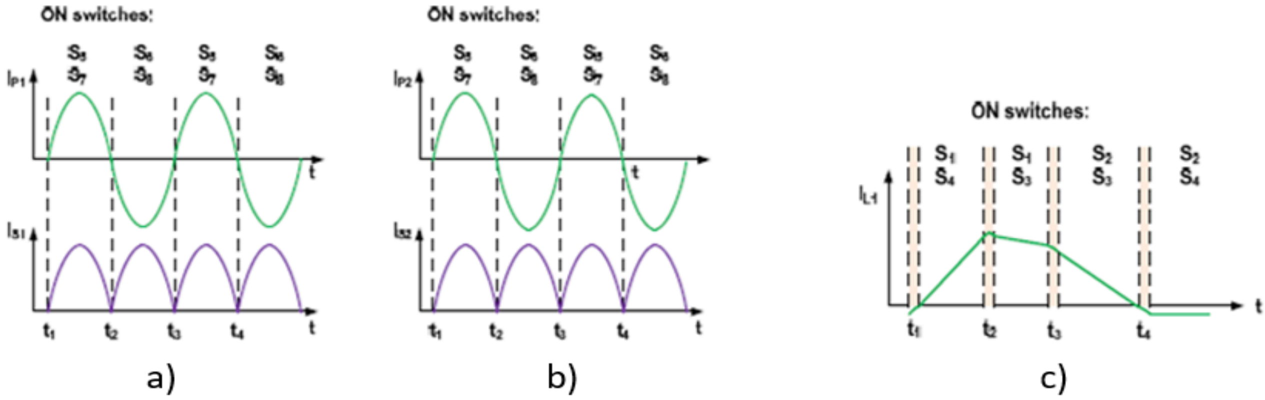

Figure 56: Resonant Current in Primary and Secondary Side. (a) At Charging Mode, (b) At Supporting Bus Mode), (c) Current Passing Inductor at ZVS Period

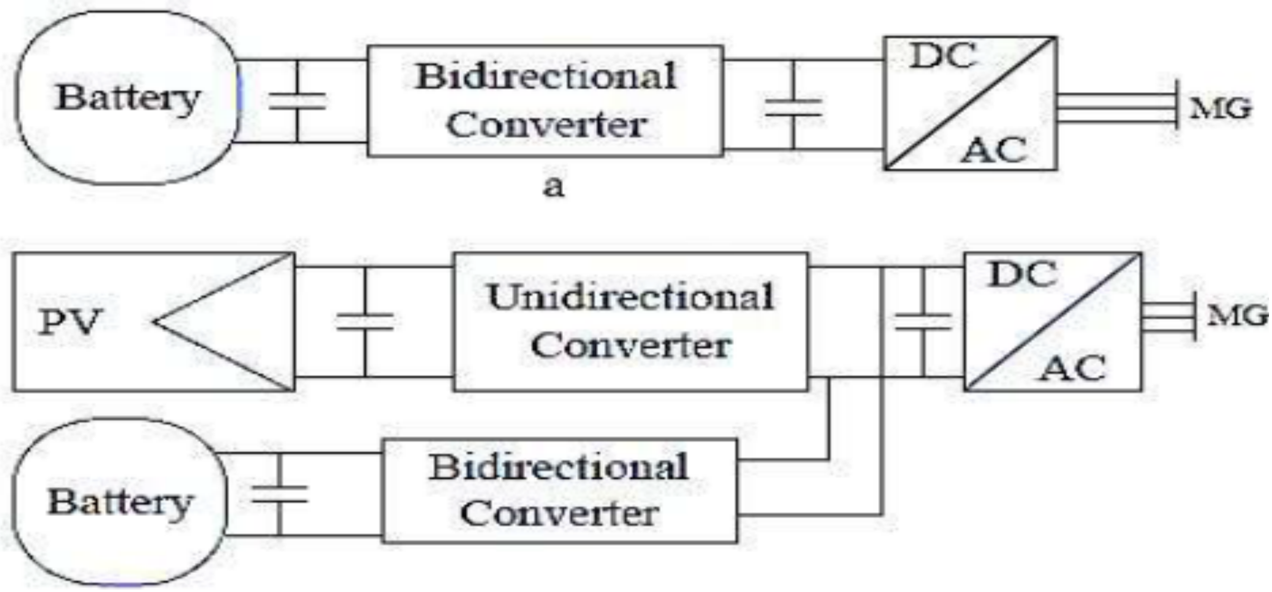

Figure 57: Photo Voltaic Arrays Connected to Bidirectional Converter

The control strategy is built depends on circuit and battery status; it classified the control period into three modes. The first mode considered battery is Empty and connected in parallel with grid while supply get its power from grid. The result in Figure 58 shows the circuit response. In second mode converter runs as boost and battery feeds the load as displayed in Figure 59. The last modes, battery does not play any role while power is flow from grid at continuous state even at critical loads.

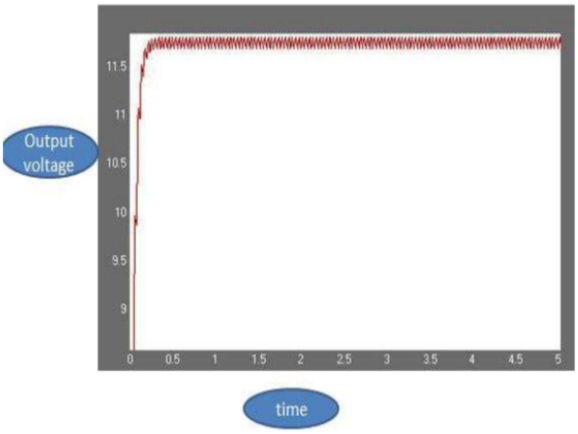

Figure 58: $q1$ Mode Output Voltage

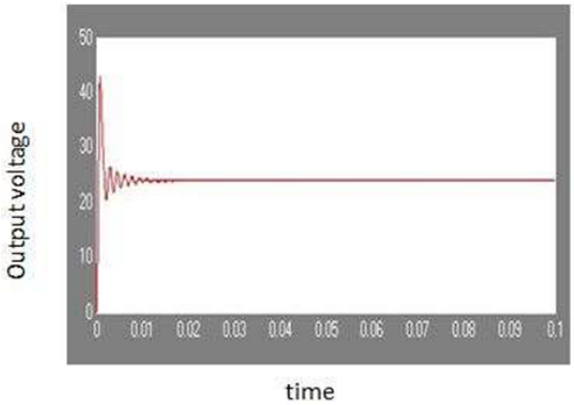

Figure 59: $q2$ Mode Output Voltage

In the last section of paper, the conclusion proved that converter controller played great role in power flow of battery, to execute the controller scheme of converter it is important to take account the characteristic of grid. The control strategy used in search make the converter and battery operate in al condition modes [30].

Qiang Li, Di Liu, Shen Chen, Zhu Liu, Wenjing Li, Lvchao Huang, Jinguo Fang and Yuqiang Zhuang, explore enhancing the stability of Buck-Boost bidirectional DC/DC converters under adjustable load status. they study the control techniques, counting droop control for parallel operation of two system .as presented in Figure 60.

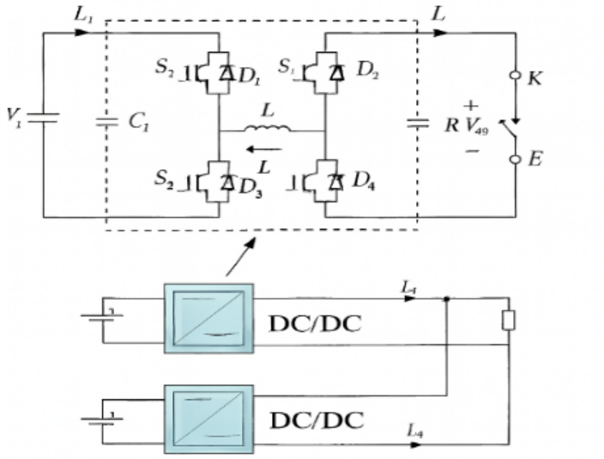

Figure 60: Proposed System Including Two Bidirectional Converter

For the case study they illustrated the modes of operation for both cases charge and discharge status for two converters. For the two cases the new strategy dropped control was implemented, it is depending on load current feedback, below the same droop coefficient between two machines. For this work the coefficient is inductance current as shown in Figure 61.

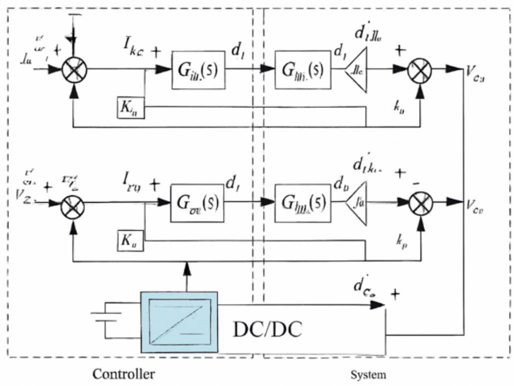

Figure 61: Propose Control Strategy (Drooped Control)

For validation results researchers also built a prototype to achieve an experimental platform using The DSP adopts TI's TMS320F28335, and the CPLD adopts Altera's EPM570T100I5.For both theoretical and practical results the conclusion showed the following facts. The usage of feedforward current in control circuit enhances the dynamic response for system under abrupt change, at parallel state when two machine are operate feedback current is the best choice in dropped control [31].

Achwak Alazrag, L. Sbita addresses the challenge of energy storage system and interfacing with loads when they used with renewable energy sources such PV array cell and wind turbine. They studied a non-isolated bidirectional DC-DC converter linked with battery energy storage and DC grid interfacing. Researchers applied control strategy to regulate the duty cycle depends on the state of battery (charge) at day where converter played as buck while played boost at night (when battery runs at discharge mode). Investigator also present a study for maximum power point (MPPT) depending on usage of fuzzy logic and observe controller scheme. By using different algorithm researcher conclude that applying to adjust MPPT. The simulation results indicate that the INC algorithm performs better than the P&O and the fuzzy logic-based control shows good behavior and better performance compared to the P&O, the better algorithm INC, developed both dynamics and steady state performance of the PV system addition to the efficiency of the dc-dc converter system [32].

Mehmet Kurtoğlu, and Fatih Eroğlu. present a study designs, analyzes, and simulates of non-isolated BDC with buck and boost operation principles. The BDC adjust the power drift among the battery and DC link and loads. They implement PI controller to regulate BDC operation for charging and discharging battery researchers illustrate different states of converter, when it operates at buck (charging mode) and boost (discharging mode) as shown in Figure 62 (a) and (b).

After implementing the whole circuit researchers as shown in Figure 63, used PI controller to regulate the selected operation case.

1. **Constant reference current .in this case power transmitted from DC link to battery**
2. **Variable reference current. in this case power transmitted from DC link to battery**
3. **Constant DC link voltage .in this case power transmitted from battery to loads**
4. **Variable DC-link voltage .in this case power transmitted from battery to loads**

The conclusion of this work proved that PI controller was the suitable choice for regulating the power flow among the system [33].

V. Viswanatha, A. C. Ramachandra and R. Venkata Siva Reddy discussed current advancement and control strategy accomplished with bidirectional dc-dc converter, they analyzed topology and control of buck-boost DC-DC converters. The study take account the effect of using transformers compared to non-isolated converters. At state when circuit uses transformer-based converters it introduces an AC line, given that well protection for high-voltage applications. Also, researchers reviewed different types of isolated and non-isolated converter for different topologies as shown in Figure 63 (a, b, and c).

After reviewing the topologies of converter according to their application researchers also extinguished many kinds of controller strategy as well as the algorithm used with them. They mentioned to PID, particle swarm, artificial neural network, fuzzy logic, etc. by implementing this strategy on non-isolating and transformer converter circuit the conclude that non-isolated converters create a direct DC path, but transformer-based converters introduce an AC line, posing well protection in high-voltage applications. The status of suitable control schemes and algorithms for managing power between DC sources and loads is emphasized. Isolated topologies, which include transformers, provide advantages such as safeguarding sensitive loads and allowing multiple input/output ports [34].

Hajer Gaied1, Flah Aymen. Habib Kraiem.Claude Ziad El-Bayeh, Yahia Said and Mishari Metab Almalki. Conducted a detailed simulation of the PIDRN controller for a three-phase converter, considering several initial battery charging situations. When they modeled system and run simulation performance was analyze at differences initial battery charge levels, figure 64 shows the studied system.

By implementing an appropriate PID and neural network controller on circuit the conclusion verified the following fact. Usage of interleaved converters needing high output capacity and stability, such power transmission systems and industrial application. Using unique modulation for DC-converter increase the efficiency and current distribution. The selection of a three-phase parallel MOSFET converter depends on application requirements and operating conditions. the term three phase refers to use three-phase parallel MOSFET converter which depends on how and when it operates. under different status of charging battery using PID with neural network (PIDNN) improve voltage regulation as well as make the interleaved converter more efficient and intelligent [35].

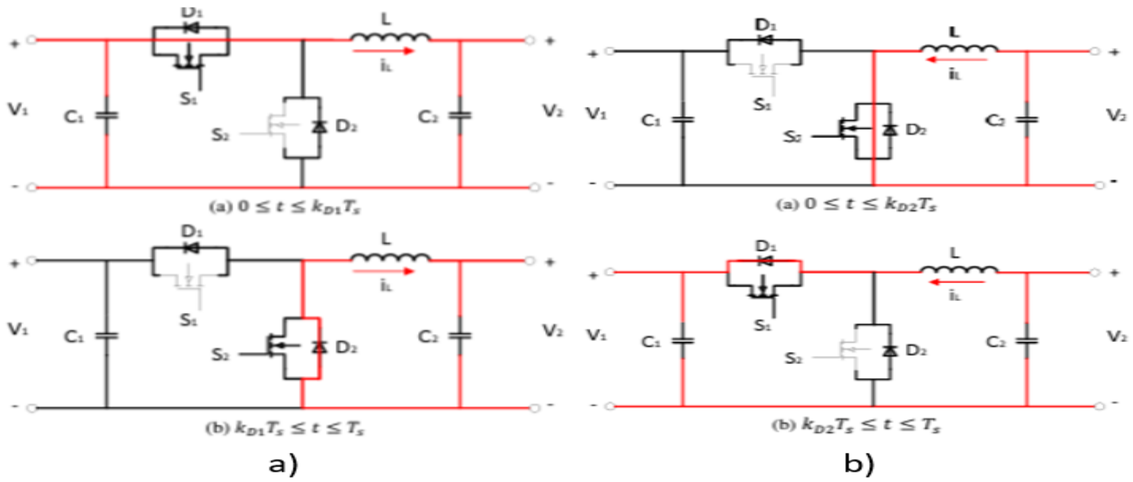

Figure 62: Modes of Converter Operation in States Operation. (a) Charging Mode, (b) Discharging Mode

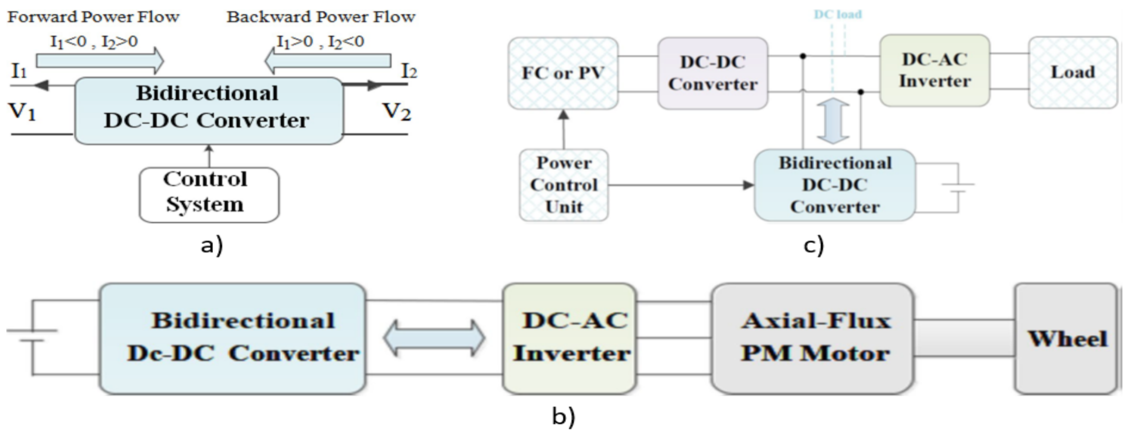

Figure 63: Different Types of Bidirectional Converter Circuit Related to Their Application. (a) The General Structure of Bidirectional DC-DC Converters, (b) The Bidirectional DC-DC Converter in EV Powertrains, (c) The Bidirectional DC-DC Converter in FC or PC Sys

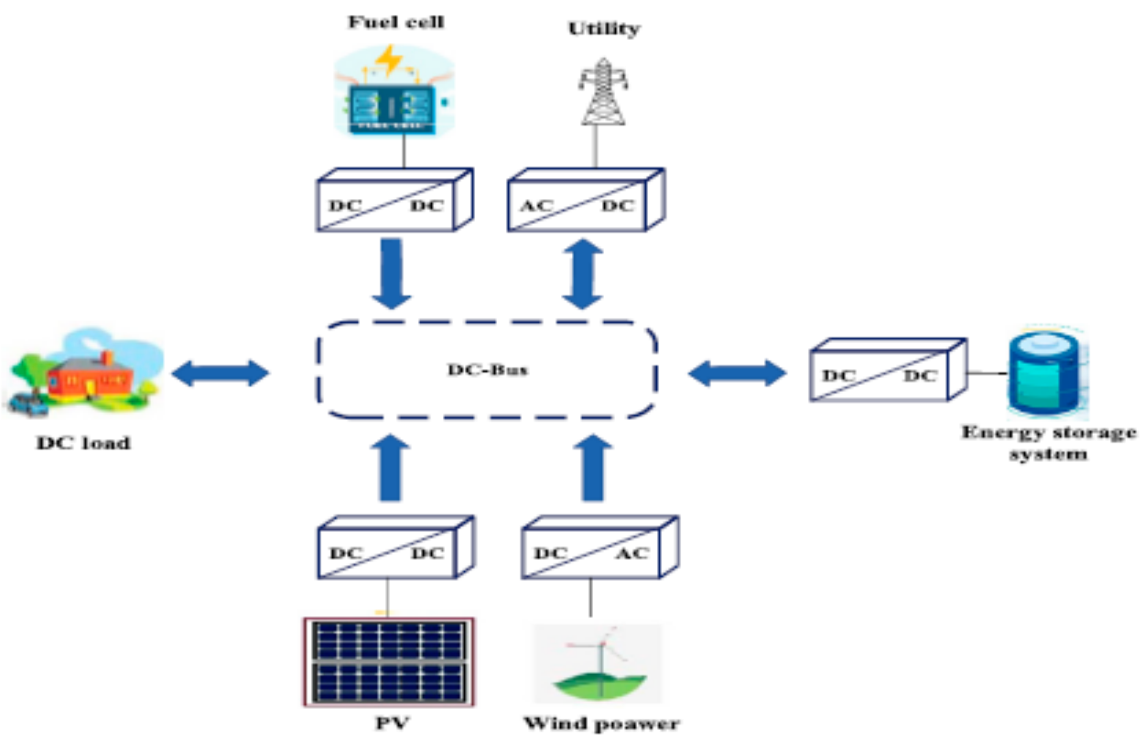

Figure 64: Case Study of Bidirectional Converter Connected to Renewable Energy System

Erik Martínez-Vera, Pedro Bañuelos-Sánchez1, Alfredo Rosado-Muñoz. Emphases on designing a bidirectional converter control used in electric vehicles (EVs), the designed model featured as step-up, step-down operation. Figure 65 shows the designed model.

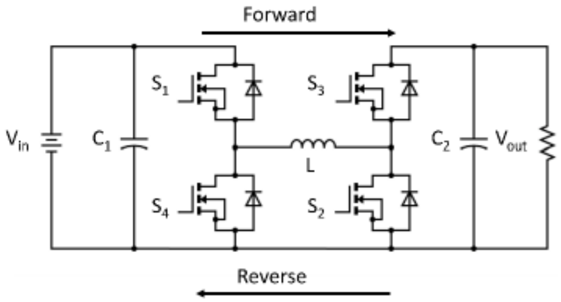

Figure 65: Proposed Bidirectional Converter

Researchers present the period of converter operation when it operates as buck (step down), boost (step up) according to how switches triggering as shown in TABLE VI.

TABLE VI. SWITCHING MODE OF POWER DEVICE

Mode	Direction	S1	S2	S3	S4
Buck	FW	s	0	0	0
Buck	FW	1	s	0	0
Boost	RE	0	0	s	0
Boost	RE	0	0	1	s

For regulating converter operation, a PID controller strategy employed to control switching of semiconductor device as shown in Figure 66.

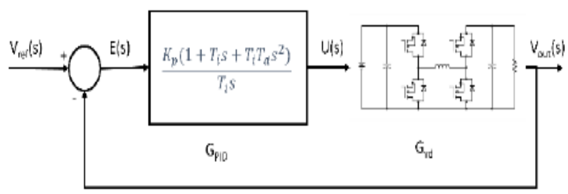

Figure 66: PID Controller Linked with Converter

Researcher at the end of work implement an experimental test for the circuit. using FPGA to validate the simulation results. From the final result researchers conclude that the converters have wide output voltage range facilitates efficient interfacing between the EV battery and the propulsion motor. Then the design includes wide bandgap (WBG) devices, enabling a high switching frequency of 500 kHz, which is not viable with traditional silicon (Si) devices. Increased switching frequency led to reduces the size of passive components. Control circuit uses independent PID control for both buck and boost modes, permitting power to flow in both forward and reverse directions. The control system's justification through Field-In-the-Loop (FIL) methodology accelerates algorithm development and offers a cost-effective alternative to traditional Hardware-in-the-Loop (HIL) validation [36].

CONCLUSION

Through this work a general and comprehensive review was presented for type of power converter (dc-dc converter) where this type permit to the power to flow in both side of it. It is used in in modern power system, electric vehicle, industrial application etc. This converter includes many kinds such buck-boost, full bridge, cuk as well as interleaved type. Each one has its own topology and operating principle. Different control strategy is achieved to regulate power flow of converter and enhance their performance related to efficiency and power quality. Most of the presented control strategy aimed to optimized the performance and reduce the conduction losses to earn higher efficiency. The conclusion must highlight/comment/discus the results presented in previous sections.

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