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# Self-Governing Power Management for Networked AC-DC Micro Grids

***R.Mounika[1], Rajesh Thota[2], G.Sandeep Reddy[3], G.Praveen Kumar[4], MC. John Wseli[5]***

*1, 2, 3, 4 Assistant Professor, Department of Electrical and Electronics Engineering, Vaagdevi College of Engineering, Warangal, Telangana-506005, India.*

*5 Professor, Department of Electrical and Electronics Engineering, Vaagdevi College of Engineering, Warangal, Telangana-506005, India.*

***Abstract***—There are a number of operational issues with the current power management plans for interconnected AC-DC micro grids. Certain control methods now in use are primarily intended to distribute electricity across interconnected micro grids according to their loading circumstances, whilst other schemes are intended to manage the interconnected micro grids' voltage without taking load conditions into account. The current plans, however, are unable to successfully accomplish both goals. In order to tackle these problems, an autonomous power management strategy is put forth that, prior to importing power from the interconnected AC micro grid, specifically takes into account the unique loading status of the DC micro- grid. In addition to lowering the number of converters in use, this technique allows voltage adjustment in the DC micro grid. While maintaining plug-and-play functionality, the suggested system is completely independent. The suggested plan keeps the tie-converters and generators plug-and-play capabilities while being completely independent. The suggested control scheme's effectiveness has been confirmed under a variety of operating conditions. The outcomes show how well the suggested plan works to preserve the DC micro grid's improved voltage control while effectively and independently managing the power shortage..

***Keywords:*** *Power management, interconnected micro grids, hybrid micro grids, distributed control, droop control, and autonomous control.*

## 1. INTRODUCTION

The deployment of renewable and alternative energy technologies, which have been widely implemented in various network topologies and configurations to date [4], [5], is greatly aided by the technological advancements in power electronics [1]–[3]. In a similar vein, they have been managed and regulated using a variety of control systems and methodologies [6, 7]. Their control mechanisms and network topologies are primarily chosen to optimise the benefits while satisfying load requirements. These days, micro grids use a lot of renewable and alternative energy technology. It is desirable to use these new technologies as micro grids because of the following benefits: such as better supply dependability, increased power quality, and efficient resource utilisation [8]–[10]. Zone-based grid designs [11], multi-micro grids [12]–[15], interconnected AC-AC micro grids [16], [17], and interlinked AC-DC micro grids [18]–[22] are some of the more sophisticated grid systems that have recently come into existence. These cutting-edge network designs' primary goal is to maximise the advantages of renewable and alternative energy sources. For instance, linking two or more micro grids will allow reserve sharing, support voltage and frequency, and improve the interconnected micro grids' overall resilience and dependability. The overall goals and the control and management plan employed in each micro grid are the main determinants of the interlinking configuration between two or more micro-grids or with utility grids. Through harmonising tie-converters or direct connections, the micro grids can be connected. When two or more micro grids have differing operating voltages and/or frequencies, harmonising tie-converters are often utilised. If the micro grids to be linked have various control techniques and the power flow between them has to be managed, tie- converters are also necessary [16]. Similarly, tie-converters are needed for the DC micro grid to be interlinked with the utility grid or another AC micro grid in order to manage power flow among other functions. This has been studied in the published literature under a variety of conditions [18]–[22]. Demand-droop control for the interlinking or tie-converters of AC-DC micro grids has been proposed in [18]. The normalized terminal voltage and frequency of the droop regulated interconnected AC-DC micro grids are used to calculate the power flow action. With this technique, two interconnected micro grids may autonomously transmit electricity to each other according to their respective loading conditions. The interlinking converter could run constantly as a result of the power flow choice based on relative loads, which could lead to needless operating losses. Micro grids with a storage system that are connected have been given access to the same power sharing plan [19]. By utilising interlinking converters to minimise energy flow, this approach is further enhanced by progressive auto-tuning [20]. Only when one micro grid is significantly loaded and another micro grid is lightly loaded does the suggested auto-tuning allow for power transfer. Further research on the droop-based power sharing idea has been done for various interconnected AC and DC micro grid operation circumstances in [21]. The power management plan for a three-port system with AC, DC, and a storage network is described in [22]. Power sharing decisions are made in accordance with the interconnected networks' loading conditions, which are essentially the same as those shown in [20]. Moreover, a multilayer supervisory control based on communication is suggested to lessen the need for interlinking converter operation. The goal of another power management plan for the connected AC-DC micro grid, which was given in [23], is to control the DC micro grid's voltage without taking the generators' individual loading levels into account. This method restricts the plug-and-play functionality because it can only be applied to a single tie-converter. Furthermore, for connected AC-DC micro grids, a few centralised power management techniques have been studied [24], [25]. The dependability of the quick communication lines is the main issue with centralised solutions. Consequently, decentralised solutions are typically used.

Voltage control or the droop principle form the basis of all decentralised power sharing methods for interconnected AC-DC micro grids that have been reported thus far. The power sharing solutions that rely on drooping distribute electricity according to the relative loads of interconnected micro grids. The voltage is supported by the power transfer in the event of a contingency or uneven loading situation. Regardless of the need for power transfer, the following tie-converter only turns on when the first converter's power capacity is reached. The suggested plan has improved features and is completely independent. The power transfer that takes place in the event of an emergency or unequal loading scenario maintains the voltage and frequency of the interconnected micro grids, but it does not control them. Nonetheless, these techniques allow the interlinking converters to be used as plug-and-play devices. When more than one interlinking converter is present, this feature ensures that all of the converters will function regardless of the total power transfer need. This might result in needless operational losses for the converter. On the other hand, the voltage regulation techniques lack the plug-and-play tie-converter functionality and control the DC micro grid's voltage without taking the generators' unique loading circumstances into account. In the proposed autonomous power management strategy for interconnected AC-DC micro grids, the voltage of the DC micro grid is regulated while power is transferred from the AC micro grid to the DC micro grid during peak-load demand, taking into account the unique loading conditions of the generators. In order to prevent needless losses, the suggested approach lowers the number of converters in use and activates the plug-and-play functionality for tie converters. Because of the significant demand unpredictability and renewable output in the scenario under consideration, the DC micro grid's generating capacity is insufficient. It is believed that the AC micro grid has controlled voltage and frequency in addition to having excess power to move to the DC micro grid in case of emergency or peak demand. For the tie-converters in interconnected AC-DC micro grids, a hybrid droop and voltage regulation mode control has been developed to achieve the attributes covered above. The droop-controlled DC micro grid's overall loading state is determined by the proposed control strategy using the tie-converter terminal voltage information. The tie-converter begins operating automatically based on the predetermined loading threshold and feeds power to the DC micro grid in the event of a peak-load demand or emergency. The voltage of the DC micro grid is regulated at a specified nominal level by the suggested hybrid control mechanism. Furthermore, more than one tie-converter can be interfaced under the proposed scheme; however, unlike the current scheme, which operates all tie-converters simultaneously regardless of the demand for power transfer, the subsequent tie-converter only activates after the first converter's power capacity is saturated. The suggested system has improved features and is completely independent.

## 2. CONTROL OF AC AND DC MICRO GRIDS

As seen in Fig. 1, the studied DC micro grid consists of dispatchable generators (micro turbine, fuel cell) and loads in addition to a non-dispatchable generator (solar PV). Because the non dispatchable solar PV system is configured to run in current control mode, it always draws the most power possible.

Usually employed to stabilise renewable capacity, dispatchable generators can be managed via a decentralised or centralised control system. Due to its simplicity and dependability, the decentralised drop scheme is the most popular and commonly utilised. Consequently, the dispatchable generators of the DC micro grid have been designed using the conventional droop (P-V) scheme (see Fig. 1), which is provided by

$V_{dc,ref,i} = V_{dc,max} - \partial_{dc,i} P_{dc,i}$

$$\partial_{dc,i} = \frac{V_{dc,max} - V_{dc,min}}{P_{dc,max,}} = \frac{\Delta V_{dc}}{P_{dc,max,i}} \qquad (1)$$

where, for each i, there is a DC generator (i = 1, 2, 3,.. ); $V_{dc,ref,i}$ is the generator's reference voltage; $P_{dc,i}$ is its output power; $V_{dc,max}$ and ($V_{dc,min} = V_{dc,nom,TC1}$) are its defined maximum and minimum voltages; $P_{dc,max,i}$ is its maximum or rated power; and $\partial_{dc,i}$ is its droop gain.Equation (2) and (3) may be used to get the voltage reference for the droop regulated generators 1 and 2 based on (1). As a result of the fact that generators 1 and 2 share a common DC bus voltage ($V_{dc,ref,1} = V_{dc,ref,2}$), (2) and (3) can be rewritten by (4), showing that the droop regulated generator will share power according to its rated capacity

$V_{dc,ref,1} = V_{dc,max} - \partial_{dc,1} P_{dc,1}$ (2)

$V_{dc,ref,2} = V_{dc,max} - \partial_{dc,2} P_{dc,2}$ (3)

$\partial_{dc,1} P_{dc,1} = \partial_{dc,2} P_{dc,2} \rightarrow , = \frac{P_{dc,1}}{P_{dc,max1}}, = \frac{P_{dc,2}}{P_{dc,max2}}, = \frac{P_{dc,n}}{P_{dc,max,n}},$ (4)

The identical voltage at the generator terminals serves as the foundation for the equation in equation (4). Because the generator terminals are connected via feeders or cables of varying lengths, the voltage at each terminal is practically different. The precision of power sharing is impacted by this voltage imbalance at the generator terminals, which must be corrected using any suitable compensation techniques [26], [27]. It is possible to rewrite the droop equation with feeder voltage drop correction as

$$V_{dc,ref,i} = V_{dc,max} - \partial_{dc,i} P_{dc,i} + i_{dc,i} X_i . (5)$$

The voltage and frequency of the AC micro grid in Fig. 1's example of interconnected micro grids are regarded as stiff. The AC micro grid can function in grid-connected mode or be droop regulated via secondary voltage and frequency regulation. Figure 1 depicts the features of the AC micro grid, with nominal values of 50 Hz and 415 V for the voltage and frequency, respectively, remaining constant. Furthermore, as seen by the suggested independent operation of the tie-converters, the AC micro grid has enough generation capacity to fulfill its local demand and export excess power to the DC micro grid. Section III provides the tie-converters control information.

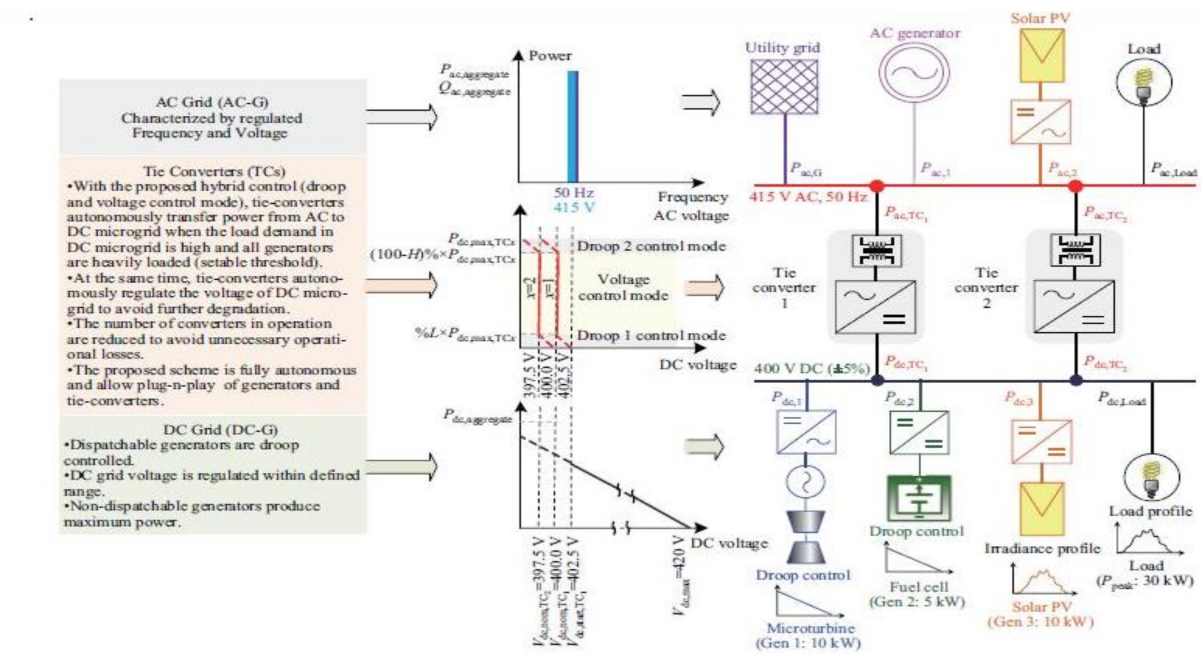


Fig1. Interlinked AC-DC micro grids and their control strategy

## 3. PROPOSED HYBRID CONTROL OF TIE-CONVERTERS

The power rating of storage devices or dispatchable generators used to firm the renewable capacity is determined by the micro-grid's loads and the renewable source's unpredictability.

Due to the extreme unpredictability of renewable energy sources and demands, high power rating storage systems or dispatchable generators may not be a practical option. An alternative would be to directly link the micro grid with insufficient generation capacity to another micro grid or utility grid, or use harmonizing converters to do so. Only tie-converters may be used to attach a DC micro grid to an AC micro grid or utility grid, as seen in Fig. 1. The AC micro grid in the proposed interlinked system is described as a regulated voltage and frequency system with sufficient generation capacity, while the DC micro grid, because of the high variability of the renewable and loads, is described as a droop controlled system with insufficient generation capacity. The DC micro grid imports electricity from the AC micro grid to cover its power shortfall during periods of high demand or low renewable power supply. Ideally, it can be accomplished independently and efficiently using the tie-converters' suggested control.

In conclusion, the following goals serve as the foundation for the tie-converters' control scheme development: 1) To move energy from the AC micro grid to the DC micro grid in the event of a DC micro grid generation contingency or peak load demand; 2) In order to reduce power transfer losses, tie-converters should only be used when the DC micro grid is experiencing peak load demand, and the quantity of tie-converters should be determined by power transfer demand; 3) To manage the DC micro grid's voltage via droop control; 4) To attain complete independence from the communication network in terms of control; 5) To make tie-converters and generators plug-and-play compatible.

A hybrid droop and voltage regulation mode control is suggested for the tie-converters, in contrast to the current approaches for the interconnected AC-DC micro grids [18]–[22]. The proposed control scheme's mathematical form is provided by:

$V$dc,ref,TC$x$=OFF;
$V$dc>$V$dc,start,TC$x$
$V$dc,start,TC$x-\delta$L,TC$x\times P$dc,TC$x$;0≤$P$dc,TC$x$≤$L$%×$P$dc,max,TC$x$
$V$dc,nom,TC$x$;$L$%×$P$dc,max,TC$x$<$P$dc,TC$x$<(100−$H$)%×$P$dc,max,TC$x$
$V$dc,nom,TC$x-\delta$H,TC$x$[$P$dc,TC$x$−(100−$H$)%×$P$dc,max,TC$x$];(100-
$H$)%×$P$dc,max,TC$x$≤$P$dc,TC$x$≤$P$dc,max,TC$x$

where TCx is the tie-converter number (x = 1, 2, 3, etc.); Vdc is the DC micro grid voltage; Vdc,ref,TCx is the tie-converter's reference voltage; Vdc, start, TCx is the tie-converter's threshold voltage to begin operation; Vdc,nom,TCx is the nominal voltage that the tie-converter is supposed to regulate; Pdc, TCx is the tie-converter's DC power output; Pdc, max, TCx is its maximum power limit; L% and H% are the percentage of tie-converter rated power allotted for droop1 and 2 mode, respectively; The DC micro grid voltage at which the xth tie-converter transmits the maximum amount of power is Vdc,nom,TCx+1; The droop 1 gain (at low power) of the xth tie converter is represented by δL, TCx = (Vdc,start,TCx − Vdc,nom,TCx)/(L% × Pdc,max,TCx); the droop 2 gain (at high power) is represented by δH,TCx = (Vdc,nom,TCx − Vdc,nom,TCx+1)/(H% × Pdc,max,TCx). As seen in Fig. 1, when the voltage in the DC micro grid falls to the predetermined threshold of Vdc,start,TCx, tie-converter 1 enters droop 1 control mode. This voltage threshold suggests that every generator in the DC micro grid is operating at a high load (more than 80%, for example). When the tie-converter starts in the droop control mode and reaches the set condition (Pdc,TCx> L% × Pdc,max,TCx), a seamless transition to the voltage regulation mode is made possible. The tie-converter imports power from the AC micro grid in the voltage control mode in order to fulfil the peak power demand of the DC micro grid and to regulate its voltage to the nominal value of Vdc,nom,TCx. As seen in Fig. 1, when the voltage in the DC micro grid falls to the predetermined threshold of Vdc,start,TCx, tie-converter 1 enters droop 1 control mode. This voltage threshold suggests that every generator in the DC micro grid is operating at a high load (more than 80%, for example). When the tie-converter starts in the droop control mode and reaches the set condition (Pdc,TCx> L% × Pdc,max,TCx), a seamless transition to the voltage regulation mode is made possible. The tie-converter imports power from the AC micro grid in the voltage control mode in order to fulfil the peak power demand of the DC micro grid and to regulate its voltage to the nominal value of Vdc,nom,TCx. Additionally, the functioning of the converters has been given priority, in contrast to the present methods where all tie converters operate in tandem. It is only until every generator in the DC micro grid is fully loaded that the first tie-converter activates.Once the first tie-converter power capacity is near to saturation at Pdc, TCx = (100 − H)% × Pdc,max,TCx, its control mode is changed from the voltage regulation to droop 2 control mode to allow minor voltage drop. Due to the little voltage drop brought forth by the droop 2 control mode, the following tie-converter can begin to function. The second tie-converter will immediately begin operating in the event that the first tie-converter fails, which will cause a voltage drop because of the high load demand. As a result, the suggested control technique guarantees effective operation under all operating circumstances without sacrificing the droop-based scheme's inherent flexibility. The user-definable values of L% and H% determine how much power is allotted to the tie-converter for the droop 1 and droop 2 control modes. These values should be adjusted to facilitate a seamless transition between modes while taking the micro grid's voltage and power measurement errors into account. The DC micro grid's overall voltage regulation performance can be enhanced using the suggested voltage regulation mode. The voltage of the DC micro grid is regulated at the nominal value, especially during peak load demand. This is not the case with the current power management techniques for interconnected micro grids. As outlined in Section IV, the effectiveness of the suggested approach has been verified under various load operating conditions.

## 4. PERFORMANCE VALIDATION

The performance of the proposed scheme has been validated for two different scenarios of the DC micro grid. In the first scenario, the micro grid comprises a dispatchable micro turbine (Gen 1), fuel cell (Gen 2) and variable load. In the second scenario, a non-dispatchable solar PV generator (Gen 3) is added to scenario 1. The system parameters are summarized in Tables I–III.

TABLE I
CONTROL MODE OF DC AND AC MICROGRIDS

| Entity | Control Mode | |
|---|---|---|
| AC microgrid | Islanded-microgrid with regulated voltage and frequency<br>Grid-connected mode | |
| Tie-converter | Hybrid droop and voltage control mode | |
| DC microgrid | Dispatchable generators | Droop controlled |
| | Non-dispatchable generators | Current control mode with MPPT |

TABLE II
DC MICROGRID PARAMETERS

| Description | Parameter | Value |
|---|---|---|
| Voltage | $V_{dc}$ (V) | 400 (+5%, −1.25%) |
| Micro-turbine | $P_{dc,max,1}$ (kW) | 10 |
| | $\vartheta_{dc,1}$ (V/kW) | 2.5 |
| Fuel cell | $P_{dc,max,2}$ (kW) | 5 |
| | $\vartheta_{dc,2}$ (V/kW) | 5 |
| Solar PV | $P_{dc,max,3}$ (kW) | 10 |
| Load | $P_{Load,peak}$ (kW) | 25 |

TABLE III

AC MICROGRID AND TIE CONVERTER PARAMETERS

| Description | Parameter | Value |
|---|---|---|
| AC microgrid | $V_{ac}$ (V) | 415 $(l-l)$ |
| | $f$ (Hz) | 50 |
| Tie-converter | $P_{dc,max,TC_1}$ (kW) | 10 |
| | $V_{dc,start,TC_1}$ (V) | 402.5 |
| | $V_{dc,nom,TC_1}$ (V) | 400.0 |
| | $V_{dc,nom,TC_2}$ (V) | 397.5 |
| | $L\% = H\%$ | 10% |

The mode transition logic of the tie-converter is given in the logic flow diagram shown in Fig. 2, and the detailed control block diagram of the tie-converter is shown in Fig. 3. Both scenarios have been tested at different load operating conditions to demonstrate the robustness and effectiveness of the proposed scheme.

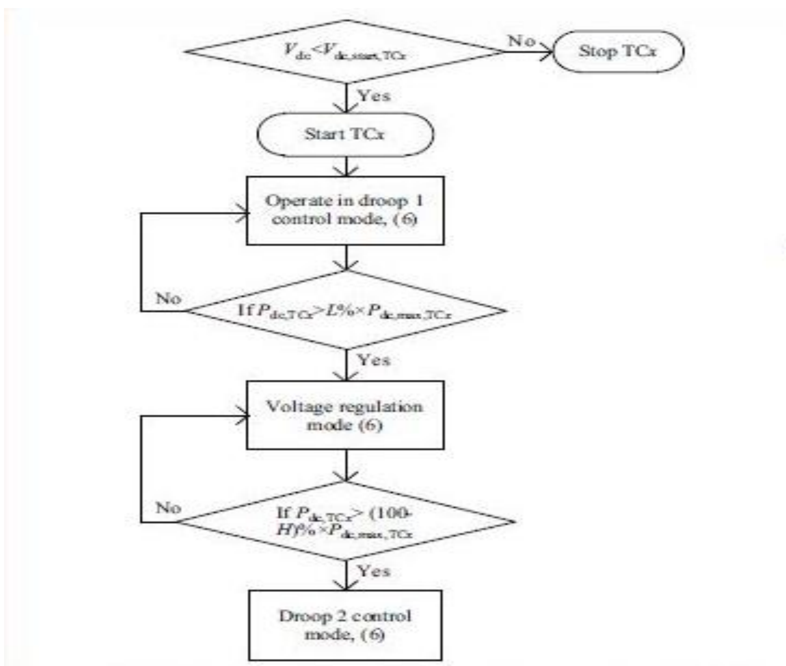


Fig. 2. Logic flow diagram showing mode transitions of tie-converter

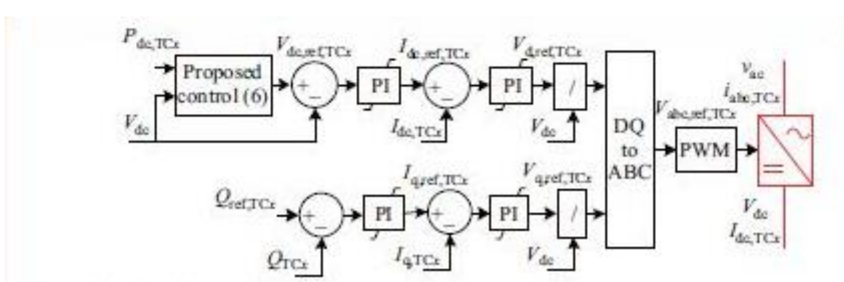


Fig. 3. Control block diagram of tie-converter

***Scenario1:DC Micro grid with Variable Load***

The DC micro grid comprises micro turbine($P_{dc,max,1}$=10 kW), fuel cell ($P_{dc,max,2}$= 5 kW) and variable DC load($P_{Load,peak}$= 20kW) and it is interlinked with the AC micro grid through a tie-converter ($P_{dc,max,TC}1$ = 10 kW), asshowninFig.4.

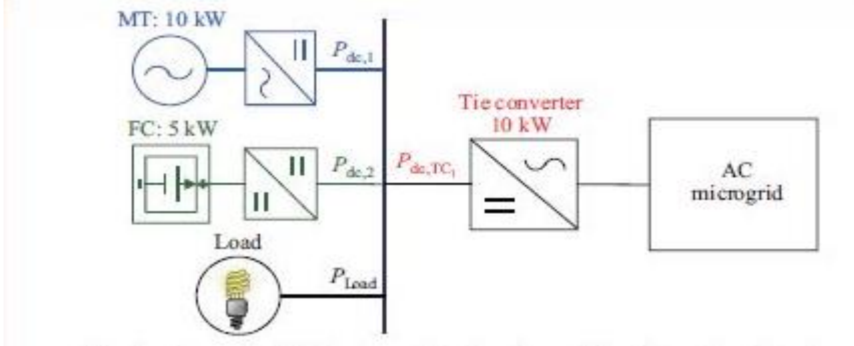


Fig. 4. Scenario 1: DC microgrid with microturbine, fuel cell and load

between 10 and 15 kW. At point 2, this voltage drop causes tie-converter 1 to enter the droop 1 control mode. The tie-converter control mode instantly switches to the voltage regulation mode at point 3 after beginning in the droop 1 control mode because the predetermined threshold (Pdc,TC1 > 10% Pdc,max,TC1) is met. At 12 s, the power transmitted from the AC micro grid is boosted in proportion to the additional rise in demand from 15 kW to 20 kW in the DC micro grid. Tie-converter 1 continues to function and controls the DC micro grid's voltage during the DC micro grid's peak-load demand, which lasts from 8 to 12 seconds.

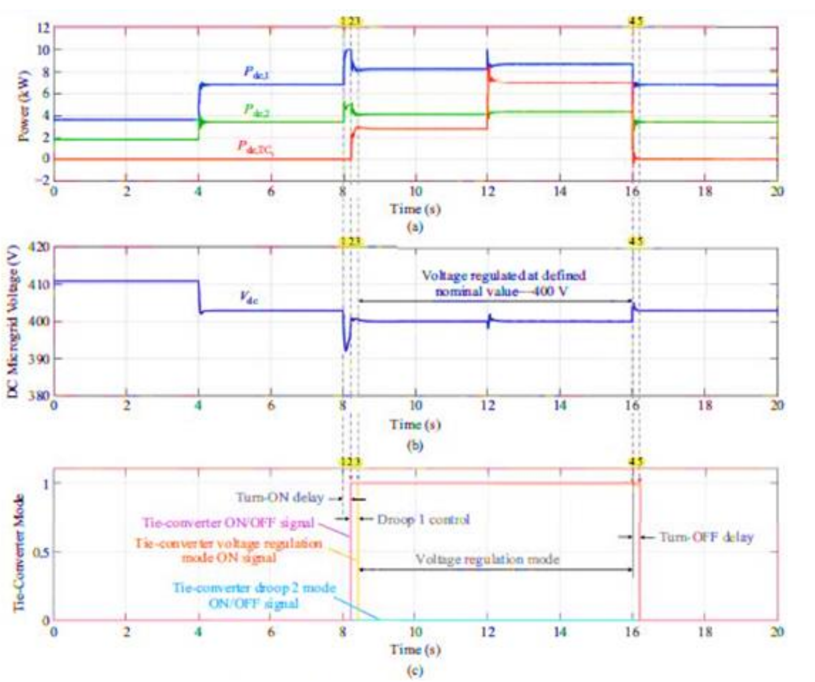


Fig. 5. Scenario 1: Results showing (a) generators and tie-converter power, (b) DC microgrid voltage and (c) tie-converter control signals for different load operating conditions

As observed in Fig. 5, the tie-converter automatically switches off at point 5 after a short delay after a decline in the load demand in the DC micro grid at the highlighted point 4, at 16 s. Tie-converter 1 only operates when all DC generators are completely loaded, as can be observed. During operation, the DC micro grid's voltage is regulated to sustain a nominal value of 400 V. Consequently, the proposed method provides better voltage control performance and ensures effective operation.

***Scenario2:DC Micro grid with Non-dispatchable Generator and Load Profile***

Scenario 1 is expanded by adding a non-dispatchable generator–solar PV combination, as seen in Fig. 6. The power output of the solar photovoltaic system is dictated by a dynamic irradiance profile. The load in scenario 2 has a variable profile and a maximum demand of 25 kW. This test scenario is intended to demonstrate the effectiveness of the recommended technique under various real-world renewable generating and load demand scenarios.

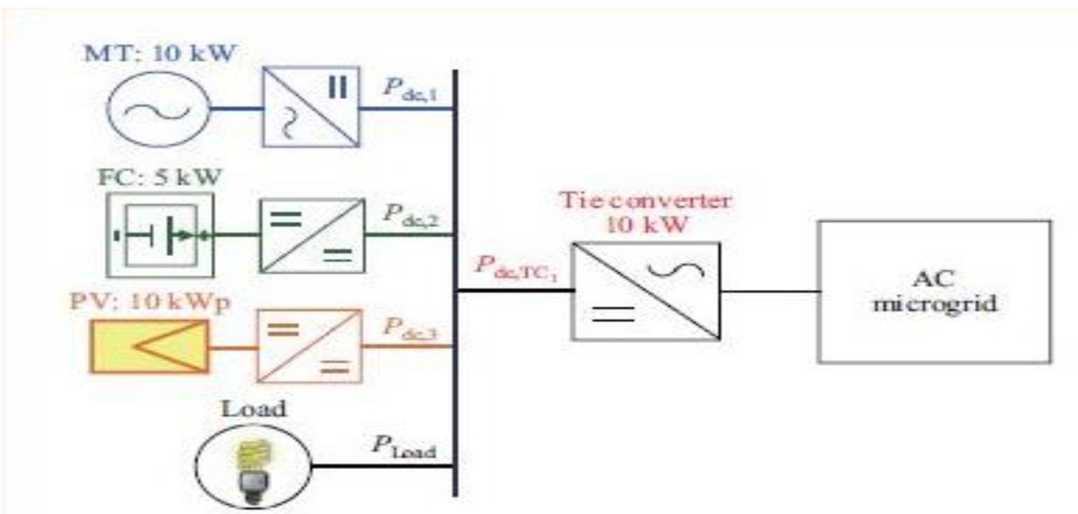


Fig. 6. Scenario: DC microgrid with microturbine, fuel cell, solar PV and load

As load demand rises, so does the loading on the DC generators. When the load demand is high and the solar PV output is low, the voltage of the DC micro grid falls below the predetermined threshold of Vdc,start,TC1 = 402.5 V at the highlight point 1. At this point, the loading on generators 1 and 2 surpasses 80%. Tie-converter 1 begins at highlighted point 1 in accordance with the suggested control, importing power from the AC micro grid to fill the DC micro grid's power shortage while controlling its voltage. The voltage-regulating mode is used by tie-converter 1 from point 2 at 8.5 s to point 3 at 14.2 s. The DC micro grid's load decreases from point 3 onward, causing the tie-converter's power output to drop below 10% Pdc,max,TC1. In order to meet this requirement, the tie-converter must run in the droop 1 control mode until shutting off at highlighted point 4 at 16.4 s. Starting at point 4, the DC micro grid's load demand is smaller than its generation, meaning that local generators can meet it. It has been shown, as anticipated, that the tie-converter only functions when there is a power shortfall in the DC micro grid. In addition, the voltage of the DC micro grid is also regulated by importing power from the AC grid. This behavior depicts the grid-connected mode of the AC micro grid but through a tie-converter.

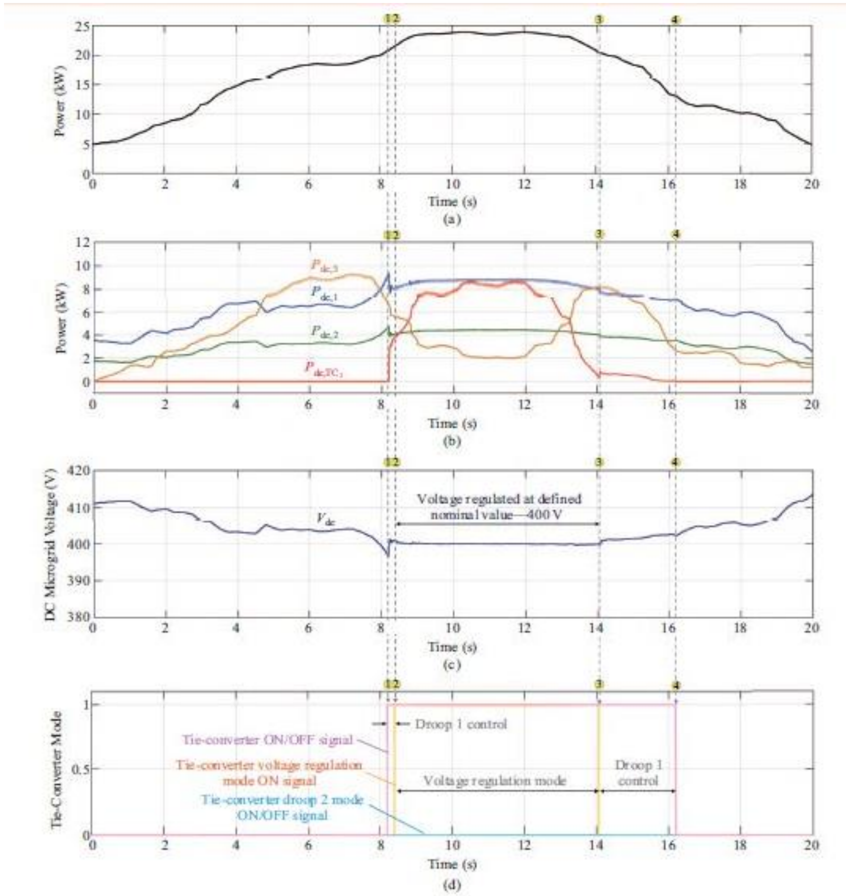


Fig. 7. Scenario 2: Results showing (a) DC microgrid load demand, (b) generators and tie-converter power, (c) DC microgrid voltage, and (d) tie-converter control signals at varying solar PV and load operating conditions.

**Conclusion:**

This study introduces a self-governing power management strategy for interconnected AC-DC microgrids with diverse configurations. The proposed strategy effectively and autonomously manages power deficits within the DC microgrid. By prioritizing specific operations, fewer tie-converters are actively engaged, thus reducing unnecessary operating losses. Additionally, the strategy enhances voltage regulation within the DC microgrid. Validation of the proposed scheme's robustness and performance under varying load conditions has been demonstrated through two distinct DC microgrid scenarios.

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