CONTROL AND FUNCTIONALITY OF A DC POWER ELECTRONIC TRANSFORMER BASED ON SERIES CONNECTION OF FULL-BRIDGE CONVERTERS

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ABSTRACT

For trains, AC/DC mixture framework and other isolated medium voltage and high-power applications a cunning DC power electronic transformer (DCPET) geography is proposed. Differentiated and customary PET topography, the proposed scatter has less power semiconductor contraptions and high detachment transformers which can additionally foster the power thickness and steadfastness. Inadequacy dealing with or clear tedium design can be achieved to moreover additionally foster the limit when some DC module discrete. Further more input voltage sharing control (IVS) can be disregarded to only the control framework and work on the strength. Meanwhile, devote trading is harmed for all of the switches, which is valuable to augment trading repeat and further foster power thickness. In this paper the rules progression and control of the proposed DCPET independently presented and focused on thoroughly. Finally, a model of the proposed DCPET is manufactured and exploratory results affirm the authenticity and transcendence of the proposed geology.

1. INTRODUCTION

Power electronic transformer is a sort of force change gadget with the properties of high rehash, bidirectional power stream and electrical division considering power contraptions improvement, which can likewise be named solid areas for as transformer (SST) as of late PET is widely utilized in AC/DC half and half association, DC spread framework, new equilibrium converter for train which is customary named as power hardware foothold transformer PETT the different necessities of the power change there are many streamed planes of PET for models AC,DC, AC/DC and DC-AC. With the exemption of AC structures, other streamed plans of PET routinely contain a DC stage. The DC stage is utilized to accomplish DC voltage change, bidirectional power stream and high rehash and electrical separation, which can be viewed as the point of convergence of PET. Consequently, the DC time of PET can likewise be named as DC PET.

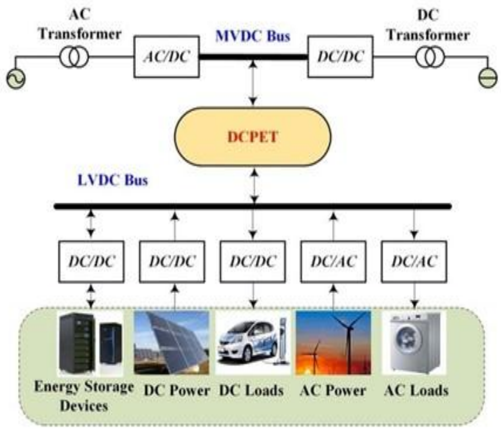

Fig. 1.1 Common construction chart of the DC dissemination network in view of DCPET

Taking a state-of-the-art DC dissemination lattice as a model, a DCPET is supposed to completed to Change for the voltage DC (MVDC) move the low voltage DC (LVDC) transport. In Fig. 1.1, when DC loads, energy limit gadgets and appropriated power induction to LVDC transport, a solitary separated change to see the essential to meet solicitations. In any case, there is a more prominent neighborhood MVDC transport and LVDC transport, a solitary isolated DC change to be stayed aware of to be fulfilled due to the limitation of the voltage stress of the switches. MVDC applications is a sort of data series yield equivalent same (ISOP) DC converter, which has been fundamentally inspected and scattered. ISOP detachment and fundamental activity, yet with the reaching out of the voltage and a power level, 5 different DCDC

modules are required. Accordingly, different medium or high repeat transformers and power semiconductor contraptions will be applied and the demonstration of DCPET, like drive thickness, cost and reliable quality won't be moreover moved along. To lessen how much transformers, a three-level DC converter is utilized to dislodge two modules. In any case, how much transformers basically can be lessened extensively. To moreover dimmish how much transformers and switches, the shocked development and switches-series plot, for these plans, simply a solitary transformer is required. In any case, staggered converter and equilibrium activity of series switches 3 in high recurrent states are explicit bottlenecks.
Simultaneously, a DCPET with an ISOP structure has less elements to sidestep dissatisfactions and to offer clear overt repetitiveness. That is, precisely when a dc module separates, on the off chance that this module can't be stayed away from right away, the by and large DCPET construction will stop working. To keep away from this issue, aby-pass change should be applied in concurrent with the DC input capacitor of every single Dc module. Notwithstanding, when the Dc input capacitor id dodged, there will be a hindrance is utilized to be series with the by-pass change to control the flood current. Precisely when the voltage and power level are high, the expense and loss of opposition.

In addition, DCPET with ISOP structure in this way has an issue of force balance. To accomplish power concordance of the DC modules, an information voltage sharing (IVS) control technique ought to be applied. The associate control circle will make by and large control system more mind powering and the last yield variables of the regulator for every DC module will be remarkable, which will not just lead irregularity of each DCPET module yet additionally dimmish the fearlessness of the control framework. Taking into account the examination presented in advance, an extraordinary DCPET geography is proposed further.

As a matter of fact, decreased at a similar voltage level, which could increment any power thickness and further encourage reliability. Besides, the execution of shortcoming managing and obstacle is improved, which can make DCPET more solid even the sub-modules are unique. Moreover, by utilizing this geography, IVS control strategy isn't needed on account of the voltage self-changing brand name and as such control circle will be furthermore streamlined. This paper is created as follows: District II presents the essential DCPET topography. The standard and qualities of this geography are dismantled thoroughly. Locale III conversations about the progress of the principal topography. Several subordinate geographies are proposed and examined, which can be utilized for different applications. Area IV proposes the control strategies of the referred to DCPET geologies, which on a very basic level covers the voltage besides, power control strategy and issue dealing with methodology. Region V affirms the authenticity of the proposed DCPET geology and the control framework by tests. Fragment VI makes an examination between the proposed geography and the current geographies. At length final, Segment VII final this paper is utilized to move energy among ports and detach all ports from one another. In this bidirectional geography, each port is taken as an info or result. Every module comprises of three fundamental parts, including modulator, demodulator, and high-recurrence disengagement transformer (HFIT). The modulator is a dc-ac converter and the demodulator is an air conditioner ac converter; both with bidirectional power flow capacity. Every module operates independently and can move power between ports. These port scan have a wide range of qualities, for example, voltage level, frequency, stage point, and waveform. Therefore, FPET can satisfy practically any sort of utilization, which are wanted in power electronic transformation frameworks and address future issues of electricity organizations. By taking this point into note, it is named flexible. The re-enactment consequences of high-voltage application are given.

2. BASIC TOPOLOGY AND PRINCIPLE

A. Fundamental Geography

The basic plan of the proposed dissipate topology is shown in Fig. 2.1 involves two segments: voltage-changing stage what's more, disconnected change age. The voltage changing stage is a n+1 level stage changing converter VBC because they are in series capacitors and in half-flatforms conceivable yield voltages of the VBC. Isolated change stage is a data series yield equivalent converter with in isolated bidirectional DC converters in figure 2.1 there are n DC capacitors there are n DC capacitors (C_{i1}, C_{i2},…, C_{in}) in series

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beginning to the end, which are related with MVDC transport P_p-P_n, and these capacitors are filled in as the data DC capacitors of the IBDCs.

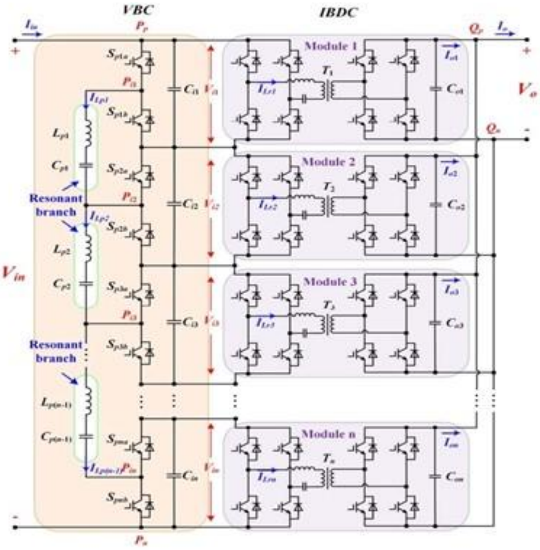


Fig. 2.1. The basic structure of the proposed DCPET topology

There are likewise n DC capacitors (Co1, Co2, … , Con) in same, which are connected with LVDC transport Qp-Qn, and these capacitors are filled in as the result DC capacitors of the IBDCs. In the voltage-changing stage, n exchanging ranges (Sp1a, Sp1b), (Sp2a, Sp2b), … , (Spna, Spnb) are in series among Pp and Pn. (n-1) reverberating branches (Lp1, Cp1), (Lp2, Cp2), … , (Lp(n-1), Cp(n-1)) contain resounding with the midpoint of exchanging ranges (Pi1-Pin). The n+1 level VBC can assist with achieving conditions. In the disengages change stage, the geography past or new arrangement. Without loss of understanding, a full-length DC converter is picked as the IBDC in Fig. 2.1. transport Qp-Qn, and these capacitors are filled in as the result DC capacitors of the IBDCs. In the voltage-evolving stage, n exchanging ranges (Sp1a, Sp1b), (Sp2a, Sp2b), … , (Spna, Spnb) are in series among Pp and Pn. (n-1) resounding branches (Lp1, Cp1), (Lp2, Cp2), … , (Lp(n-1), Cp(n-1) contain reverberating with the midpoints of the exchanging ranges (Pi1-Pin). The n+1 level VBC can assist with achieving conditions. In the detaches change stage, the geography past or new arrangement. Without loss of understanding, a full-length DC converter is picked as the IBDC in Fig. 2.1.

The HFIT of each and every unit module used in a SST structure ought to each have restriction credits that cover more than the edge of the MVAC input voltage level. Since each unit module has a plan including a HFIT and the volume required by the HFIT is high, restricting the application with HFIT for downsizing of the SST framework is critical. As shown in Figure 1a, by virtue of a development wherein a climate control system/DC converter and a Spot converter are participated in a 1:1 extent, it is the disadvantage that anyway numerous HFITs as the amount of unit modules thought to be used.

It should be figured to the topography in Fig. 2.1 is just a fundamental DCPET size. Considering the central topography, other few modified geology can be also induced on the other hand changing the amount of IBDCs as shown by different essentials, but somewhere near one IBDC should be saved. At the point, when some IBDCs are cleared out or or on the other hand potentially, how much IBDCs is humbler than the information DC capacitors, the voltage agreement will be guaranteed by VBC. Thus, the remainder of the IBDCs can in any case work at an evaluated voltage. This improvement can help on a very basic level decrease how much disengaged transformers and switches. In the interim, precisely when an IBDC issue, we can straight forwardly catching the drive beat of the obliterated IBDC to make by and large PET framework proceed with routinely working and with basically no by-pass switch or various gadgets. At last, in light of the voltage self-changing brand name, IVS control philosophy can be discarded and the control construction will be also gotten to a higher level. The recently referenced attributes will be investigated thoroughly following locales.

B. Voltage-Balancing Converter (VBC)

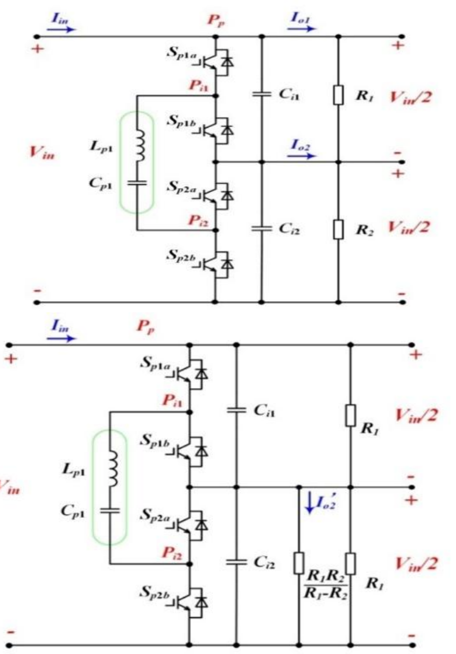
For the proposed DCPET geology, VBC is utilized to guarantee voltage concordance of the data series DC capacitors, and is moreover filled in as an issue dealing with device. Nowadays, the non-detached voltage-changing approaches are for generally part utilized for battery charging. In this paper, a resounding VBC is proposed in Fig. 2.1. For this converter, n exchanging ranges: (Sp1a, Sp1b), (Sp2a, Sp2b), …, (Spna, Spnb) are in series with the MVDC input voltage. The boisterous branches which are produced using blasting inductors and capacitors: (Lp1, Cp1), (Lp1, Cp1), …, (Lp(n-1), Cp(n-1)) are progressively associated with adjoining midpoints (Pi1-Pin) of the exchanging ranges. The drive beats of

VBC are fixed and open circle control is applied. In exchanging period, the condition of the drive beats is kept in TABLE I, where 1 tends to turning on the switches and 0 tends to turning off the switches.

TABLE I
THE DRIVE PULSES OF VBC

TIME	S_{p1a}, S_{p2a},………, S_{pna}	S_{p1a}, S_{p2a},………, S_{pna}
0-0.5T_s	1	0
0.5T_s-T_s	0	1

For assessment, a three level VBC is considered to show the working rule. The topography frame is shown in Fig. 2.2(a). Resistive weights R1 and R2 are independently related with DC capacitors Ci1 and Ci2, which can be seemed, by all accounts, to be as the DC modules. Right when R1=R2, the voltages of Ci1 and Ci2 are same. Exactly when R1 ≠ R2, the voltages of Ci1 and Ci2 will be one of a kind. By utilizing the VBC, the voltage concordance can be accomplished again Concerning the three level VBC, acknowledge that R1 > R2, the essentially indistinguishable topography format can be displayed in Fig. 2.2(b).



(a)

Fig. 2.2. The topology diagram of a three level VBC. (a) The basic topology diagram of a three level VBC. (b) The equivalent topology diagram when R1>R2

3. TOPOLOGIES EVOLUTION

In this manner, in Fig. 5.3 (Fig. 2.1 shows the crucial novel DCPET geography. As alluded to above, tolerating some IBDCs are dropped, because of the voltage self-changing constraint of the VBC, the voltage of all the series DC capacitors can keep balance. In the interim, the remainder of the IBDCs can notwithstanding work at evident voltage. Taking into account this beginning, we can pick numerous IBDCs to conclude different geographies as per the various necessities. A for the most part standard derived topography is displayed in Fig. 3.1.

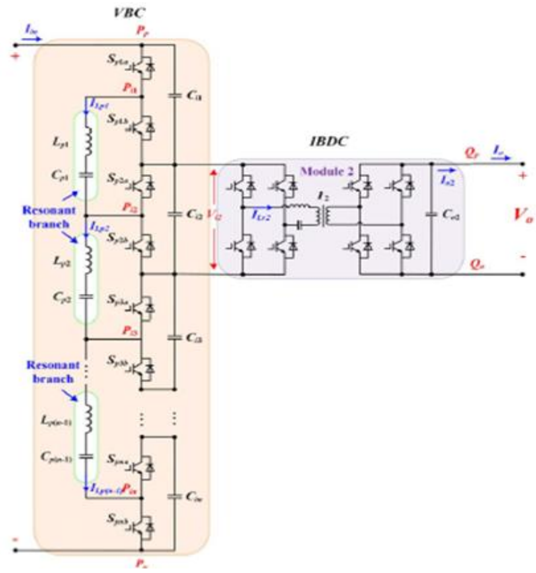


Fig. 3.1. A typical derived geography when k=1

In Figure. 3.1, the quantity of IBDC (k) diminished to one and any DC capacitor can be chosen as the information capacitor of this IBDC.

Concerning the geography in Fig. 2.1, assume the evaluated input voltage of PET is V_{in} and the evaluated power input is P_n, then the appraised input voltage of each IBDC is in $\frac{V_{in}}{n}$ the appraised input current is in $\frac{P_n}{V_{in}}$. Concerning the geography in Fig. 3.1, in particular one IBDC is utilized and this DC module will deal with full info power P_n. Since VBC can keep voltage balance constantly, the evaluated input voltage of this single DC module is still $\frac{V_{in}}{n}$. Inside the outline of proposed transformer, the cover situated between the channels of the anode has a high dielectric consistent, and the potential contrast is high at the level of the framework voltage

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level, causing an undesirable high parasitic capacitance. The level copper plate made a fairly high difference, so a roundabout Litz wire is utilized for both the essential and optional windings. EE centre and Shell-type structures are utilized to accomplish low spillage inductance. The winding construction diminished the quantity of segments and expanded the quantity of columns. In this manner, a level electric field dispersion between the high and low voltage conduits is guaranteed and the MMF is likewise decreased. Primary separation is gotten utilizing three sorts of Teflon bobbins. The inward bobbin for winding the low voltage windings protect between the centre part and the low voltage twisting part. An external bobbin that breezes the high-voltage windings protect between the high-voltage and low-voltage windings. The centre gatekeeper protects between the high-voltage windings and the centre. The transformer has three information ports with an exchanging voltage of ±1000 V. To guarantee a reasonable inductance between every essential winding and optional winding, a bifilar winding strategy is applied to the essential side. Be that as it may, the likely contrast of up to 6 kV happens between the layers in the principal twisting part because of the bipolar winding design. Besides, high-recurrence exchanging debilitates the dielectric material breakdown voltage. Consequently, interlayer protection is guaranteed by utilizing Litz wire impregnated in the adaptable protecting cylinder and electric field results are displayed.

EtherCAT Slave Regulator (ESC) is expected for the association between Ether CAT correspondence and MCU. ESC is carried out as FPGA or ASIC or as firmware in a sub processor incorporated into the fundamental processor. In this paper, Beckhoff's ET1100 ASIC ESC is utilized for information trade between Ether CAT correspondence and micro controller unit (MCU). The ET1100 and MCU trade information utilizing an outside memory interface (EMIF) or a sequential fringe interface (SPI) as displayed in Figure 3.1. For this situation, since a specific measure of time is expected to send and get information, there is a breaking point for single-centre MCU to perform both Ether CAT correspondence and a confounded control calculation inside a fast correspondence cycle. To steadily control a SST framework made out of various unit modules, correspondence of a high transmission speed is required, and adequate computational time should be guaranteed since a confounded control calculation activity is required. In this way, on account of utilizing a multi-centre MCU, both high velocity correspondence cycles and convoluted control calculation execution can be accomplished by purposefully isolating the Ether CAT correspondence process and the control application process. By utilizing TI's TMS320F28379D double centre DSP, CPU1 performs EtherCAT correspondence and different calculations, and CPU2 plays out the control calculation to guarantee adequate computational time in this paper. Figure 3.1 depicts the equipment construction of the unit module regulator applied to the model of the SST framework.

4. CONTROL STRATEGY

Concerning the topography in Fig. 2.1, accept the assessed input voltage of PET is Vin and the assessed input power is Pn, then, at that point, the evaluated input voltage of each IBDC is in Vn the evaluated input current is in In.

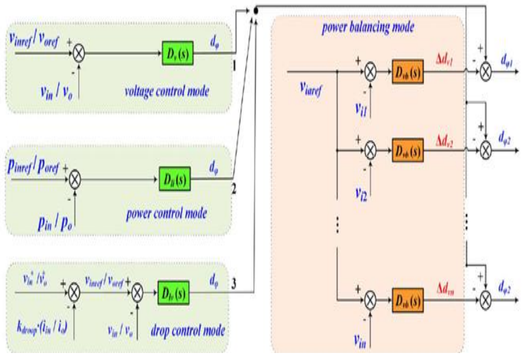


Fig. 4.1. The basic voltage and power control diagram for the conventional PET with ISOP topology

Concerning the geology in Fig. 3.1, specifically one Vn. IBDC is used and this DC module will manage full data power Pn. Since VBC can keep voltage balance continually, the assessed input voltage of this single DC module is still Vn additionally, subsequently the assessed input flow of the IBDC is n in, which is ‘n’ times of the topography in Fig. 2.1. Disregarding this, the topography in Fig. 3.1 can actually decrease amount of transformers and power semiconductor contraptions in isolated change stage, which can help with lessening cost, further foster power thickness and reliability. In the break, the business power semiconductor device, for instance, IGBT, is available with high assessed current what's more, the switch equivalent advancement is similarly strong, which satisfy the essential in high-current stage. Fig. 2.1 and Fig. 3.1 simply exhibits two plans of k=n and k=1. In feasible use, the extents of IBDCs can be voltage consistent yet in addition to accomplish power equilibrium, all things considered. In those circumstances, the information and result voltage reference worth can be expressed as follows

$$\begin{cases} V_{inref} = V'_{in} - k_{droop1} \cdot I_{in} \\ V_{oref} = V'_o - k_{droop0} \cdot I_o \end{cases} \quad (6)$$

$$V_{inref} = \frac{V_{i1} + V_{i2} + \cdots + V_{in}}{n} \quad (7)$$

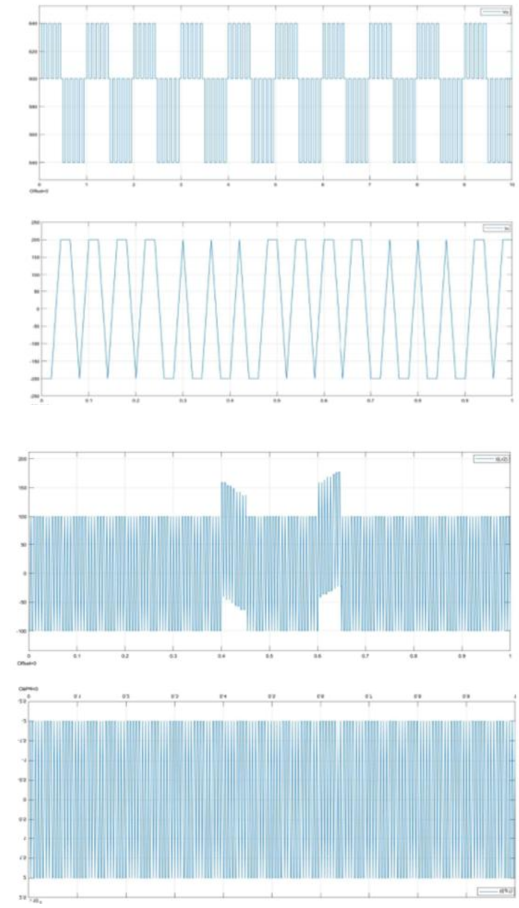
Thus, the final control value of every DC-DC module can be evaluated as

$$d_{\varphi j} = d_{\varphi} - \Delta d_{\varphi j}$$

Where V'_{in} and V_o are the appraised worth of information and result voltage. With various control goals, 3 control stages can be picked unreservedly.

In any case, the information voltages of every DC module are connected with their own control variable as well as connected with other DC modules control factors, which is somewhat hard to plan a legitimate regulator. Moreover, the dependability of the control framework will be impacted by utilizing IVS control procedure. Also, the last result control variable is normally unique as a result of conflicting boundaries of every DC module, which might lead unequal current pressure of IBDCs. Notwithstanding which control mode is used to ensure the power balance of the DC modules in a PET, a power-changing control system is fundamental.

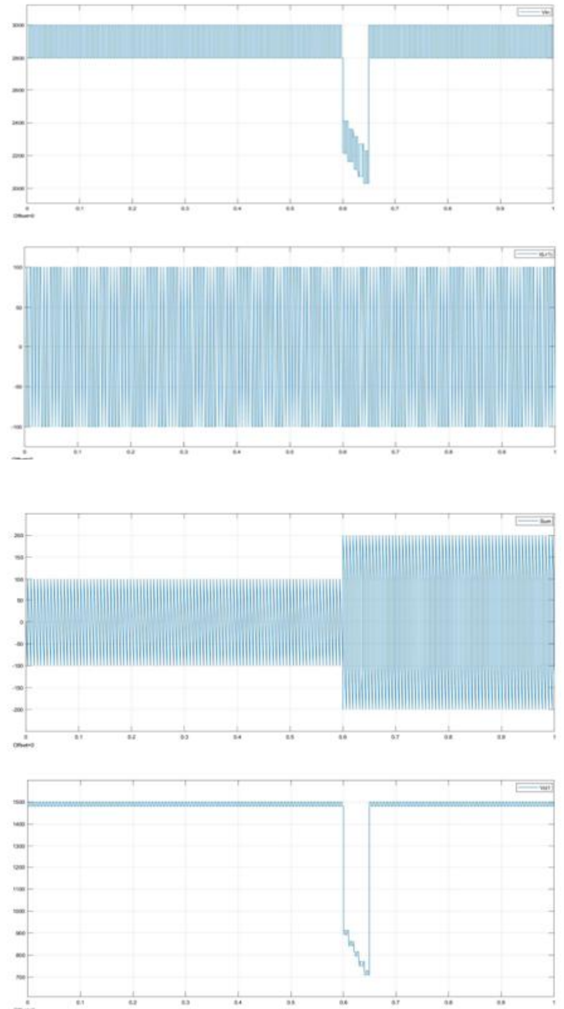
For ISOP converter the power balance should be assured by using input voltage sharing (IVS) control strategy. The right 50% in Fig. 4.1 is the control chart of IVS control philosophy. The data voltages Vi1, Vi2 ,… ., Vin of all the DC modules are independently differentiated and reference regard Viaref and the changed control factors as coupled system for IVS control technique, which is somewhat difficult to design a genuine controller. Additionally, the trustworthiness of the control structure will be impacted by using IVS For the proposed novel PET geography, on the grounds that VBC is applied, input voltage self-equilibrium can be ensured. In this manner, IVS control methodology can be dropped and just the three control modes are held, which will work on the dependability of control framework and improve on the plan strategy. To investigate the control qualities, a reproduction stage is fabricated. The fundamental circuit boundaries are recorded in Table II yet the information appraised voltage is 3000V, the external evaluated voltage is 600V, and the evaluated power is 150kW, which is utilized to reproduce the commonsense application. The geographies are 3-level VBC + 2 LLC RCs (n=k=2) and 3-level VBC + 1 LLC RC (n=2, k=1), which are separately displayed in Fig.5.1 and also in



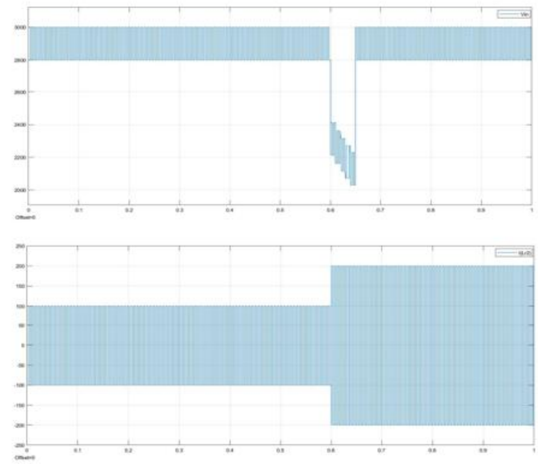
(b)

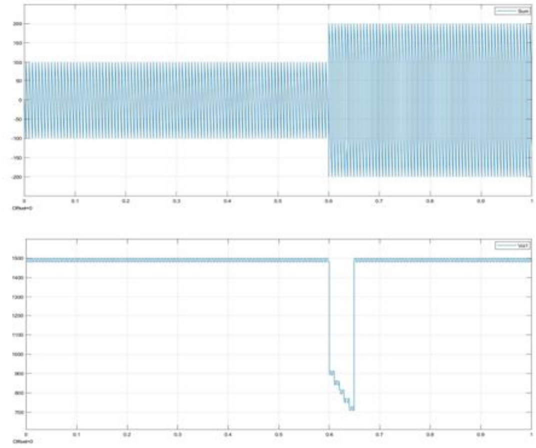
Fig. 4.2. The simulation waveforms of the two topologies when the power flow changes from forward rated power +150kW to backward rated power -150kW. (a) 3-level VBC +2 LLC RCs (n=k=2) (b) 3-level VBC +1 LLC RCs (n=2, k=1)

The simulation waveforms when the MVDC voltage is controlled by DCPET are shown in Fig.4.3. it can be found that MVDC voltage kept constant and the voltage balance of C_{i1} and C_{i2} can be guaranteed, which verifies good control characteristics of the proposed topology.



(a)





(b)

Fig.4.3. The simulation waveforms when the MVDC voltage is controlled by DCPET. (a) 3-level VBC +2 LLC RCs (n=k=2) (b) 3-level VBC +1 LLC RCs(n=2, k=1)

5. CONCLUSION

This paper proposes a sharp DCPET geology, which can't achieve power change between MVDC and LVDC transport, still what's more be used in ACPET geology as a high-repeat change stage. The characteristics of this geography are as
per the accompanying:
1) Additionally, also decrease costs, further poster power thickness and steady quality.
2) The DCPET can continue to work when some DC modules isolated and doesn't need other issue avoid devices, which can chip away at the limit of deficiency dealing with.
3) IVS control can be neglected to chip away at the control structure and further foster the control strength.
4) The DCPET can achieve fragile trading for all of the switches, which will help increase trading repeat and further foster thickness. Geology will make heads or tails of the special case of these models, the proposed DCPET.

FUTURE WORK

For making control system of every module of DCPET consistent and stable in final output, the auxiliary control loop of the overall control system should be made easier to be analysed.

In DCPET with ISOP structure, issues of power balance should be minimised.

With the recent advancements of soft magnetic core materials and switching devices, the replacement of conventional line recurrence transformers and the power transformers

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outline used in power electronic converters will have to be examined and its solicitation areas, operating frequency values, core material types are investigated and classified further.

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