Improvement of Power Quality in Multi-Terminal Hybrid Ac/Dc Microgrid by using Fuzzy Logic Controller

K.Sharmila Gowd, K.Jithendra Gowd, D.Dharani Lakshmi

Abstract: In this paper analysis of 3-Terminal and 5-Terminal hybrid(cross breed) micro grid using Fuzzy logic controller is proposed. The cascaded H-bridge interfaces between supply and DAB converter. The DAB(Dual Active Bridge) converter connects between cascaded H-bridge and load. By using Zero sequence voltage (ZSV) and inner current controller improvement in grid current and voltage balance are achieved. To boost the grid current and unbalance voltage, 49 ruled fuzzy controller based scheme is used. The analysis of the concept mainly deals with maintenance of power quality and uninterrupted in power supply by tuning and Fuzzy logic controlling. The cascaded H-bridge hybrid micro grid with 3-terminal or 5 terminal would have better performance only if there is balanced voltage as well uninterrupted grid current. Fuzzy logic based controller performances are analyzed through simulation results.

Index: 3-Terminal and 5-terminal microgrids, Secondary Voltage balance control, Outer Voltage control, Fuzzy-Logic-Control (FLC)

I. INTRODUCTION

Points of interest like ecological agreeableness, expandability along with adaptability have molded distribution generation (DG), supplied by different renewable sources, an appealing alternative to arrange present day electrical networks. At the point when a couple of appropriated sources and loads are additionally connected together, elements called as micro grids are framed, on a basic level, bigger controllable circulated generators that have combined advantages of different renewable sources. Going with the advanced improvement in DG is the improvement of different fundamental power conditioning interfaces and their related control for making small scale sources of generation to the microgrids, and from there on endeavoring the microgrids to the regular power framework. With that interconnection, microgrid activity is exceptionally adaptable, enabling it to work uninhibitedly in the grid associated or isolated method of activity for the previous, every small scale source can work like a current source of maximum power transferring capacity to the grid. That is possible if grid is higher in capacity, and can therefore be treated as an infinite bus.[1 2] DG systems are energized by small sources such as fuel cells, photovoltaic cells, batteries, and micro turbines and so on., and have just been utilized to divide highest generating load hours where expenditure of power is more and to provide reserve generation amid system outages.

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K.Sharmila Gowd, PG research Scholar, E.E.E. Dept, JNTU Anantapur, AP, India.
K.Jithendra Gowd, Assistant Professor, E.E.E. Dept, JNTU Anantapur, AP, India.
D.Dharani Lakshmi, Ph.D research Scholar, E.E.E. Dept, JNTU Anantapur, AP, India.

An another idea is to gather a group of loads and paralleled DG systems inside a specific neighborhood structure a micro grid [2, 3]. Being an efficient association of DG frameworks, a micro grid has bigger power capability and more control adjustments to satisfy system reliability and power quality requirements, additionally all the advantages of a single DG system are inherited. [3 4]. The problems are mainly due to environmental issues caused by fossil fuels power plants. In the other way light emitting diodes (LED) and Electric Vehicles (EV)’s are related to the energy power system and saving the environment from pollution. Main aim is to use the methods more and more achieve the greenery environment [5]. By using the AC grids we can send the power from feasible power sources to normal ac systems. Accordingly Photo Voltaic panels (PV) generate the power via DC/DC converters and DC/AC converters to the grid. In the industrial area part motors mostly ac motors are used to generate the power [6 7].

In regular micro grids the line frequency transformer used to interchange the power and the Distributed Generator (DG)’s are isolated from the Grid. In this way by using transformer occupies huge volume, and weight highest nature contamination as there is utilization of oil for transformer protection where it is absent in high frequency transformer (HFT). By using regular transformer it has drawbacks like protection and cooling of power transformer [14, 15]. To reduce cost and size line frequency transformer can be removed and dual active bridge conversion devices with high frequency transformers can be replaced.

In the PI based three-terminal Hybrid AC/DC miniaturized scale lattice, showed up in Fig. 1, three-stage AC flows or DC capacitor voltages of CHB converters probably won't be adjusted. The unequal circumstance is achieved by the not coordinated DC control in these DC smaller scale lattices. Also, when the single-arrange framework shortcoming happens at the same time, as a result of the improvement of the DC circuit topology by DAB converters, these not adjusting circumstances can be logically muddled and clear. 3-stage exchanging flows and DC voltage of capacitor equalization expect a noteworthy activity in the power quality and solid working of miniaturized scale matrix framework, independently. In outrageous cases, they are genuinely hurt due to overvoltage, affecting the common errand of litter scale organize system.

So as to diminish cost of equipment of Power-Electronics devices of decreased number in power transformation steps and fulfill the needs of medium-voltage requirements without line-frequency transformer joining, a cascaded H-bridge 3-Terminal based schematic...
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In the 3-stage AC terminals or DC voltages of capacitor of Cascaded H-Bridge converters may be unstable. 3-Phase AC Currents and DC Capacitor Voltage levels considered as to achieve Power quality and reliability in the Micro grid system. In DC loads some problems rise like load stress and decrease the operating capacity of power module circuits. Overvoltage will appear in the serious cases like irregular DC Micro Grid power change and sag at grid side voltage. The controller main aim is to analyze 3-phase AC Current and DC-Capacitor voltage by using controllers like FUZZY using simulink.

II. THE FUZZY CONTROLLER BASED 3-TERMNAL CASCADED H-BRIDGE HYBRID MICRO GRID

In this the system consists of two parts. The first one three terminal ac/DC cross breed micro grid and evaluation of grid current and voltage balancing equations.

1. System configuration

The 3-Terminal cascaded H-Bridge Ac/DC Micro-Grid with two DC Micro grids shown in fig. 1. In the circuit diagram it showing that as cascaded h-bridge as three phases. The Dual Active Bridge (DAB) associated over the DC Micro-Grid and Cascaded H-connect 3-terminal or 5-terminal. In the Cascaded H-Bridge (CHB) terminal as 4 H-Bridge terminal as every stage. In the smaller scale Grid side it relies on the three terminal based or five terminal based. In the DAB converter consists of line frequency and Cascade H-bridge terminals. The two Cascaded H-Bridge terminals interconnected by line frequency transformer. The DAB converter connects to the DC/DC converter – 1 and DC/DC converter – 2 together loads. In each DC/DC converter 6 parallel associated DAB converters. Every stage of CHB converters contains 4 cells, which have DC capacitor voltages as \( V_{dcj} \) \((j=1, 2...12)\). The initial four CHB Terminals are associated to the DAB devices remaining are related to the second phase. The way of connection proceed in the 5-terminal Cascaded H-bridge terminal.

III. IMPROVED GRID CURRENT AND DC CAPACITOR VOLTAGE BALANCING METHOD:

In terms of fundamental frequency obtained by injected Zero – Sequence Voltage as

\[
V_{OM} = V_{OM} \cos(\omega t + \gamma)
\]  

Where,  
VOM and \( \gamma \) are Phase angle and Magnitude of Zero – Sequence Voltage individually; \( \omega \) Angular – frequency of the Grid

At point when the network voltage compared as Negative grouping voltage and Zero-Sequence Voltage as

\[
\begin{align*}
V_{ggM} &= V_{gag} + V_{gag} + V_{gag} = V_{gao} + V_{OM} \\
V_{gbM} &= V_{gbg} + V_{gbg} + V_{gbg} = V_{gbo} + V_{OM} \\
V_{gcM} &= V_{gac} + V_{gac} + V_{gac} = V_{gco} + V_{OM}
\end{align*}
\]

\[\text{Where} \]

\[V_{gm} = M (m = a, b, c)\]

Where \( V_{gm} \) denoted as 3-phase voltage at the point of M: \( V_{pgm}, V_{ngm}, V_{0gm} (m = a, b, c) \) are the terms of Positive, Zero-Sequence-Generation (ZSVG) and Negative sequence voltage (NSV) \( V_{gmo} (m = a, b, c) \) is average of negative and positive sequence voltage of every phase voltage. The optional voltage adjusting method, with the PWM reference guideline esteem \( \theta m (m = a, b, c) \) and PI controller yield as indicated by the voltage mistake among \( V_{dcm} \) and \( V_{dcm_ave} \), between extension powers is traded among H-bridge modules of a similar stage to acknowledge singular voltage adjusting control. The last adjustment voltage in Fig. 1 can be portrayed by

\[
V_{mn}^{*} = \frac{1}{4} (V_{m}^{*} + V_{om}) + V_{mn}
\]  

In the ZSV/G, by fuzzy controller in accordance as per voltage delusion among \( V_{dcm} \) and \( V_{dcm_ave} \) power of every phase are interchanged between H-bridge circuit of all stages. With the conditions in (10)-(12), the desired zero-sequence voltage produced. Negative and positive Sequence by using Park
transformation, every stage framework flows $igm(m = a, b, c)$ are changed into positive sequence d-axis and q-axis currents $I_{pd}$, $I_{pq}$ and negative-sequence $d - \alpha$xis and $q - \alpha$xis currents $I_{nd}$, $I_{nq}$ separately. The transient genuine power at each stage are resolved as

$$P_{mn} = V_{mn}I_{mn}$$  \hspace{1cm} (4)

Here, $pmn(m = a, b, c)$ are the transient power produced by $v_{gmO}$ and $igm$. Thus, the average actual power at every stage are determined as

$$P_{mm} = \frac{\omega}{2\pi} \int_0^{2\pi/\omega} P_{mm} \, dt$$  \hspace{1cm} (5)

Here, $Pmm(m = a, b, c)$ is the comparing average power of$Pmm$. The general average real power is determined as

$$P_{ALL} = P_{aa} + P_{bb} + P_{cc}$$  \hspace{1cm} (6)

$$= \frac{3}{2} \left( V_{aa}^2 + V_{pq}^2 + V_{dq}^2 + V_{nq}^2 \right)$$  \hspace{1cm} (7)

Where $PALL$ is the average true power of three-stage conversion device; $Vpd$ as well $Vpq$ are sure and negative-grouping part of d-axis voltage of lattice voltage; $Vnd$ and $Vnq$ are sure and negative-succession part of $q - \alpha$xis voltage of framework. The congregated average power is resolved as

$$P_{Cm} = P_{mm} - \frac{P_{ALL}}{3}$$  \hspace{1cm} (8)

Where $PCm(m = a, b, c)$ is the inter-phase power delusion amid of average true power of AC/DC conversion device and true power of every stage as shown below

$$P_{Ca} + P_{Cb} + P_{Cc} = 0$$  \hspace{1cm} (9)

Hence, inter-stage power is totally interchanged amid of three stages and no extra power is imparted in three-stage conversion device. In process of control, the desired zero-sequence voltage produced to again adjust the inter-stage power to balance the inter-phase power. Later, congregate average power again adjusted with $ZSVI$ in two-stage constant system is determined as

$$\left[ \begin{array}{c} \alpha \alpha \\ \alpha \beta \\ \beta \alpha \\ \beta \beta \end{array} \right] = \left[ \begin{array}{c} \frac{1}{2} \left( I_{pd}^p + I_{nd}^q \\ -I_{pd}^q + I_{nq}^p \\ I_{dq}^p + I_{nq}^d \right) V_{OM \ \cos \gamma} \\ \frac{1}{2} \left( I_{pd}^q - I_{nd}^p - I_{dq}^p - I_{nq}^d \right) V_{OM \ \sin \gamma} \end{array} \right]$$  \hspace{1cm} (10)

Where Pm0($m = a, b, c$) is group normal power is again adjusted with $ZSVI$ in three-stage constant system. Hence, the $d - \alpha$xis and $q - \alpha$xis value of $v_{om}$ are determined as

$$\left[ V_{OM \ \cos \gamma} \\ V_{OM \ \sin \gamma} \right] = k \left[ \begin{array}{c} \frac{1}{2} \left( I_{pd}^p + I_{nd}^q - I_{pd}^q + I_{nq}^p \right) P_{p0} \\ \frac{1}{2} \left( I_{dq}^p + I_{nq}^d - I_{dq}^p - I_{nq}^d \right) P_{p0} \end{array} \right]$$  \hspace{1cm} (11)

$$k = \frac{(1_\alpha^p)^2 + (1_\alpha^q)^2 - (1_\alpha^p)^2 - (1_\alpha^q)^2 \right)}{(1_\alpha^p)^2 + (1_\alpha^q)^2 - (1_\alpha^p)^2 - (1_\alpha^q)^2 \right)}$$  \hspace{1cm} (12)

$Vom$ generated from above equation

$$V_{OM} = \sqrt{(V_{OM \ \cos \gamma})^2 + (V_{OM \ \sin \gamma})^2}$$  \hspace{1cm} (13)

$$\tan^{-1} \left( \frac{V_{OM \ \sin \gamma}}{V_{OM \ \cos \gamma}} \right) \quad \text{if } V_{OM \ \cos \gamma} \geq 0;$$

$$\gamma = \tan^{-1} \left( \frac{V_{OM \ \sin \gamma}}{V_{OM \ \cos \gamma}} \right) + \pi \quad \text{if } V_{OM \ \cos \gamma} < 0, V_{OM \ \sin \gamma} \geq 0;$$

$$\tan^{-1} \left( \frac{V_{OM \ \sin \gamma}}{V_{OM \ \cos \gamma}} \right) - \pi \quad \text{if } V_{OM \ \cos \gamma} < 0, V_{OM \ \sin \gamma} < 0;$$

IV. ANALYSIS OF CONTROLLING SCHEME:

a) Outer side voltage control:

On basis of Fig. 2, the main motto of control block is to produce zero sequence voltage in front end. The true power derived as

$$P_{ALL} = \frac{3}{2} V_{he}^p I_{he}^p = -3 I_c V_{DC}$$  \hspace{1cm} (15)

![Fig. 3 the Fuzzy based control for multi-terminal hybrid AC/DC micro grid](image)

Where $I_c$ and $V_{DC}$ are the current flow and unbalancing state voltage of DC capacitor that the CHB converters contain.. In reference to (13) and Fig. 2, when test postpone ignored and 3-stage framework is unbiased, block diagram of control of outer side voltage depend on Laplace transformation hypothesis is given. When exact current observation is obtained in the internal current controlling, its transfer function $Gcpi(s)$ be roughly 1. The closed loop transfer function be demonstrated and the parameters of $kp$ and $ki$ can be discovered comparing configuration procedure is same as that in the reference[15]

b) $ZSVG$:

By considering Fig.3 Fuzzy controller is utilized in order to determine the redistributed power for the balance of inter-phase power. To perceive the control part, the Zero sequence voltage is introduced. The congregated adjusting control dependent on $ZSVG$ mirrors a group of single stage Cascaded conversion devices in each stage as a one stage H-Bridge converter. For example consider phase A, the mathematical relation of congregated voltage of capacitor and active power. If the sample delay is ignored, then controlled block diagram of $ZSVG$ is presented. Then, closed transfer function can be determined as when components like CHB converter outputs are connected by DAB converters, the control parameters of $Kp$ and $Ki$ are defined depending on (16) and the block diagrams are as shown in the reference[17]

c) Secondary voltage balancing control:

Taking Fig. 2 as a basis, For example take phase A, derive $\Delta V_{gen}$ as the result of the reference voltage
The traditional control of a system configuration is not equal to the terminal values by readjusting. By zero 3

\[ V_{an} = K_p \Delta V_{dcn} \cos \omega t \]  
(16)

By assuming that \( p > q \), \( i_{ga} \) can be approximately expressed as

\[ i_{ga} = I_p \cos \omega t \]  
(17)

The real power of the each stage in order to maintain voltage of capacitor unbiased can be determined as

\[ P_{an} = v_{an} i_{ga} = D_{an} \]  
(18)

Where \( Dan \) shows the loss of power or interruption of H-bridge cell [15]. Where the motto is to perceive voltage balancing control of an individual stage and closed transfer function of this expressed as

\[ \frac{\Delta V_{dcn}(s)}{D_{an}(s)} = \frac{1}{C_{Vdc} + K_p I_p^2/2} \]  
(19)

By depending on (11), the parameters of control of \( Kp3 \) and \( KI3 \) are found and the same architecture is available in reference [16]. The stable operating region analysis is same as explained in the reference [17]. The traditional control of this microgrid is explained in the reference [17].

### TABLE 1. Parameters of simulated system

| SCENARIO | TIMES | LOAD1 (KW) | LOAD2 (KW) | GRID-VOLTAGE |
|----------|-------|------------|------------|--------------|
| 1        | 0-2   | 25         | 25         | Balanced     |
| 2        | 2-3   | 25         | 25*1.2     | Balanced     |
| 3        | 3-4   | 25         | 25*1.2     | Sag 50% (Phase C) |

### TABLE 2. Simulation scenarios

V. FIVE-TERMINAL HYBRID AC/DC MICROGRID:

The block diagram of five terminal hybrid micro grid is as shown in Fig. 2. System configuration in this contain one AC terminal and 4 DC terminals.

As voltage demand always varies various DC voltages taken as 750 V, 700 V, 600 V and 400 V respectively. Step 1 gives the result of the steady state with DC power is (25 kW, denoted as P1) same in initial 2 s; step 2 simulates where the DC power is not equal (P1, 1.2 * P1, 1.5 * P1, 1.2 * P1) condition from 2 s to 3 s; step 3 simulates where the DC power is not equal and grid sags (grid voltage sags 50% in phase C) condition from 3 s to 4 s. The system configuration of fuzzy controlled five terminal system is same as given in reference [17].

### Fig: 4. Fuzzy controller method for five-terminal hybrid AC/DC micro grid

| PARAMETER | VALUE |
|-----------|-------|
| LOAD1 (KW) | 25    |
| LOAD2 (KW) | 25    |
| GRID-VOLTAGE | Balanced |

### Table: 3. Simulation scenarios

VI. SIMULATION RESULTS USING FUZZY CONTROLLER:

In some cases, 3-phase grid currents may not get balanced when the DC voltages of capacitors in CHB are balanced. In that case zero sequence voltage is injected in CHB to change the voltage reference values by readjusting. By zero sequence voltage injection generally the switch on time of heavy loads gets raised that happens in the case of phase c where as in the case of light loads that value gets diminished. Thus our both objectives gets controlled. RMS grid current shown in Fig. 15.
the difference between each phase of current is within 0.2 to 0.7 A from scenario 2 to 3. In Fig:7 the voltage of DC capacitor is almost controlled and it is balanced in even severe cases in both multi-terminal hybrid micro grid. Fuzzy logic controller used to reduce the error by using Fuzzy Rules & Membership functions. The region of rules value as Boolean logic values of 0 or 1.

Table: 4. Fuzzy logic rule table

| e | delta e | NL | NM | NS | EZ | PS | PM | PL |
|---|---------|----|----|----|----|----|----|----|
| NL | NL | NL | NL | NL | NM | NS | EZ |
| NM | NL | NL | NL | NL | NM | NS | EZ |
| NS | NL | NL | NM | NS | EZ | PS | PM |
| EZ | NL | NM | NS | EZ | PS | PM | PL |
| PS | NM | NS | EZ | PS | PM | PL | PL |
| PM | NS | EZ | PS | PM | PL | PL | PL |
| PL | NL | NM | NS | EZ | PS | PM | PL |

VII. 3-TERMINAL HYBRID AC/DC microgrid BY USING FUZZY LOGIC CONTROLLER:

Fig: 5. Membership function for error

Fig: 6. Membership function for change in error

Fig: 7. Membership function for output

Fuzzy logic controller has been implemented via truth table like true (T) or false (F) where the value of the controller fully true and fully false. In this concept fuzzy logic controller (FLC) used as two inputs and 1-output. In the input side as error and change in error and the output as resultant of input. In the membership functions as 7 – triangle membership-function is used. The Structure of membership functions as input and output shown in below figures. The fuzzy rules are connected via fuzzy factors Negative large (NL), Negative Medium (NM), Negative Small (NS), Zero (EZ), Positive Small (PS), Medium positive (MP), positive large (PL) with each and every membership functions. After the fuzzy membership function designing completed as 49 rules via as error and change in error and getting the output.

Fig: 8. DC capacitor voltages of AC/DC converter

Fig: 10. Three phase voltage at (2 to 3s)

Fig: 11. Three phase voltage at (3 to 4s)
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Fig: 12. $V_{om}$ voltage (2 to 3s)

Fig: 13. $V_{om}$ voltage (3 to 4s)

Fig: 14. Dc micro-grid power

Fig: 15. Grid rms current

Fig: 16. Dc bus voltages from dc-dc converter

Fig: 9. DC bus voltages of ac-dc converter

VIII. FIVE-TERMINAL HYBRID AC/DC MICROGRID USING FUZZY LOGIC CONTROLLER:

Fig: 17. DC voltages of capacitor in AC/DC converter by the fuzzy controller method.

Fig: 18. Dc/Dc bus voltages

Fig: 19. $V_{om}$ voltage (2 to 3s)

Fig: 20. $V_{om}$ voltage (3 to 4s)
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AUTHORS PROFILE

Kadirisani Shrarmila Gowd Received Graduation degree in Electrical and Electronics Engineering from G. Pulla Reddy Engineering College, kurnool, Andhra Pradesh in 2017. Currently doing Post Graduation in Electrical Power System from Jawaharlal Nehru Technological University, Anantapur.

Fig: 21. Three phase voltage at (2 to 3s)

Fig: 22. Three phase voltage at (3 to 4s)

Fig: 23. Rms current of grid

Fig: 24. DC-Micro Grid Power

IX. CONCLUSION:

Thus, in this paper 3-terminal and 5 terminals AC and DC cross breed microgrids is studied. The main motto in the process is to solve the issues like grid current irregularities and voltage unequal situation to maintain power quality which is a major issue. In the controlling part inner current controller gives improvement in gridcurrent if any fault occurs on grid side. The outer voltage and Zero sequence voltage controlling gives voltage balanced controlling if any fault occurs in CHB converter because of unbalanced power of DC microgrids and even in the fault condition.
Mr. K. Jithendra Gowd working as a Assistant Professor in Department of Electrical Engineering, JNTUA College of Engineering, Anantapur. He completed his post-graduation in HVE from Jawaharlal Nehru Technological University, Hyderabad. He completed his under graduation in EEE from Jawaharlal Nehru Technological University, Hyderabad. His Research interest includes HVE, FACTS and Power System, Microgrid. He is now a Life Member of IE, ISTE and SESI and a Member of IAENG and senior member of IEEE.

Mrs. Devanga Dharani Lakshmi, completed her post graduate in M.tech power system specialization from ALTS Anantapur, Completed Bachelor Degree in EEE from JNTUA. Worked as the project manager in reputed MNC like cognizant and RDP Workstations Pvt.ltd. She is currently pursing Ph.D(Full time) Research scholar in Electrical Engineering from JNTUA Anantapuramu Dated from March 2018 to till date. Her research interest includes Hybrid Microgrid and Distributed Generation. She is now a member of IEEE.