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Design and Implementation of Three-Terminal and Five-Terminal Hybrid AC/DC Micro Grid with an Improved Grid Current and DC Capacitor Voltage Balancing Method

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ABSTRACT- Micro grid structures allow more efficient utilization of renewable energy resources as well as for autonomous operation such as small scale distributed generators. A three terminal hybrid AC/DC micro grid with two DC terminals and one AC terminal and a similar five terminal micro grid are proposed in this paper. The projected system consists of cascaded H-bridge (CHB) converters based mostly AC grid interface and 2 twin active bridge (DAB) converters based DC sub grid interface that connects 2 isolated DC buses. In order to decrease the number of power conversion stages and power devices, the DAB converters are directly connected to CHB DC rails according to the system operation requirement. To beat the unbalanced grid currents and DC rail voltages caused by this changed system configuration with solely 2 power conversion stages, AN improved technique is projected through zero sequence voltage injection and therefore the voltage or current regulation of the system, impacts of the control parameters to the system stability and dynamic responses are investigated. Analysis results from each three terminals and five terminal hybrid AC/DC micro grids shows generalized effectiveness of the projected 3 phase AC current and DC rail voltage leveling technique.

Keywords: Three terminal hybrid AC/DC micro grid, five terminal Micro grid, voltage balancing, Grid currents, voltage sags.

I. INTRODUCTION

Because of growing applications of DC distributed generations like photo voltaic (PV) panels or fuel cells and increasing DC loads (ex. electrical vehicles), hybrid AC/DC micro grid has attracted sizeable attention in recent years [1]-[6]. Such a hybrid AC/DC micro grid contains AC/DC loads and distributed generations (DGs). It has strict benefits, like direct renewable energy integration, versatile power flow and regulation, mutual support between DC and AC sub-grids. As a result, it's thought of united of the foremost enticing configuration for future sensible power distribution systems [7]-[10]. Compared with freelance AC or DC micro grid system, AC/DC loads or DGs is directly connected to the several AC/DC sub-grids to scale back hardware price of power converters [11]. Hence, the system reliability and efficiency are improved [12]-[13]. Considering these advantages, hybrid AC/DC micro grid is the foremost promising micro grid structure within the future.

The traditional hybrid AC/DC micro grid embrace one AC bus and one DC bus [1], [2], [11], [13]. The AC and DC terminals are integrated by three-phase bidirectional AC/DC converter. The AC terminal is connected to the low-tension utility grid. Numerous AC/DC loads and DGs are connected to the corresponding AC/DC terminal. The line-frequency transformer is enclosed within the power transfer method to isolate DGs from the grid. However, it has some disadvantages like giant volume and weight, and much environmental pollution because of the usage of transformer insulation oil, compared with high-frequency transformer. Because of the indispensable part, transformer insulation oil plays a crucial role within the insulation and cooling of power transformer [14]-[15]. For promoting direct integration of DGs and meet the increasing trendy DC loads demand below the specified numerous DC bus voltages, multi-terminal hybrid AC/DC micro grid with one or a lot of extra DC terminals is considerably necessary. Meanwhile, for greater power transmission capacity and improved conversion performance, the recent trend of the multi-terminal hybrid micro grid system is connected to a three-phase medium or high voltage grid. Therefore, the direct theme is desired without the line-frequency transformer. To fulfill this

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demand higher than, cascaded H-bridge (CHB) converters is used because the grid interface to directly transfer power to medium-voltage grid while not line-frequency transformer [16], [17]. Additionally, dual active bridge (DAB) converters are used because the DC micro grid interface for analytic the transmitted power and wide-range voltage conversion magnitude relation [18]. Thus, association of CHB converters and DAB converters is applied within the hybrid AC/DC micro grid. The standard multi-terminal hybrid AC/DC micro grid system sometimes consists of 3 power conversion stages, as shown in Fig.1. The primary stage is that the AC/DC device of CHB type; the second stage is that the DC/DC devices of DAB type; the third stage is that the DC/DC device of the standard bifacial buck/boost converter, wherever the specified DC voltage is obtained by the extra DC voltage transformation.

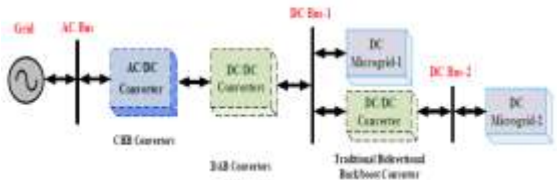

Fig.1.The conventional three-terminal hybrid AC/DC microgrid

During this case, as every of 3 power conversion stages are a smaller amount coupled, it's comparatively simple to manage power flow, voltage and current. However, this hybrid micro grid structure is involved a lot of power devices which result in lower efficiency because of the adoption of extra DC/DC conversion stage. So as to scale back hardware price of power devices with reduced variety of power conversion stages, this typical three-terminal hybrid AC/DC micro grid structure has not developed in analysis. By the standard voltage equalization management of grid interfacing AC/DC device [19]-[21] and common phase-shift control methodology of DC/DC converters [22] within the projected three-terminal hybrid AC/DC micro grid, shown in Fig.2, either three-phase AC currents or cells' DC capacitor voltages of CHB converters could also be unbalanced. The unbalanced condition is caused by the mismatched DC power in these DC micro grids. Moreover, once the single-phase grid fault happens simultaneously, because of the growth of the DC network topology by the DAB converters, these unbalancing problems will be a lot of sophisticated and obvious. The three-phase AC currents and DC capacitor voltage balance play a crucial role within the power quality and safe reliable operation of micro grid system. It's worthy mentioned that by unsuitable DC capacitor voltage equalization management methodology, voltage rise of some DC capacitors will increase the voltage stress and cut back the operation lifetime of power modules. In order to scale back hardware price of power physics devices with reduced variety of power conversion stages and meet the need of medium-voltage applications while not line-frequency transformer integration, a three-terminal hybrid AC/DC micro grid structure is projected to boost the efficiency and suppleness of power transfer. Additionally, an improved grid current and DC capacitor voltage equalization method of CHB converters is projected to stay three-phase grid currents and DC capacitor voltages of AC/DC device balanced at the same time even just in case of mismatched DC micro grid power and grid fault.

II. PROPOSED SYSTEM

Here we have two parts: First, the proposed three terminal and five terminal hybrid ac/dc micro grid systems and advantages are discussed. Second, the faced control problems are described.

1. Configuration of Systems:

Three phase hybrid AC/DC micro grid is proposed in Fig.2 where 2 DC ports and 1 AC port is connected directly to 3 phase voltage grid. It consists of an AC/DC converter (CHB) and DC/DC compact converter (DAB) consisting of two DC/DC converter groups, namely DC/DC converter-1 and DC/DC converter-2 respectively. The proposed three-terminal hybrid AC / DC micro grid has different types of internal structures, taking into account the effect of different link patterns of DAB converters, namely different wire connections between CHB converter outputs and DAB converter inputs, and different DAB sub module numbers in each DC / DC converter. The DAB converter branches in different loads can be randomly attached to the outputs of the CHB cells, where the proposed control scheme would solve the problem of capacitor voltage unbalance. Relation patterns of the DAB converter are thus not illustrated in Fig. 2. For clear description of power flow of DC Micro grids, The DC microgrid-1 and DC microgrid-2 are respectively replaced by load1 and load2. Each step of the CHB converter consists of 4 cells with Vdcj (j=1, 2... 12) as their DC capacitor voltage.

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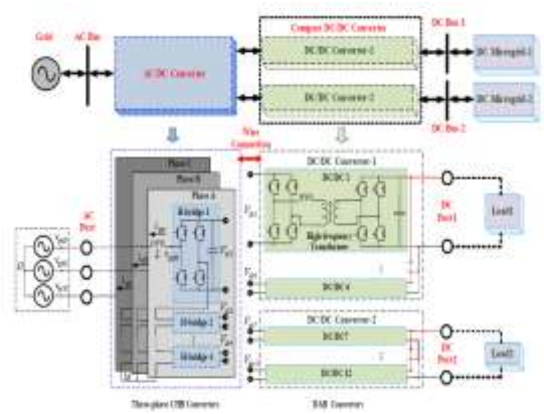

Fig.2. the proposed three-terminal hybrid AC/DC micro grid

The DC / DC converters are connected to the front-end CHB structure's DC outputs. Six parallel-connected DAB converters are composed of each DC / DC converter. The first four inputs of six DABs are successively connected to the outputs of the phase A CHB converters in the DC / DC converter-1 and the other two inputs of six DABs are successively connected to the first two outputs of the phase B CHB converters; similarly, the first two inputs and the other four inputs of six DABs are successively connected to the latter two outputs of the phase B CHB converters in the DC / DC converter-2 converter. The six output DABs in DC / DC converter-1 are connected to load1 together; similarly, the six output DABs in DC / DC converter-2 are connected to load2 together.

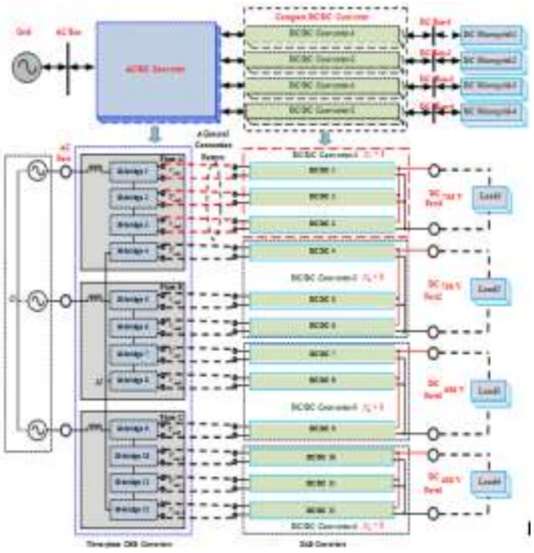

Fig.3. the proposed five terminal hybrid AC/DC Micro grid

The four DC micro grid power and DC bus voltages of the DAB converter are shown in the proposed method in Fig.3. In their separate references, DC capacitor voltages of CHB converters and three-phase grid currents are shown in Fig.17, showing the four distinct DC bus voltages can be traced. Fig.18, which clearly shows that it is possible to achieve the dual control objectives of DC capacitor voltage and grid current balancing; dynamic zero-sequence voltage and three-phase grid voltages are shown in Fig.19, showing that the desired zero-sequence voltage is produced in order to retain control of the inter phase power balance. It is easily seen from these simulation results that the suggested approach is also efficient for dual balancing power.

Characteristics of Proposed system are:

1) Dual DC output ports have the characteristics of more versatility of control and increased reliability. Different types of loads may be connected to different DC ports based on equivalent DC bus voltage, such as linear load and nonlinear load.

2) The medium-voltage or high-voltage grid may be directly connected through the front-end CHB structure without a traditional line-frequency transformer.

3) It is possible to eliminate this additional DC / DC conversion stage here for the second DC bus so that the hardware cost of power electronics devices is reduced and the performance of the system is increased.

4) The power transmission isolation feature is built into high-frequency transformer DAB converters that are more compact and cost-effective than line-frequency equivalents.

2. Description of Problems:

While these superior performances are obtained, two key control issues must be addressed as follows:

1. In the case of load mismatch for DC microgrid-1 and DC microgrid-2, under the traditional control system, the phenomenon of grid current imbalance arises due to mismatched power in the inter-phases of AC.
2. These DC capacitor voltages of the grid-interfacing AC / DC converter can be unbalanced when grid-voltage sag occurs, and three-phase grid currents are further unbalanced by the traditional control process, seriously affecting the quality of power of the device.

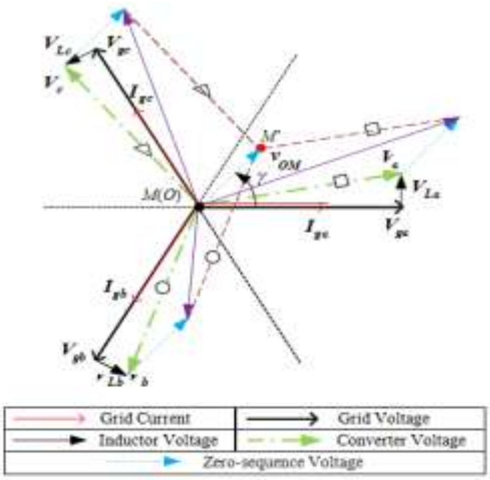

Fig.4. Phasor diagram of AC/DC converter with ZSVI in balanced operation.

Therefore, even in the extreme case of extremely mismatched DC power and grid-voltage sags, grid current and DC capacitor voltage balancing control are required to be realised simultaneously to further increase the capabilities of operational balance. Furthermore, the proposed approach should always be applicable to the various internal communication systems of the proposed three-terminal hybrid hybrid network under different grid operating conditions.

III. PROPOSED METHOD

At first, by analyzing unbalanced three-phase power, the proposed method in detail to solve the above mentioned two issues simultaneously. Secondly, guide of control parameters design are shown. And finally, the analysis of Stability operating region is shown.

1. Improved Grid Current and DC capacitor Voltage balancing method

The power imbalance problem of front-end CHB converters can be classified into two categories as follows: 1) the inter-phase (clustered) power unbalance, which occurs when each phase flows different power caused by mismatched DC network power or grid faults;
2) the inter-bridge (individual) power unbalance, which happens when each bridge in the same phase flows different power.

With zero-sequence voltage injection (ZSVI), phasor diagram of front-end AC/DC converter with ZSVI in balanced operation is shown in Fig.4. **Vgm** (m=a, b, c) is the grid voltage vector; **VLm** (m=a, b, c) is the inductor voltage vector; **Vm** (m=a, b, c) is the AC/DC converter voltage vector; **Igm** (m=a, b, c) is the grid current vector; **VOM** is the zero-sequence voltage vector and γ is its phase angle; Fig. 4 reveals a critical fact that it is possible to rebalance these three-phase power by shifting the floating neutral point of three-phase converter from point M(O) to point M', which transfers the inter-phase power errors between overall average power of AC/DC converter and actual real power of each phase.

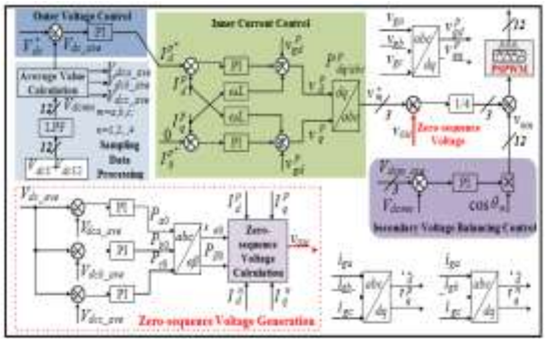

Fig.5.the proposed method in the three-terminal hybrid AC/DC micro grid.

In the outer voltage control, by PI controller according to the voltage error between Vdc_ave and DC voltage reference V * dc, the positive-sequence d-axis current reference I p* d is got to adjust the overall active power interaction between AC/DC converter and grid. Meanwhile, positive-sequence q-axis current reference I p* q is set to regulate overall reactive power. Therefore, inter-phase power is wholly exchanged among three phases and no additional power is transmitted into three-phase converter. In the control process, the required zero-sequence voltage can be generated to readjust the inter-phase power in order to keep the inter-phase power balanced.

2. Control parameters selection

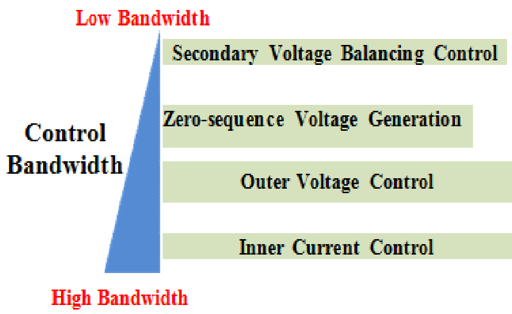

Fig.6. control bandwidths of CHB converter controllers.

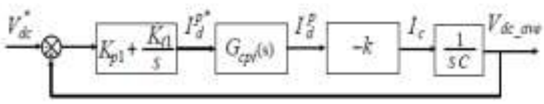

Fig.7. Control block diagram of outer voltage control

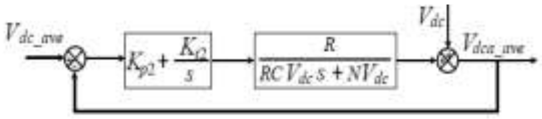

Fig.8. Control block diagram of clustered balancing control based on ZSVG

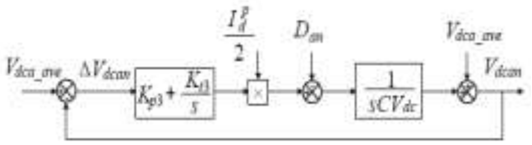

Fig.9. Control block diagram of secondary voltage balancing control

3. Analysis of Stable operating region

The intrinsic performance of front-end CHB converters results in the limited inter-phase power adjustment, because of the increased converter output voltages by the proposed method. When the grid-voltage balance are extremely unbalanced and the inter-phase power caused by mismatched DC power, the over modulation occurs. Where in practical operation, the phase power pm (m=a, b, c) can easily obtained by grid-current iga and the grid-voltage vgaO, both of which are obtained by the corresponding sensors; the transfer power pi (i=1, 2, … , 3*N) of each H-bridge cell can be calculated by monitoring the dc-side output current of each cell and the corresponding DC capacitor voltages of each cell. Based on pmax, the allowable maximum power of each H-bridge system, stable operating region can be shown in Fig.10.So that the three-terminal hybrid microgrid can be in stable operation region by the proposed method.

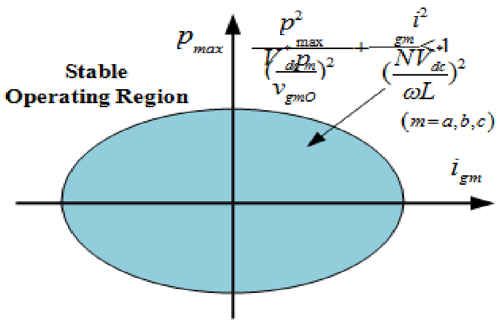

Fig.10. Stability region of a system

IV. SIMULATION RESULTS

The detailed topology of the test system in MATLAB / Simulink is the same as that in Fig.2 and Fig.3, in order to check the proposed topology and control strategy. TABLE I lists the simulation parameters of the proposed three-terminal hybrid AC / DC micro grid. In the three simulation scenarios, as shown in TABLE II, the traditional method (DC capacitor voltage balancing method) and the suggested method (an improved grid current and DC capacitor voltage balancing method) are evaluated. The voltage reference value of the DC bus is based on the same DC bus voltage. In the first 2 s, scenario 1 simulates the steady state with matched loads; scenario 2 simulates the case of load mismatching from 2 s to 3 s; scenario 3 simulates the case of load mismatching and grid sags from 3 s to 4 s (grid voltage sags 50 percent in step C).

TABLE I: PARAMETERS OF SIMULATED SYSTEM

Type	**Circuit parameters**	**Values**
Three-phase grid	Rated power	150 kW
	Line voltage, frequency	2500 V, 50 Hz
	Input inductance	5 mH
AC/DC converter	Switching frequency	4 kHz
	DC capacitor, voltage reference	4 mF, 750 V
DC/DC converter	Switching frequency	4 kHz
	Leakage inductor	0.5 mH
	DC capacitor, voltage reference	1 mF, 700 V or 400V
Type	**PI control parameters**	**Values**
Outer voltage control	K_{p1}, K_{i1}	0.5 A/V, 5A/(V·s)
ZSVG	K_{p2}, K_{i2}	300 W/V, 3000 W/(V·s)
Secondary voltage balancing control	K_{p3}, K_{i3}	2, 20
Current controller	K_{p4}, K_{i4}	300, 300

Table II: SIMULATION SCENARIOS

Scenario	**Time/s**	**Load1/kW**	**Load2/kW**	**Grid-voltage**
1	0~2	49	49	Balanced
2	2~3	49	**98**	Balanced
3	3~4	49	**98**	**sag 50% (phase C)**

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Fig.11. DC capacitor voltage of AC/DC converter by the three terminal conventional methods

Fig.12. DC capacitor voltages of AC/DC converter by the three-terminal proposed method

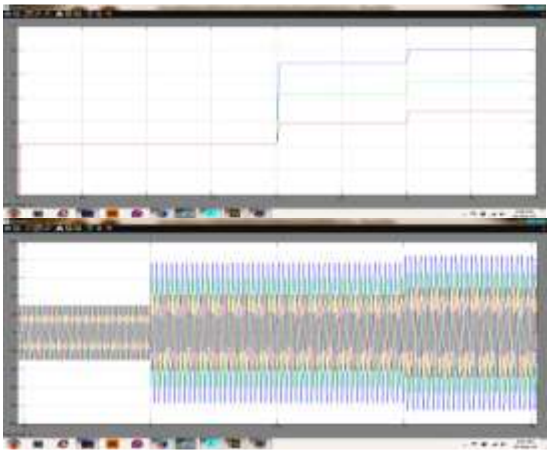

Fig.13. Three-phase grid RMS currents and transient values by the conventional method.

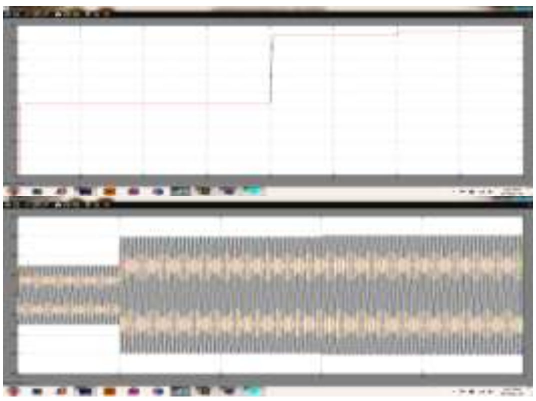

Fig.14.Three-phase grid RMS currents and transient values by the proposed method.

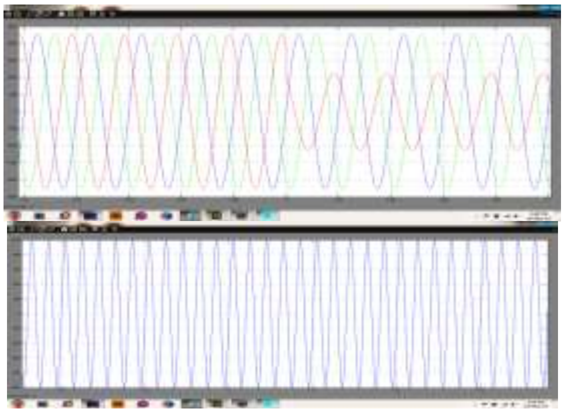

Fig.15. Dynamic zero-sequence voltage and three-phase grid voltage by the three terminal proposed method.

(a) AC/DC converter is controlled by the conventional method.

(b) AC/DC converter is controlled by the proposed method

Fig.16.DC bus voltages of DC/DC converters by the conventional three phase-shifted control method.

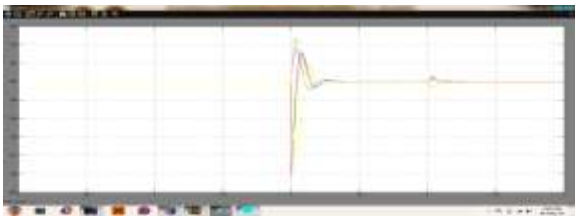

Fig.17. DC capacitor voltage of AC/DC converter by five-terminal proposed method

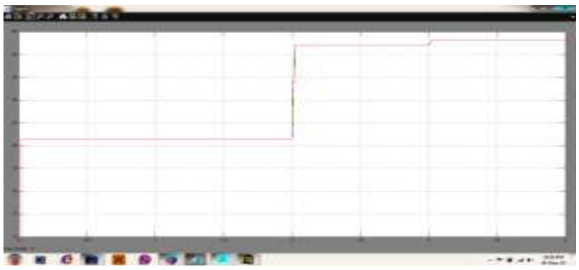

Fig.18. Three-phase grid RMS currents and transient values by the five-terminal proposed method.

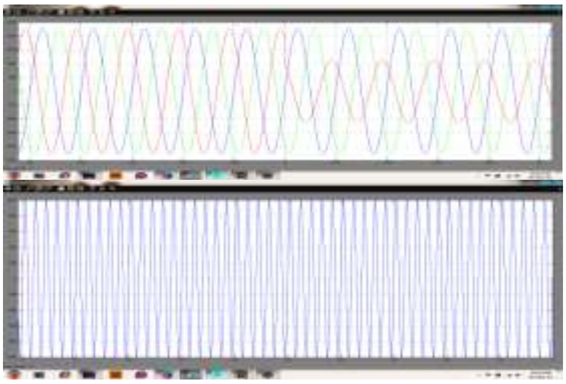

Fig.19.Dynamic zero-sequence voltage and three-phase grid voltages by the five-terminal proposed method

We can see better improvement and accurate results when the PI controller in the proposed method is replaced by PR controller and as in the below simulation results:

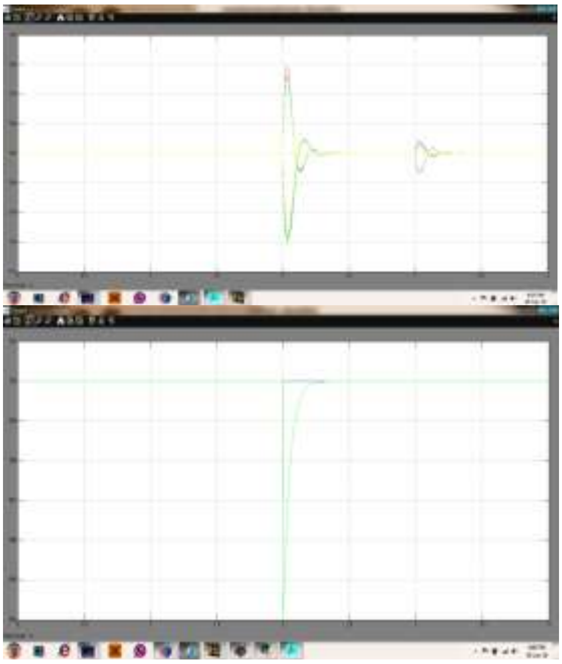

Fig.20. Three terminal Hybrid AC/DC micro grid with PR controller

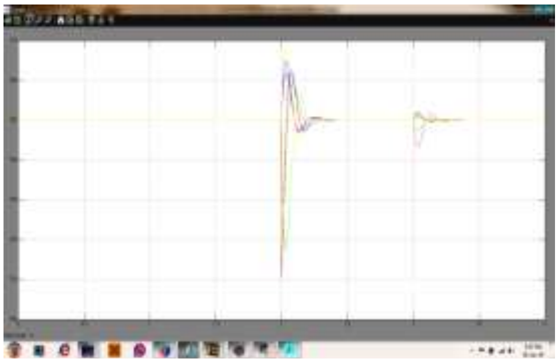

Fig.21. Five terminal Hybrid AC/DC micro grid with PR controller

V. CONCLUSION

In this paper, a multi-terminal hybrid AC/DC micro grid structure with two power conversion stages is described in detail and a three-terminal hybrid micro grid with two DC ports is mainly selected for case study. In order to solve the issues of DC capacitor voltages and three-phase grid currents unbalance caused by mismatched DC power between DC ports, an improved control method through the adoption of zero-sequence voltage injection is developed. It's been extensively verified that the grid current and CHB capacitance voltage equalization management are often achieved at the same time even within the severe case with extremely mismatched DC power, grid-voltage sags, or changes of association between AC and DC sub grids.

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