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AN IMPROVEMENT OF STABILITY AND DYNAMIC RESPONSE IN HYBRID AC-DC MICROGRIDS USING OPTIMAL POWER CONTROL MANAGEMENT

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ABSTRACT

Microgrid topologies enable more effective use of renewable resources as well as the autonomous process. Microgrids are effective frameworks for managing dispersed assets such as renewable structures with small-scale distributed generator supplies. Smart grids are adaptable electricity networks that have arisen as a result of the introduction of new technologies and features. It is suggested that a three-terminal AC/DC hybrid microgrid with DC two and AC one terminal be used. A two dual active bridge (DAB) with cascaded H-bridge (CHB) converter with AC grid link-based interactions that connect isolated two DC buses are included in the suggested structure. To minimise the energy generation stages and power devices, the DAB converters are intrinsically linked to the CHB of DC rails based on the structure-specific requirements. To present the unnecessary grid currents and DC rail voltage issues exist by this revised structure topology by simply two power alteration stages, a better solution is suggested that employs zero-sequence voltage (ZSV) injection in the CHB converters. The impacts of managed settings on structure stability and dynamic responsiveness are investigated in order to reduce conflicts among ZSV injection by structure voltage/current regulation. This paper compares the performance of a PI and a PR for DC voltage regulation. A comparison of simulation results for both control approaches is provided. The major difficulty is to normalise the system model in order to identify the appropriate controller settings for robust control. The findings are confirmed and compared to the conventional regulator PI. The suggested 3-Φ AC current and DC rail voltage regulating approach's universal efficacy is proved by MATLAB/Simulink analytical model from the three and five-terminal hybrid AC/DC power structures.

Keywords: microgrid; ZSV control; CHB converter; DAB converter, PI controller, PR controller.

1. INTRODUCTION

Energy security is vital to the survival of our contemporary society. Electric power systems have been built and developed to be very dependable; power outages occur seldom and for short periods of time when relative to other industrial applications of equivalent complexity, such as the transmission line. AC structures dominate power structure networks globally [1]. The revolutionary growth of semiconductor technology and power electronic converters is growing interest in DC power structure applications. Ustun. S [2] discussed the growing interest in DC structures stems from the inherent benefits of DC structures over AC structures. Many household loads, such as computers, microwave ovens, and lamps, require DC power, and converting AC to DC results in a considerable energy loss of 10-25 percent. DC electric arc furnaces use less energy than AC furnaces in industrial applications. Another stimulus for the development of DC structures is the focused emphasis on increasing the penetration of environmentally friendly renewable energy sources (RES) into the power structure suggested by [3]-[4]. DC-based RES, such as photovoltaic (PV) and fuel cells, may be immediately incorporated into the network, avoiding alteration stages and therefore increasing structure energy efficiency. The adoption of energy storage (ES) technology, which enhances power supply dependability, is more enabled by DC structures than by AC structures. As KVM Reddy [5], the term "microgrid" refers to a local energy network that incorporates distributed generation (DG), loads, and storage devices. The notion of DC microgrids is gaining popularity due to their simpler structure and improved energy efficiency. AC MG technology has already been established; however, DC MG technology requires more study to address the issues of steady and dependable implementation.

In [6], every energy source generates an alternative power signal, for example, photovoltaic cells generate DC and wind generates AC. Adaptation must be required between them. This adaptation is known as coupling. Coupling can be accomplished in two ways: AC or DC. They can be used as part of an on-grid, off-grid, or hybrid design. The number of pieces in AC-coupling and DC-coupling is nearly the same, with the exception that dump load is employed in DC and WTG inverter in AC-coupling discuss as in [7]-[8]. To safeguard the inverter rather than a dump load, the WTG inverter is commonly built with a breaking chopper, which is effectively a DC-DC converting harmful current and voltages into a resistor causing heat.

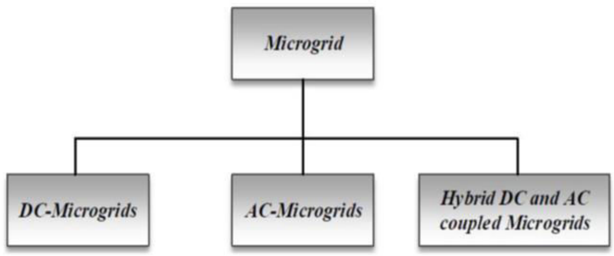

Figure-1. Types of grid connection.

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AC one and DC one bus are used in a usual hybrid AC/DC microgrid. A 3-Φ bidirectional AC/DC converter integrates the AC and DC terminals. As A.Emadi [9], describes the alternating current terminal is linked to LV utility grid. A variety of AC/DC loads and DGs are linked to the appropriate AC/DC connector. To separate DGs from the grid, a line-frequency transformer is incorporated in the power transmission process suggested in [10]-[11]. However, when compared to high-frequency transformers, it has various drawbacks such as huge bulk and weight, as well as significant environmental pollution owing to the use of transformer insulating oil. AC 3 Φ currents and DC capacitor voltage adjusting are crucial in microgrid usable capacity quality and effective, dependable operation, respectively. It should be noted that if an inadequate DC capacitor voltage adjusting manage structure is used, voltages of such DC capacitors may rise, causing voltage stress and limiting power module working life. Elavarasan, R.M [12], the Overvoltage significantly damages them in extreme cases, affecting the proper usage of the microgrid structure. In the area of unequal DC microgrid energy reassign with grid-voltage sags, the management goals of AC 3-Φ current with DC capacitor voltage assessment have seldom been presented. A CHB converter is often used as a grid side to openly transmit power to a MV grid, eliminating the need for a line-frequency transformer. To isolate the processed power and variable voltage alteration ratio, DAB converters may also exist as the DC microgrid interface discuss in [13]-[16]. Thus, in the hybrid AC/DC microgrid, CHB and DAB converters will be connected. Microgrid Energy Management (MGEM) is defined as mixed integer linear programming in [17]-[19], and it is used to control the energy flow of a certain Hybrid Energy System (HES) that includes wind, PV, fuel cell, micro turbine, fuel, and energy storage. HESs that employ inefficient energy sources, like as diesel, enhance greenhouse gas emissions and diminish the system's efficiency in preventing the environment from contamination as in [20]-[21].

To enhance the accuracy and adaptivity of energy transfer while reducing the equipment power cost of electronics devices with some less energy alteration stages and fulfilling the criteria of MV implementations without LF transformer combination, a three-terminal hybrid AC/DC microgrid structure is suggested [22]. In addition, an enhanced grid current and DC capacitor voltage assessment strategy for CHB converters is offered in order to keep 3-phase grid currents and DC capacitor voltages of AC/DC converters regulated at once time even in the face of unequal DC microgrid power and grid failure. Furthermore, the PI control algorithm or the PR control algorithm can be utilised in the control scheme. The PI control algorithm appears to be straightforward and robust. However, it can only monitor DC signals with no difference and has significant limitations in AC signals. Because it can get infinite gain at the fundamental frequency, PR control techniques for an AC tracking controller can increase control precision. Despite the unfavourable circumstances, a PR & PI controller are used to govern the output DC voltage. Both controllers determine the error based on the difference between the measured and reference power. When compared to the PI controller, the findings show that the PR controller can reduce overall ripple. The PR controller has a higher performance in the specified reference due to the decrease of ripple under all situations. This paper compares the performance of a PI and a PR for DC voltage regulation. A comparison of simulation results for both control approaches is provided. The major difficulty is to normalise the system model in order to identify the appropriate controller settings for robust control. The findings are confirmed and compared to the conventional regulator PI.

This paper is structured as follows. Section 2 explains the system architecture and describes the voltage control architecture utilising PI and PR controllers, including parameter adjustment via frequency response. Section 3 compares the results of simulation findings, and Section 4 discusses the conclusions.

2. STRUCTURE MODELLING AND MANAGE

Furthermore, when a single-phase grid breakdown occurs concurrently as an outcome of the DAB converters' extension of the DC network design, these unassessment concerns might become more intricate and visible. A 3-Φ AC current and DC capacitor voltage evaluation are critical in the structure reliable and safe, dependable process of microgrid structures, respectively. It is worth noting that by using an ineffective DC capacitor voltage assessment management mechanism, the voltages of some DC capacitors might rise, increasing voltage stress and reducing power module operating life. Figure-2 depicts a three-terminal hybrid AC/DC microgrid with DC two ports and AC one port that may be directly linked to a 3-Φ medium-voltage grid. It is made up of AC/DC and compact DC/DC converters, which are made up of DC/DC two groups converters. Taking into account the contact of different DAB converter association patterns, such as the suggested three-terminal hybrid AC/DC microgrid offers a variety of internal topologies, including varied interconnect across CHB converter outputs and DAB converter inputs, as well as variable DAB submodule figures in each DC/DC converter.

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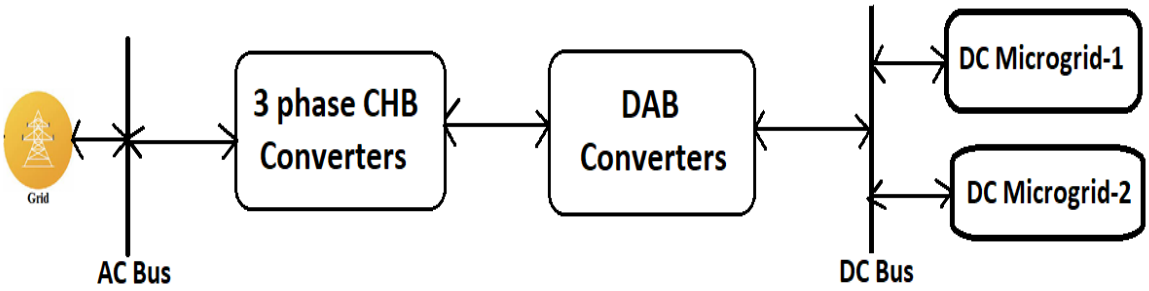


Figure-2. Schematic of suggested DC microgrid.

Under the standard managed structure, the phenomena of grid current unbalance arises related to unequal management in the AC inter-phases in the load variance condition for DC microgrid-1 & 2 When there is a drop in grid voltage, the DC capacitor voltages of the structure AC/DC converter may become imbalanced, and 3-Φ grid currents may increase imbalanced by the usual management approach, negatively impacting structure power quality. There are three management loops in the AC/DC converter: outer voltage manage, ZSVG, and internal voltage assessment manage. Outer voltage manage regulates total power shared with the grid and undertakes overall DC voltage manage; ZSVG achieves inter-phase stability power with changes the incompatible power within three seconds, where the mandatory dynamic ZSV is assessed; secondary voltage assessment manage obtains entity voltage stability with reallocates the multiple outputs with each bridge in the same phase.

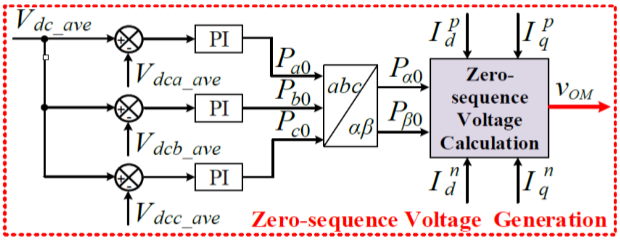


Figure-3. Conventional manage of ZSVG.

To approximate the Digital devices employ distinct sampling periods and a discrete variation of the PI equation to calculate the error integral. Non-integrating processes are defined as any process that, given this very same set of inputs and interruptions, eventually recovers to the same output required PI manage. To alleviate the drawbacks of a PI manage, an alternate strategy of proportional plus resonance (PR) manage, which is the frequency transformation of a dc type manage into an equivalent ac regulator, is presented. As a result, the comparable stationary frame current manage performs theoretically identically to the synchronous frame current manage. In a stationary frame, a PR manage can give unlimited gain at a specified frequency while achieving zero steady-state error. It is also applicable to single-phase or 3-Φ structures.

When the inductor voltage is ignored, the three-phase converter phase-voltage is,

$$\begin{cases} v_{gaM} = v_{ga}^{p} + v_{ga}^{n} + v_{ga}^{0} = v_{gaO} + v_{OM} \\ v_{gbM} = v_{gb}^{p} + v_{gb}^{n} + v_{gb}^{0} = v_{gbO} + v_{OM} \\ v_{gcM} = v_{gc}^{p} + v_{gc}^{n} + v_{gc}^{0} = v_{gcO} + v_{OM} \end{cases}$$

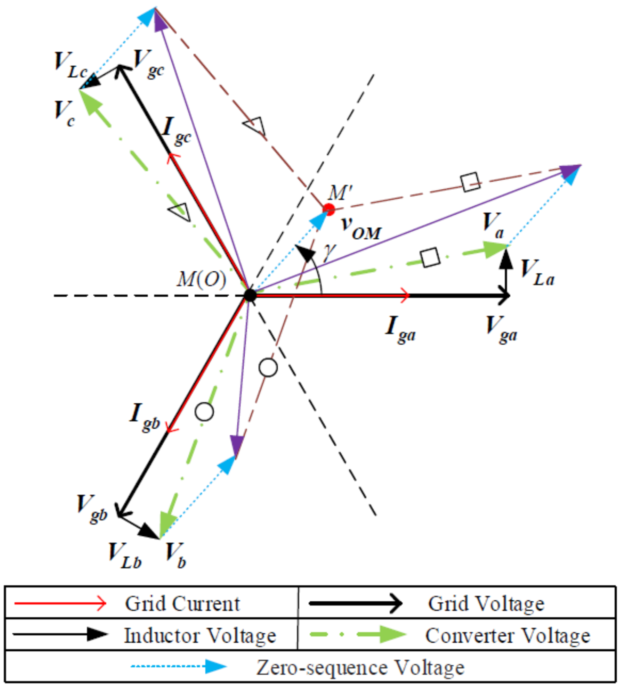
Where, *vgmM* (*m*=*a*, *b*, *c*) is the phase-voltage of a three-phase converter based on point *M*;

The transient real power is defined at each phase as,

$$p_{mn} = v_{gmO} i_{gm}$$

Where, *pmm* (*m*=*a*, *b*, *c*) are the transient power generated by *vgmO* and *igm*.

The phasor diagram of a front-end AC/DC converter with zero-sequence voltage injection (ZSVI) in balanced operation is presented.



The PI current control approach with grid voltage feed-forward is depicted in Figure-4 below (UG). Ii is the feedback inverter output current, Ii * is the inverter current reference, and Ui * is the reference voltage point.

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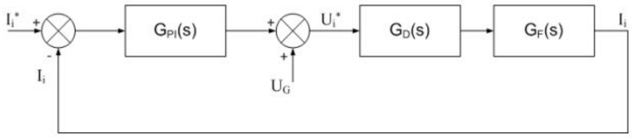


Figure-4. PI control scheme.

The $G_{PI}(s)$ of the PI current controller is represented by,

$$G_{PI}(s) = K_P + \frac{K_I}{s}$$

Where KP is the Proportional Gain term and KI is the Integral term.

To get the required phase-shift angle, the DC/DC converters uses the usual phase-shift manage mechanism. A basic PI manages the phase-shift angle based on the voltage difference between the DC bus voltage and its voltage position. The +ve sequence d-axis current position is obtained in the outer voltage manage by PI manage based on the voltage error between with DC voltage position to modify the generally active power interface between AC/DC converter and grid. Temporarily, the +ve-sequence q-axis current position is configured to manage total reactive power as shown in Figure-3.

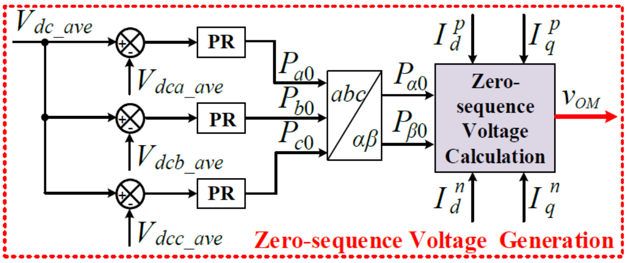


Figure-5. Suggested manage of ZSVG.

The inherent concert of front-end CHB converters exists in restricted inter-phase power alteration using the suggested technique while converter output voltages grow. Over modulation happens when the inter-phase power is significantly imbalanced due to uneven DC power with grid-voltage unequal. As a result, the maximum output margin of each cell in the steady must be maintained in time to retain 3-Φ AC currents with DC capacitor voltages constant working area must be investigated and also shown in Figure-5.

The discrete transfer function for Equation's resonant term is obtained via a bi-linear transformation as,

$$R(z) = \frac{k_i \cdot \frac{2}{T}\frac{(z-1)}{(z+1)}}{\frac{4}{T^2}\frac{(z-1)^2}{(z+1)^2} + \omega^2}$$

The function of Equation may be expressed as follows as a variable of the error E(z) and the process variable U(z):

$$G_{PR}(z) = \frac{Y(Z)}{E(Z)} = k_p + \frac{a_0(1 - z^{-2})}{b_0 + b_1 z^{-1} + b_2 z^{-2}}$$

The PR current control approach is shown in Fig. 6 below. Ii represents the inverter output current used as feedback, Ii * represents the inverter current reference, and Ui * represents the inverter voltage reference.

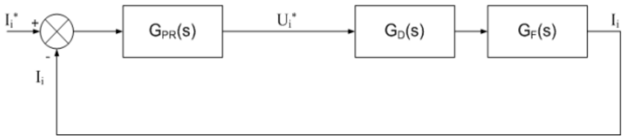


Figure-6. PR control scheme.

$G_{PR}(s)$ represents the PR current controller by,

$$G_{PR}(s) = K_P + K_I \frac{s}{s^2 + \omega_0^{\,2}}$$

Where, KP is the Proportional Gain term, KI is the Integral Gain term and ω0 is the resonant frequency.

3. SIMULATION RESULTS

To validate the suggested topology and manage technique, the evaluation structure's entire topology was created in MATLAB/Simulink.

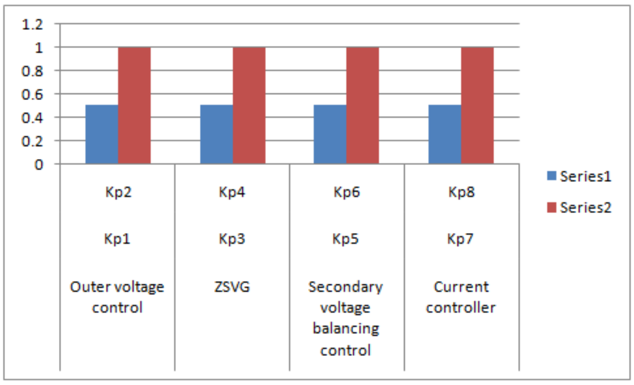
Table-1 shows the simulation parameters for the suggested three & five-terminal hybrid AC/DC microgrid.

Table-1. Structure Parameters.

Type	Circuit parameters	Values
3 Φ grid	Rated power	150kw
	Line voltage. Frequency	2500V, 50Hz
	Input inductance	5mH
AC/DC Converter	DC capacitor, voltage reference	4mF, 750V
	Switching frequency	4kHz
DC/DC converter	Switching frequency	4kHz
	Leakage inductor	0.5mH
	DC capacitor, voltage reference	1mF, 700V

Table-2. Parameters for PI control.

Type	PI Manage parameters	Values
Outer voltage control	K_{p1}, K_{p2}	0.5, 1
ZSVG	K_{p3}, K_{p4}	0.5, 1
Secondary voltage assessment control	K_{p5}, K_{p6}	0.5, 1
Current control	K_{p7}, K_{p8}	0.5, 1



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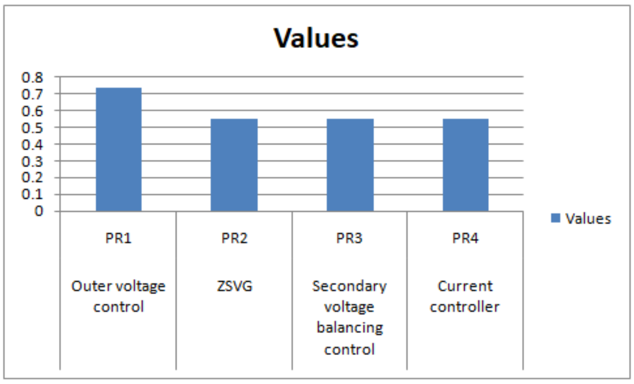
The above graph shows the existing control techniques with different PI gain parameters is suggested in the hybrid microgrid. Different values should be suggested to execute the system modelling for the microgrid.

Table-3. Parameters for PR control.

Type	PR Manage parameters	Values
Outer voltage control	PR1	0.74
ZSVG	PR2	0.549
Secondary voltage assessment control	PR3	0.549
Current control	PR4	0.549



Above graph shows the suggested control techniques with different PR gain parameters is suggested in the hybrid microgrid. Different values should be suggested to execute the system modelling for the microgrid.

Table-4. Simulation conditions for different loads.

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)

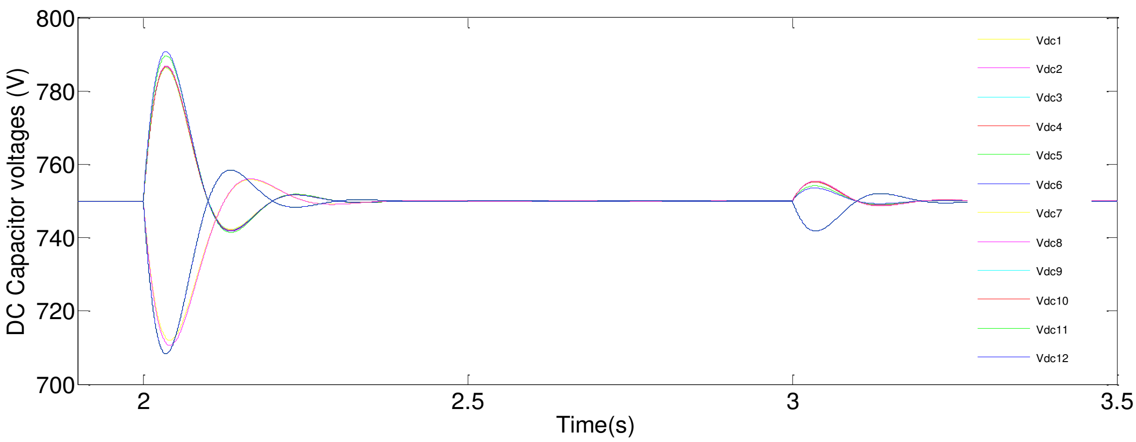
Table-5. Comparison results for three terminal structure.

	Existing technique (PI control)	Suggested technique (PR control)
DC Capacitor voltages	40 V	30 V
DC Bus voltages	10 V	6 V

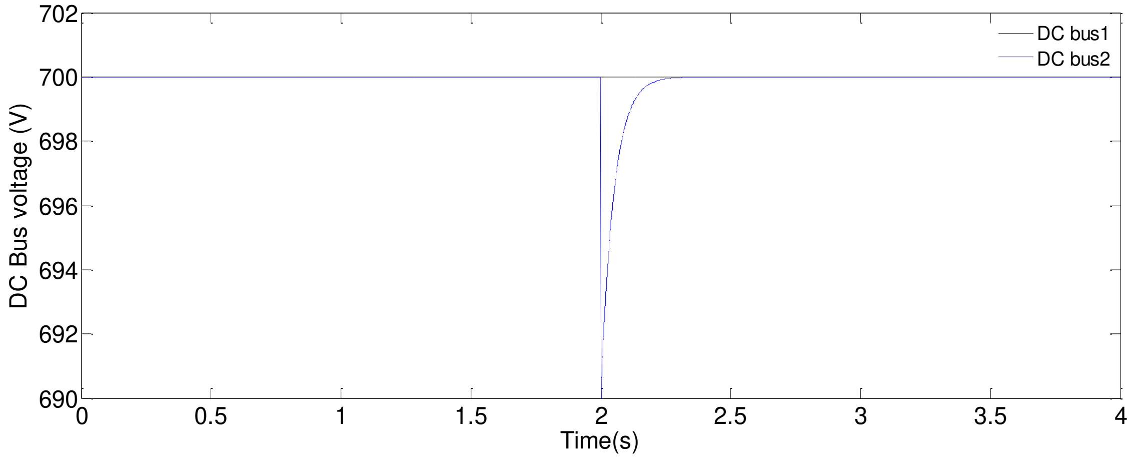
Table-6. Comparison results for five terminal structure.

	Existing technique (PI control)	Suggested technique (PR control)
DC Capacitor voltages	50 V	40 V

Tables 2, 3, and 4 show the results of testing the existing approach (DC capacitor voltage assessment technique) with the suggested technique (an enhanced grid current with DC capacitor voltage assessment technique) in three simulated cases. The voltage position level of DC bus-1 & 2 is set to 700V based on equal DC bus voltage. Case 1 simulates the steady state with corresponding loads for the first two seconds; case 2 simulates the case of load unequal from two seconds to three seconds; and scenario three exits the case of load unequal with grid sags (grid voltage sags 50 percent in phase C) from three seconds to four seconds

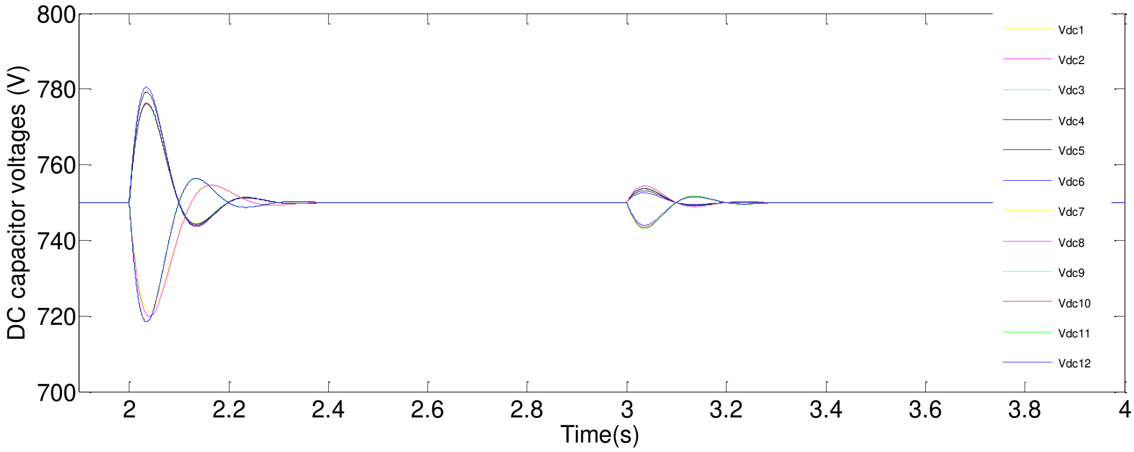


(a)

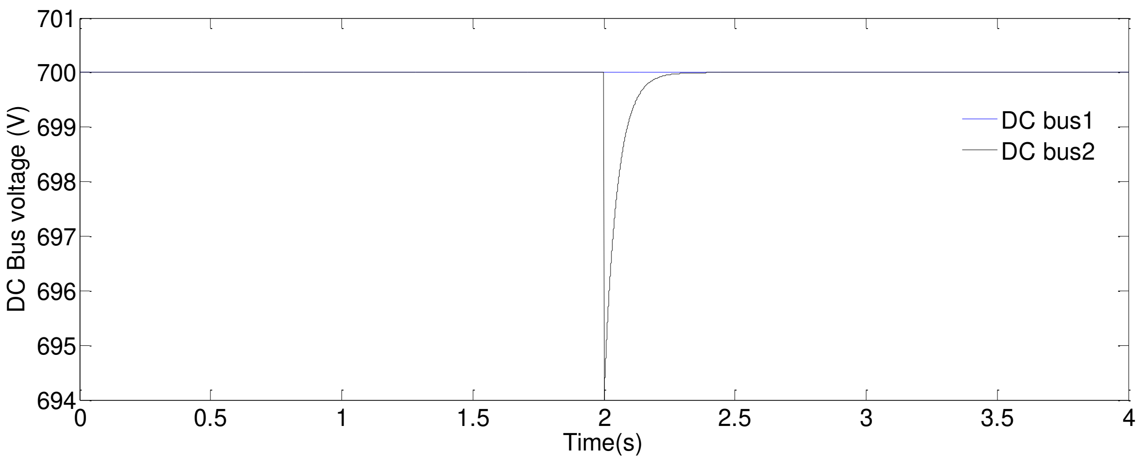


(b)

Figure-7. Existing technique (a) DC Capacitor voltages, (b) DC bus voltage. (Three terminal structure).



(a)



(b)

Figure-8. Suggested technique (a) DC Capacitor voltages, (b) DC bus voltage.(Three terminal structure).

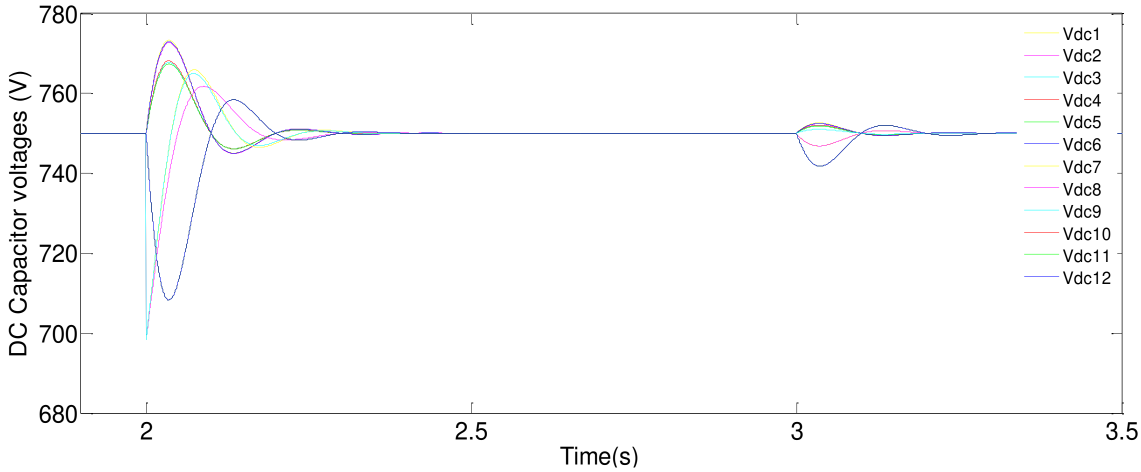


Figure-9. Existing technique DC Capacitor voltages. (Five terminal structure).

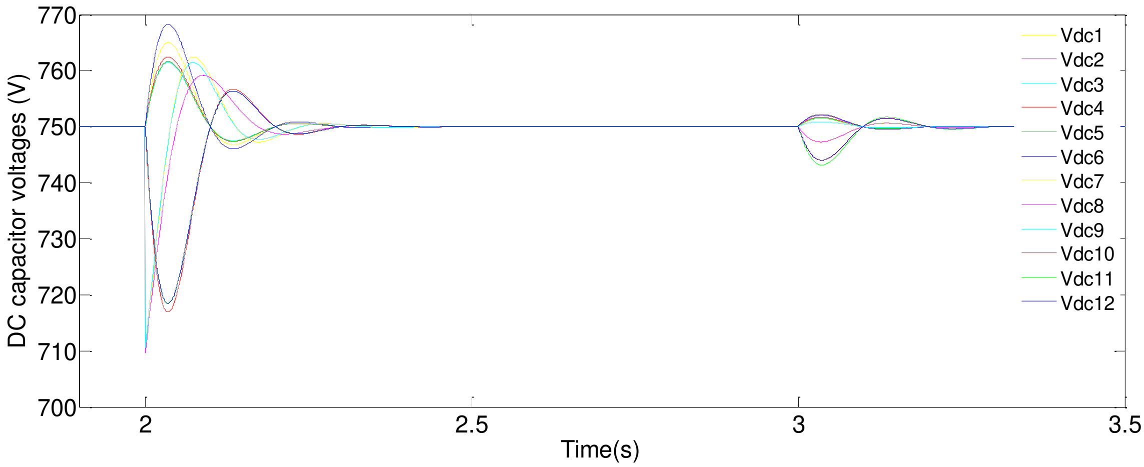


Figure-10. Suggested technique DC Capacitor voltages. (Five terminal structure).

Above all, even though the Dynamic DC capacitor voltage comparing and injected zero-sequence value may occur differ in these cases, the technique process is better and the presented scheme is always potent for instantaneous 3-Φ AC currents and DC capacitor voltages assessment, still in the massive condition with extremely dissimilar DC power with grid-voltage sags. The above tabular column shows the value difference between existing and suggested technique with improved performance of the dc capacitor voltages and dc bus voltages. The suggested method has a faster dynamic reaction speed and less voltage fluctuation after changing loads than the approaches. In other words, it enhances dynamic performance.

CONCLUSIONS

A suggested terminal hybrid AC/DC microgrid structure with two power alteration stages is suggested in detail, along with a three-terminal hybrid microgrid with DC two ports is used as the primary case study. To exist the cases of DC capacitor voltages with 3-Φ grid current imbalance produced by uneven DC power among DC ports, a better management strategy based on ZSV insertion is suggested. Grid current and CHB capacitor voltage order to balance management have been thoroughly demonstrated to work concurrently even in the extreme situations of significant incompatibility of DC power, grid-voltage sags, or connection modifications among AC and DC sub-grids.

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