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Analysis of Back To Back (BTB) Converter Control Strategies in Different Power System Applications

Bandla Pavan Babu[1], Indragandhi V[2]

[1]ResearchScholar, [2]Associate Professor

[1,2] School of Electrical Engineering, VIT Vellore, Tamilnadu, India.

Abstract Power Quality (PQ) is an important term in many industries and other electrical power consumers. Maintaining of power quality during the operation of industries is an important task as the PQ issues may arise and cause the deviation in normal mode operation. In order to maintain the stability and mitigate the PQ issues, Back to Back (BTB) are mostly used in different power systems majorly in industries. This paper provides a major review on the BTB converters role in different power system configurations which are playing important role in facing the power quality issues such as voltage sags occurred in the system due to any faulty condition or short circuits, harmonic distortions, and some other abnormal conditions. Also in this paper, the various control strategies implemented in the BTB converter at their respective power system configurations are presented which will be helpful in developing the new methods or modifications in using BTB converters for power system applications.

Keywords- Power Quality, Power Quality issues, Back to Back (BTB) converter and Control Strategies.

1. Introduction

The Utilization of power converters has developed largely especially in industries such as generation systems, Uninterrupted Power Supplies (UPS), effective transmission of power between energy sources and also capability of fault tolerance. Generally, low quality of power may result in additional losses in power, change in behaviour of the machines in industries, abnormal operations (especially effect on voltage and frequency parameters), harmonic distortion, and possibility of interference in communication systems at the transmission lines etc. This results in the need of power converters in different levels of power systems for maintaining power quality with proper control strategies [1] .

Three phase AC/DC/AC which also comes under the back-to-back (BTB) converters are operated with a proper control strategies which are extensively used in Power and Industrial applications, especially for the control of Voltage in case of High Voltage DC Transmission (HVDCT), Electrical machines, Flexible AC Transmission systems (FACTS) and Unified Power Quality Conditioners (UPQC), and some other devices [2-3]. These BTB converters with the proper control strategies protect the system by avoiding the disturbances which effect on power quality. Also this BTB converter has a high demand in controlling the power quality issues like Voltage sags under faulty or short circuited conditions, Grid operating in weak conditions etc. This BTB converter topology utilizes DC link at its intermediate station for the process of power conversion i.e., from AC/DC/AC in addition to the other shunt connected filters at AC and DC side [4-6].

BTB converters of high power ratings are employed in industries, distribute the electrical power between the numerous power semiconductor switches. In order to improve the power quality, advancements in topologies of the BTB converters such as multi-level of voltage in the converter stations are made to enhance the redundancy, reliability, and for better voltage control [7]. With this multi-level, voltage stress, power losses, harmonic content at voltage and current waveforms can be reduced.

In BTB converters, another important property is the most often power flow manipulation and balance among the two stations (AC sides) by using a capacitor across the DC link. Dynamic Control strategies for processing the power provides stability more at the DC link which results in choosing a less sized capacitor across the DC link without any affect at the converter stations [8-11]. In BTB applications, mostly electrolytic capacitors are used across the DC link so that the life time of converters can be increased with its natural characteristics.

Finally in this paper, we are presenting BTB converters at different power system configurations and the major control strategies implemented at respective power system configurations such as the Pulse Width Modulation (PWM), Space Vector-Pulse Width Modulation (SV-PWM), Proportional Integral (PI) controllers are analyzed.

2. Basic Back to Back (BTB) Converter Configuration

In industries, 3-ϕ AC/DC/AC converters with adjustable Voltage and adjustable frequency operations have gained a broad application. Diode based Voltage source Inverter (VSI) is the most commonly preferred configuration for Uninterruptible power supplies (UPS), adjustable/variable speed drives and some other industrial utilizations. As shown in figure 1, it is one of the less cost and performs more reliable operation with the usage of diode rectifier. But the drawback is that in input line currents, this diode rectifier generates extreme distortions.
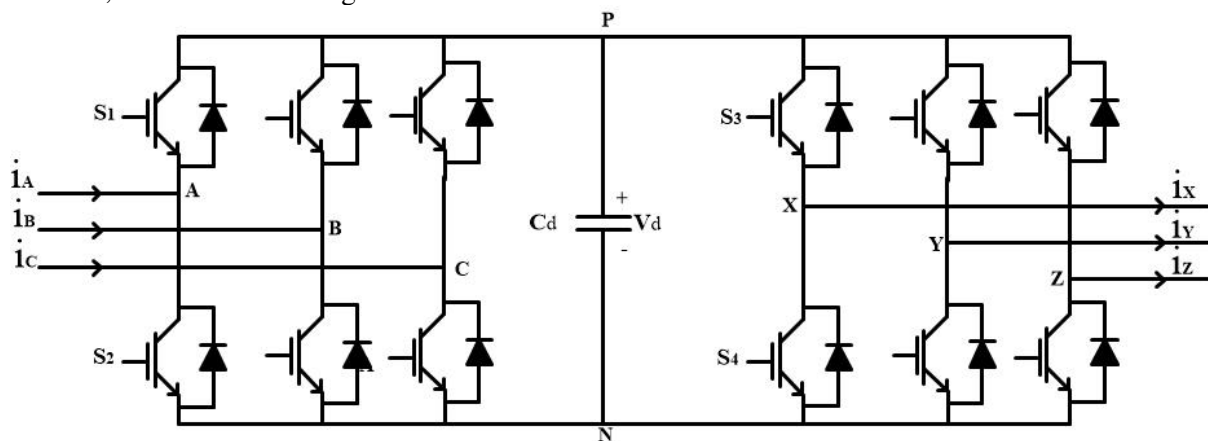

Figure 1. Three leg – Two level BTB converter
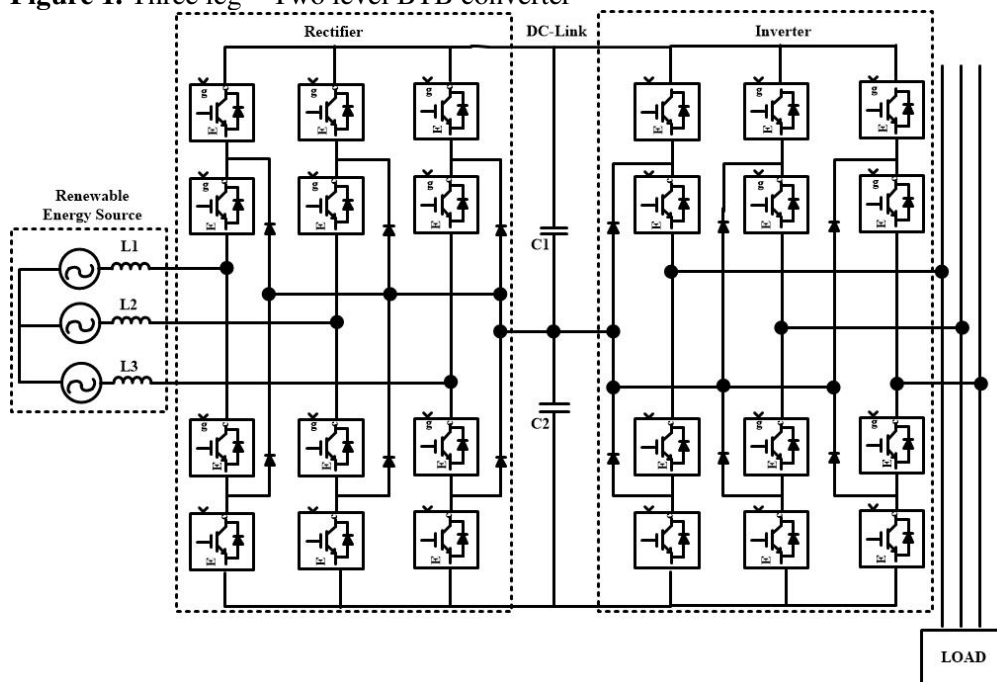
Figure 2. Three level BTB converter

In order to overcome this problem a Pulse width Modulation (PWM) based voltage source converter as shown in Fig.1, is used by replacing the diode rectifier. This BTB three leg-two level VSI lacks a twelve number of controllable switches i.e., Insulated Gate Bipolar Transistors (IGBTs) are used for controlling the voltage of higher ratings. Along with this, capacitor connected across the DC link responsible for increase in the effective operation of the converter in addition to increase in cost. Similarly figure 2, represents the three leg-three level BTB converter consisting of 24 switching devices (each converter station has 12 switches) for controlling the voltage with capacitors C_1 and C_2 connected across the DC link [1-2]. Various BTB configurations connected in power systems and their control strategies proposed are presented in this paper.

3. Back to Back Converter configuration in different power systems

3.1 *BTB in HVDCT System Configuration*

For many of the commercial applications, there are continuous growth in technologies especially in transmission techniques like HVDCT and FACTS. These transmission techniques has undergone many research and developments in the past few years and depended on the thyristors, controllable power semiconductor switches and other Voltage source converters (rectifier and inverter). Due to the increase in growth of the power semiconductor switches in the area of the power electronics, the full control over the voltage can be achieved even for higher operating levels as shown in figure 3. The major contribution of control over the voltage is due to the thyristors in the converters .i.e., either at the rectifier and inverter stations in case of HVDCT as shown in figure 4. There exist two type of converters which are mostly preferred i.e., Voltage Source Converter (VSC) and Current Sources Converters (CSC) in which the PWM is implemented at the Inverter end. VSC and CSC have the ability to withstand the sudden voltage and current respectively due to its inherent properties of the elements used in it [3].
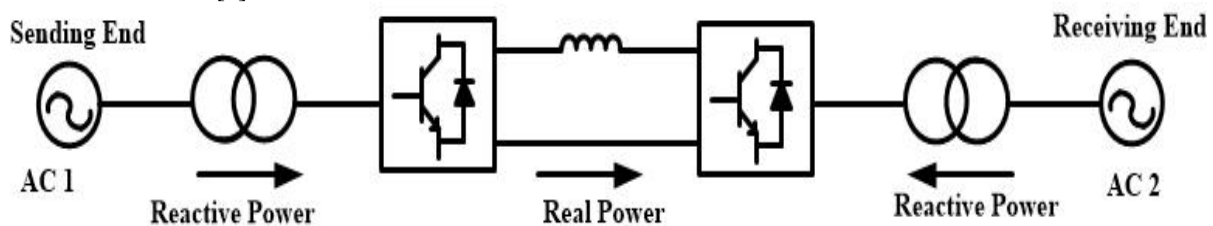
Figure 3. HVDC system based on VSC technology built with IGBTs.
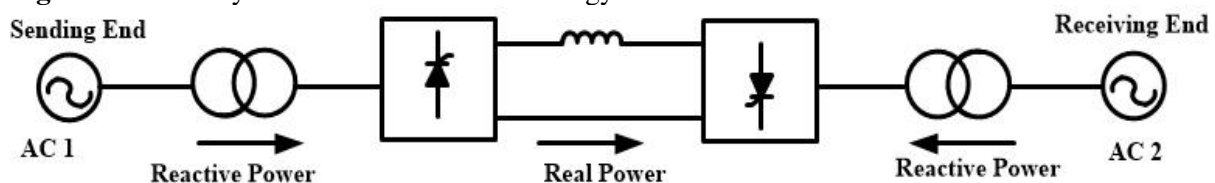
Figure 4. HVDC system based on CSC technology with thyristors.

With the use of Micro Grids (MGs), the overall effect on the environment can be reduced by exempting the use of fossil fuels for the meeting the power demand from the customers. These MGs consist of the distributed generations (DGs) which have a rapid growth in their developments will have distinct characteristics with respect to the changes in environment which are unpredictable. This leads to the cause of the power quality (PQ) issues which greatly affect the MG. An active power conditioner (APC) which consists of a three phase BTB converter as shown in figure 5, connected between the two MGs which enhancing by the PQ by limiting the disturbances/PQ issues at both ends. This APC can compensate the active and reactive power as per the dynamic behaviour of the MG and due to this APC has become a major part in the MGs [4-6].
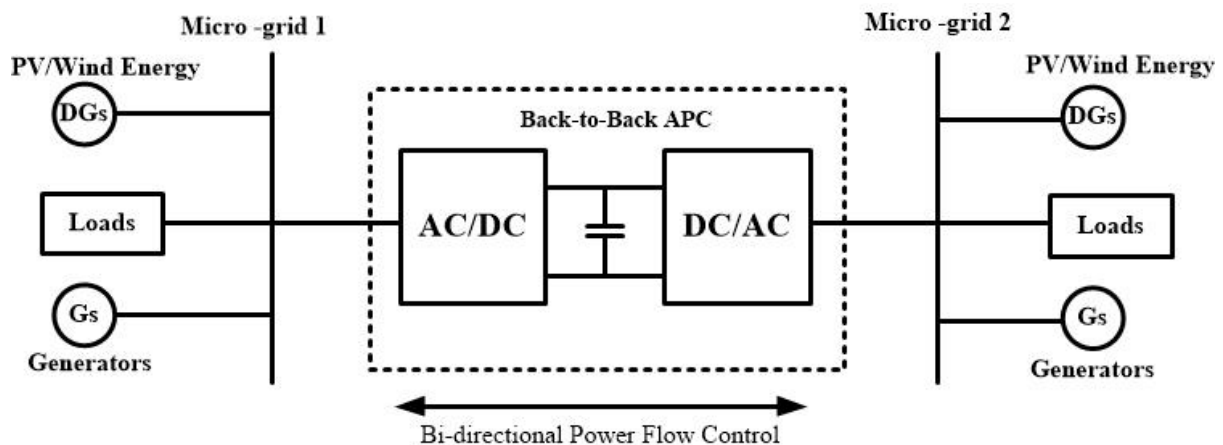
Figure 5. MG with BTB Active Power Conditioner.

3.2   BTB in flywheel applications

Nowadays on Electric Vehicles (EVs), a considerable research done recently. The evolution of robust and efficient propulsion is a fundamental task for the EVs facility. But, even though sophisticated engines and advanced electrical power trains exist, the main issue, the long-term energy storage, has not been resolved. In order to reduce the power density if the batteries, flywheels, super capacitors and their combinations are used. As shown in figure 6, the flywheel is split in to two levels of voltage over stator winding. Where Low Voltage (LV) side are associated to the battery and High Voltage (HV) side of flywheel allied to motor wheel. A bidirectional system exists which consists of two modes of operation i.e., acceleration mode (Battery-Wheel) and regenerative braking mode (Wheel-Battery).

The function of the flywheel in the mode of acceleration is basically to afford the power variant needed by motor wheel; hence the smooth operation can be performed by the battery. Whereas in the mode of regenerative, motor wheel functions as a generator and the flywheel will store the energy during this regenerative mode. In order to optimize and regulate the flux between these modes of operations, BTB converters which consist of the power electronic components mostly the fully controlled power semiconductor switches are used [7-9].
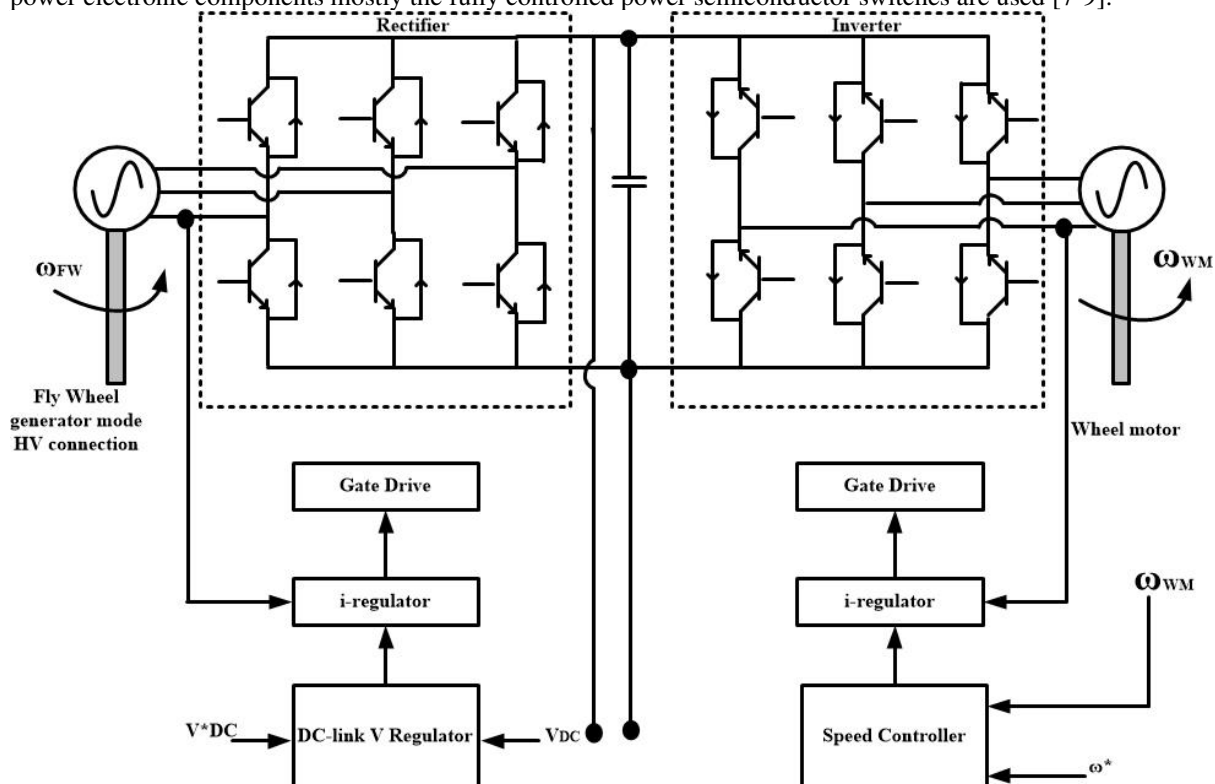
Figure 6. Acceleration mode of BTB Converter

3.3 BTB and Three Phase Induction Motor connected to a grid

In High power applications, multilevel based BTB converters are being mostly used nowadays. Numerous topologies have been used in multilevel converters (inverters) such as a flying capacitor (FC), Neutral point clamped (NPC) and cascaded H Bridge (CHB) types. With major combinations and modifications, a t-type BTB converter as shown in figure 8, is more effective than the other types of converters discussed. This T-type converter is used in industries where the most often used machine is the three phase induction motor so that the full control can be achieved with a medium switching range of frequencies [18-20].
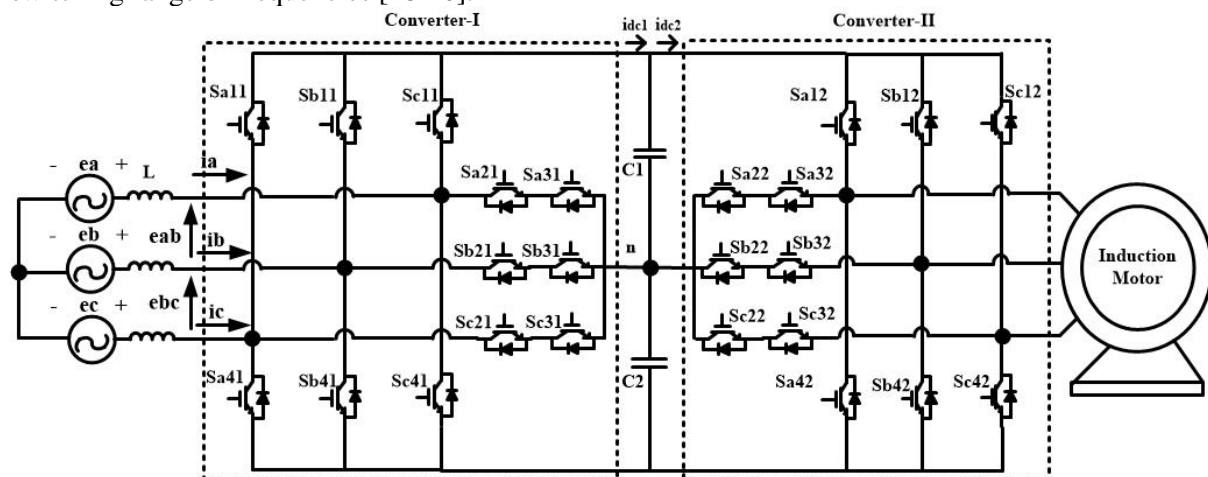
**Figure 7.** T-type three levels BTB Converter

3.4 BTB in Wind Power system Configuration

With the use of renewable energy sources such as wind energy systems for electrical power generation, the concept of stability is one of the important tasks. Due to the environmental conditions, the PQ issues like Voltage unbalance and dips may rise in the system which can be controlled by using the Power Electronic systems consisting of the BTB converters as shown in figure 8. This BTB Converter compensates the reactive power and active power which ultimately control the Voltage dips and unbalance caused in the systems due to the climatic changes in wind Power generation. A Local control level (LCL) filter as shown in Fig.6, connected at the VSC 1, used to limit the harmonics which are caused during the abnormal conditions [28-29].
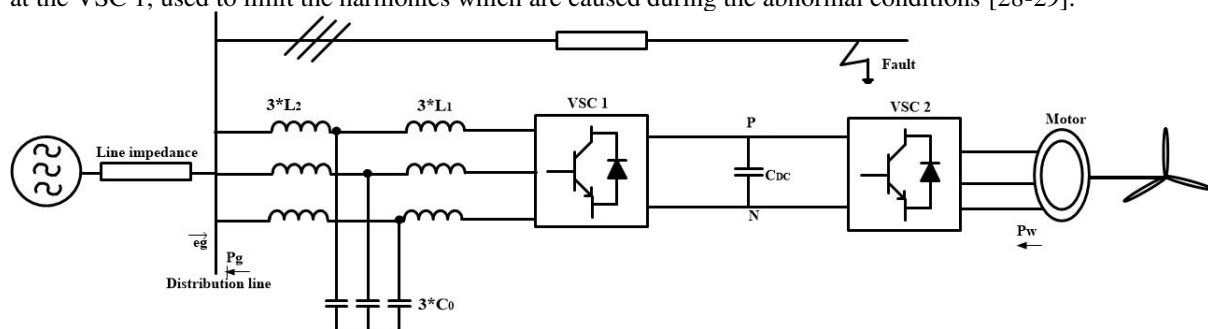
Figure 8. Back-to-back VSC connected to the utility distribution line

1.4 BTB and Double Fed Asynchronous Machines (DFAM) connected to a grid

In view of the sustainable energy sources development, the balanced usage of electrical energy signifies having the capability of network transportation for a long distance as well as to the storage plants which are adequate. Approximately most of the pump turbine groups functioning recently consist of Synchronous Motor-Generators (SMGs), working at the fundamental frequency and at constant speed. With the use of the variable speed MGs and especially by using the DFAM generators with a slip range of 0.1 to 0.15 around synchronous speed, the overall efficiency and performance of such groups can be effectively improved [30].

Some of the groups are equipped with the cyclo-converter cascade which are now replaced with BTB-3-level VSC (inverter) neutral point clamped (NPC). Regulating reactive power can be achieved with this type of

converter in the rotor cascade. Where as in case of the cyclo converter cascade there exists disturbances such as sub harmonics which are can be overcome by using the BTB converter as shown in figure 9.
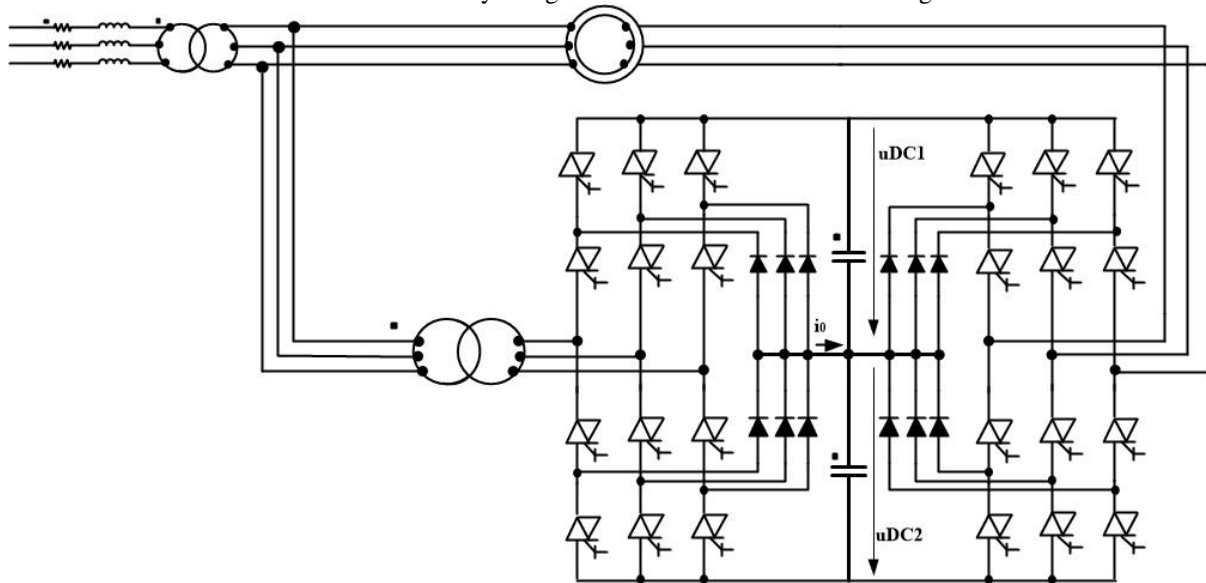
Figure 9. BTB-3 level rotor cascade supplying a DFAM

Table 1. Classification of BTB converter based on different level of control

Function	Converter Description	Area of Function	Control method(s)/ Control strategies	Reference
Voltage Control	3-phase 3-level VSC	Power Rectifier	space vector pulse width modulation (SVPWM)	[1]
Voltage balancing	3-level Neutral point clamped Converter	Inverter	Nearest-Three-Vector (NTV) Modulation	[2]
Voltage Control	Direct and Indirect Matrix Converter	DC-link	outer speed control loop and two inner current control loops	[5]
voltage control	3-Phase, 3-leg VSC	DC-link	optimal ac-line current regulation and dynamic dc-link voltage regulation (DDVR)	[6]
switching harmonic currents	3-phase 2-level VSC	DC-Link	optimal PWM shift angle	[7]
Harmonic Distortion	Three single Phase, 9-leg multilevel VSC	Inverter	SV-PWM	[8]
Voltage and Current	3-Phase, 3-leg VSC	Dc-Link and Inverter	linear multivariable	[10]
voltage control	Two 3-leg VSC	DC-Link	SV-PWM	[11]
voltage control and Harmonic Distortion	Grid Connected Converter	Dc-Link and Inverter	adaptive proportional integral (PI) controller	[12]
Voltage and Current	1-phase 3-leg CSC	Rectifier and Inverter	Cartesian space	[13]
voltage control	two single phase, 3-leg modules	DC-link	SV-PWM	[15]
Harmonic Distortion	two parallel, 1-phase 3-leg converters	Inverter	four-carrier PWM	[16]
Reactive power compensation	3-Phase, 3-leg,9-Switch VSC	PCC	closed loop proportional integral control	[17]
Oscillation	1-phase, X-type CSC	Dc Link	Pulse Width Modulation	[18]

voltage control and Harmonic Distortion	3-phase 4-wire, 3-leg VSC	Inverter	Pulse Width Modulation	[21]
voltage control	1-phase,3-leg VSC	DC Link	differential- and common current (power)-based state-feedback control	[22]
voltage control	single-phase four-leg VSC	DC Link	SV-PWM	[23]
voltage control	unidirectional neutral-point-clamped (NPC) leg and two bidirectional NPC legs VSC	DC Link	Pulse Width Modulation	[24]
voltage control	1-phase, 2-3leg VSC	DC Link	SV-PWM	[25]
voltage control and Harmonic Distortion	1-phase, 8-leg VSC	DC Link	SV-PWM	[26]
voltage control	3-phase 3-level NPC VSC	DC Link	DSP and FPGA	[28]
Reduces power losses and improves the efficiency of power converter.	5- channel, 3 L-NPC VSC	AC ends	variable speed pumped storage unit (VSPSU)	[29]

4. Classification of Back to back converter control strategies

4.1 3-level BTB Converter using Space Vector Pulse Width Modulation (SVPWM)
From [1], a new model of power rectifier circuit for BTB-3-level converter was proposed. The control is achieved at the DC link voltage by developing a control algorithm using MATLAB/Simulink. Along with this using dSPACE DS1104 board a prototype is developed. In this model, voltage and current distortions can be reduced by the converter. In addition to that DC link voltage can also be adjusted by this type of converter. From the power rectifier circuit results obtained from simulation by using SVPWM, the DC link voltage is controlled suitably and the distortions in current waveform can be reduced and hence overall performance in conversion of energy is done.

4.2 3-level BTB Neutral point Clamped (NPC) Converter
From [2], the limitations of NPC particularly, the control of current in order to balance the voltage was explained. This mathematical model applicable to converters operating with higher number of levels which is also very useful for the finding out the limitations of modulation techniques. Nearest three Vector (NTV) modulation techniques presented in this paper provides a better performance output voltage, Electro Magnetic Interference (EMI) and reducing the switching losses. All these issues are important especially while operating at higher ratings. Also this mathematical model helps in analysing the conditions such as balance during a stand-alone operation of 3-level Converter.

4.3 Micro Grids with BTB-Active power conditioner(APC)
For [6], MGs applications, a three phase BTB-APC with voltage control strategy across DC link were presented. Due to dynamic behaviour of the MGs,   the demand of active and reactive power compensation has been increased, which can be done by the BTB-APC. In this APC, two voltage regulation methods across the DC links are presented which improves the stability and power quality of the MGs. In this paper, regulation of ac line current method is capable of achieving the voltage regulation across the DC link at 60Hz frequency supply. Along with this it can reduce the variations of current in ac line.

4.4 9-leg BTB Converter using Level Shifted (LS) PWM
In [8], three phase BTB; 9-leg configuration was presented which consists of three 1-ϕ, 3-leg converter with three banks of DC link and shared legs without a circulating current and isolation transformer. SVPWM and LS-PWM methods are implemented to control the voltage across the DC link with proper developments made in PWM techniques. Along with this, a comparison of 9- level, 5-level and NPC configurations are also presented in this paper.

4.5 BTB LCL filter based Converter using state space model

In [10], a modern unified model and a procedure for controlling the BTB converter was presented in which all the interactions in dynamic nature between two ends of AC and at intermediate DC station particularly at capacitor are also presented in the form of state space. In a single linear model the BTB converter is presented in which the DC capacitor and LCL filters are together linked. In order to reduce the changes in the DC link voltage at the time of transients in active power flow, a linear Multi-variable control strategy was proposed in this paper. This strategy is also helpful to accurately control the real power flow. Even for the large variations, the size of the capacitor across the DC link has to be chosen large enough to overcome the variations and maintain the stability.

4.6   6-leg BTB Converter using SVPWM Technique

From [11], BTB topologies for the applications of non-regenerative which consist of two 3-leg converters with an equal voltage across the DC link which are in series connection are presented in this paper. In this proposed system, controllable switches, drivers and overall cost can be reduced. SVPWM at the inverter end and voltage vector redundancies across the DC links are presented in this paper.

4.7   Grid connected BTB converter using adaptive proportional integral (API) controller

In [12], an anti-windup API controller based voltage controller across the DC link is proposed. With the proposed API controller, a fast dynamic response after step rise of input current and dc link voltage can be obtained. Along with this after step rise there will be no overshoot across DC link voltage and less THD under low grid current while performing the stable operation.

4.8   3-leg BTB Converter series connected H-Bridge using SVPWM

From [15], two 3-leg converters which are connected in series with H bridge converter are investigated. This is formed by the single phase BTB multilevel converter of high power ratings. SVPWM strategy is used in this proposed model which is capable of reducing the switching losses, stress in switches and harmonic distortions. Along with this, it can also reduce the lower voltages across DC link and voltages are generated with more steps.

4.9   4-leg BTB Converter using universal active power filters (UAPFs)

In [23], based on single phase, 4-leg BTB converters, two UPAFs topologies are proposed for performing the compensation as well as mitigating the disturbances in the current which are caused by the loads (nonlinear) and power supply voltage disturbances. With the proposed topologies, Total Harmonic Distortion (THD) can be reduced wherever required and also can lower the average frequency of switching.

4.10   Transformer based 3-leg BTB converter using SVPWM

In [25], single phase BTB topology for UPQC and UPS applications are proposed which comprises of transformer and a 6 level converter (termed as 6LT). This 6LT allows power supply with a constant voltage and frequency to the load connected. It also improves the power factor by lowering the Harmonic Distortion and the losses in semiconductor switches.

4.11   3-leg,3-level BTB Neutral Point Clamped (NPC) Converter

In [24], unidirectional single phase 3 level NPC converter is proposed. This proposed converter has less in number of power semiconductor switches than the traditional converters. By using Current control loop and Phase locked loop (PLL), the utilization and its synchronization method was simulated in this paper. Between the voltage and current for synchronization at the grid, the PWM strategy depends on the direction of the current flow on the voltage synthesis. With the use of diodes which not only reduces the numbers of controllable switches but also results in less in drive circuits. This leads to reduction in complexity of the configuration.

4.12   BTB Electric Railway Application

From [27], 3-ϕ to 1-ϕ BTB topology based on multi converter is proposed, which can enhance the quality of power in electrified railways. Flexibility in control at the inverter helps in removing the neutral sections which also helps in removal of negative sequence components (currents) during the abnormal operations. With the use of H-bridge based BTB converter, control actions can be easily performed and neutral drift problem can be overcome. At the rectifier station, PWM and DC voltage control results in control of unbalanced voltage. By comparing the traditional power system at the tractions, the solution of mitigating the power quality problems can be identified.

4.13   BTB Neutral Point Clamped (NPC) Converter in Wind Turbines

In [28], BTB converter is divided in to two subsystems which are interred operating. Those are power electronic and control systems. In the first subsystem, thermal components study, filter components in grid, passive

components design, capacitors at DC bus and assembly of converter are discussed. Whereas in second sub-system, coordination between the processors are discussed.

5. Conclusion

This paper presents the overall review and discussions of the BTB converters at different power system configurations. Also numerous converter control strategies which are implemented at various stages in order to control the system from any disturbances such as voltage unbalance, voltage dips, ripples, DC link voltage variations and harmonics etc. Along with the discussion of implemented various control strategies, Classification of BTB converter based on different level of control were listed in this paper which will be helpful in in developing the new methods or modifications in using BTB converters for power system applications.

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